

HANDBOOKS IN ECONOMICS 18

**HANDBOOK OF
AGRICULTURAL
ECONOMICS**

**VOLUME 1B
MARKETING, DISTRIBUTION
AND CONSUMERS**

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NORTH-HOLLAND

INTRODUCTION TO THE SERIES

The aim of the *Handbooks in Economics* series is to produce Handbooks for various branches of economics, each of which is a definitive source, reference, and teaching supplement for use by professional researchers and advanced graduate students. Each Handbook provides self-contained surveys of the current state of a branch of economics in the form of chapters prepared by leading specialists on various aspects of this branch of economics. These surveys summarize not only received results but also newer developments, from recent journal articles and discussion papers. Some original material is also included, but the main goal is to provide comprehensive and accessible surveys. The Handbooks are intended to provide not only useful reference volumes for professional collections but also possible supplementary readings for advanced courses for graduate students in economics.

KENNETH J. ARROW and MICHAEL D. INTRILIGATOR

PUBLISHER'S NOTE

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INTRODUCTION

The subject matter of agricultural economics has both broadened and deepened in recent years, and the chapters of this Handbook present the most exciting and innovative work being done today. The field originated early in the twentieth century with a focus on farm management and commodity markets, but has since moved far into analysis of issues in food, resources, international trade, and linkages between agriculture and the rest of the economy. In the process agricultural economists have been pioneering users of developments in economic theory and econometrics. Moreover, in the process of intense focus on problems of economic science that are central to agriculture – market expectations, behavior under uncertainty, multimarket relationships for both products and factors, the economics of research and technology adoption, and public goods and property issues associated with issues like nonpoint pollution and innovations in biotechnology – agricultural economists have developed methods of empirical investigation that have been taken up in other fields.

The chapters are organized into five parts, contained in two volumes. Volume 1 contains Part 1, “Agricultural Production”, and Part 2, “Marketing, Distribution and Consumers”. These two parts include much of the traditional scope of agricultural economics, emphasizing advances in both theory and empirical application of recent years. Volume 2 consists of three parts: “Agriculture, Natural Resources and the Environment”, “Agriculture in the Macroeconomy”, and “Agricultural and Food Policy”. Although agricultural economists have always paid attention to these topics, research devoted to them has increased substantially in scope as well as depth in recent years.

A large-scale effort to review and assess the state of knowledge in agricultural economics was previously undertaken by the American Agricultural Economics Association (AAEA), with publication in four volumes from 1977 to 1992.¹ Those earlier survey volumes have strikingly different subject-matter content from that of the present Handbook, especially considering that they described the same field only 20 years ago. The AAEA volumes have extensive coverage of farm management issues, costs of production in agriculture, and estimates of efficiency of marketing firms. In our judgment little in any fundamental way has been added to our knowledge in these areas, and applications have become routine rather than imaginative research. The largest AAEA volume was devoted entirely to agriculture in economic development. This remains a

¹ *A Survey of Economics Literature*, Lee Martin, ed., Minneapolis: University of Minnesota Press. Volume 1, Traditional Field of Agricultural Economics (1977); Volume 2, Quantitative Methods in Agricultural Economics (1977); Volume 3, Economics of Welfare, Rural Development, and Natural Resources (1981); Volume 4, Agriculture in Economic Development (1992).

most important topic, but we cover it in only one complete chapter and parts of several others. This reflects in part the integration of work on developing countries with mainstream applied work. For example, our chapters on production economics, expectations, and risk management also encompass applications to agriculture in developing economies.

That integration points to another gradual but notable change in agricultural economists' research. The AAEA surveys had most of the chapters of one volume devoted to quantitative methods. We do not have any separate methodological chapters. In contrast, we have several chapters with substantial development of economic theory. This reflects an evolution in the research priorities of leading agricultural economists who, following the earlier work of Nerlove on supply and Griliches on technological change, are working at the theoretical frontiers and simultaneously undertaking empirical work – not just purveying new theories to their more “applied” colleagues.

As its title indicates, the AAEA volumes were surveys of literature, and aimed at completeness of coverage within their subject matter. We asked our authors to be selective, to focus on what they saw as the main contributions to the area they covered, and to assess the state of knowledge and what remains to be learned. This approach has left some gaps in our coverage, and has given us some chapters that are perhaps more idiosyncratic than is usual for a survey chapter. In order to pull things together at a higher level of aggregation, we commissioned five “synthesis” chapters, one for each of the five parts of the Handbook. And, to provide our own even broader overview, the editors have written closing syntheses of each volume. Because these syntheses provide capsule summaries of each Handbook chapter, we will not present further description of content here.

Although advances in research in agricultural economics are increasingly being made in many countries, our authors and coverage of applied topics is heavily U.S.-weighted (only six authors work outside of the U.S.: two in Europe, two in Australia, one in Canada, and one in Israel). Of those in the U.S., however, six are economists at the World Bank, an international rather than American institution. Probably in another twenty years or so one will have to become more international to capture the most interesting and exciting developments in the field, but that day has not arrived yet.

Among the many debts we have accrued in the preparation of this Handbook, the most important was Rachael Goodhue. She not only assessed the substance of many chapters, but she persuaded many reviewers and authors alike to complete their assigned responsibilities. Other critical contributors include the dedicated staff who provided support at the University of California, Berkeley, and at the University of Maryland. At Maryland, Liesl Koch served as copy editor and guided the authors' final revisions and preparation of the manuscript with sure judgment and a firm but diplomatic hand, a job best likened to driving a herd of cats. Coordination of correspondence with authors and reviewers was organized and carried out at Berkeley with exemplary efficiency and organizational skill by Jef Samp, Jessica Berkson, and Jennifer Michael, under the direction of Nancy Lewis.

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COMMODITY FUTURES AND OPTIONS

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Abstract

Organized exchanges have evolved methods for enforcing contracts, which allow the contracts themselves to be traded at low cost. Theorists have modeled futures contracts as tools for risk management, despite an extensive empirical literature that does not support predictions about bias in prices or speculators' behavior. Another perspective models commercial firms as using futures contracts to arbitrage, to minimize transaction costs, to substitute temporarily for merchandising contracts. Because commercial firms tie their processing and storage decisions to the constellation of futures prices, futures prices have major allocative effects, even if their forecasting power is inevitably poor.

Keywords

futures, speculation, hedging, forecasting, exchanges

JEL classification: Q13

1. Introduction

To economists, futures markets, along with the options markets associated with them, present many interesting features. First is the nature of organized exchanges, traditionally run as not-for-profit cooperatives by their members, whose individual purpose is profits pure and simple. Second is the range of participants and their motives for trading. Alongside commercial firms focused on storing, transporting, or processing a commodity are traders who hold their positions for a matter of minutes and traders who seem to enjoy the speculation itself. No law of nature compels either giant grain-exporting firms or amateur speculators – proverbially, dentists from Des Moines – to participate in futures markets, but they do. Third are the patterns in the prices that emerge from the trading. In the most active futures and options markets, prices move second by second, and moreover, tend to lead the price changes in related markets: Futures markets are said to “discover” prices. Yet these very attributes raise many issues about how futures and options markets incorporate information about, say, planting prospects. Somehow, option prices reflect the cycle of uncertainty through a crop year and the year-to-year risks of, say, a freeze. Somehow, the futures prices for various periods into the future prevailing at any one moment have a sensible structure, which is closely associated with inventories held not just in exchange-approved warehouses but worldwide. Fourth are the inherent complexities of any economic analysis of futures markets and commodity markets more generally. Economists must consider what heterogeneous price-taking firms do, yet place as central in their analysis the industry-level interactions. Economists must abstract from the particulars of a single commodity during a short stretch of time, yet must recognize that those particulars determine individual traders’ strategies.

Futures markets are interesting for a fifth reason, although one that does not concern the markets themselves as much as the approach to models and evidence as practiced among economists. For at least sixty years, two perspectives on futures markets have existed in parallel. One of these perspectives, which might be styled the *risk-management perspective*, posits that some market participants, called “hedgers”, use futures markets out of risk aversion while other participants in the market earn a “risk premium”. The other perspective, which might be styled either the *transaction-cost* or the *arbitrage perspective*, posits that commercial firms, cognizant of transaction costs, involve themselves in arbitrage-like trades in which they temporarily hold futures positions, while the other participants contribute to the market’s liquidity or forecasting ability. Judged by the large number of papers published on the theory of “optimal hedging”, the more commonly held perspective among economists is the risk-management one. The empirical evidence, however, supports this perspective poorly. Commercial firms do not use futures contracts in the proportions or timing suggested by the theories of optimal hedging; and speculators, far from earning a risk premium on average, usually break even at best. Moreover, these basic facts have been reconfirmed over the years. Yet the business of writing theoretical papers goes on, with no mention of the evidence. The transaction costs perspective, for its part, has pointed to the general seasonal movement in the use of futures markets for empirical support. But it has not offered evidence of

the day-by-day decisions of commercial firms in a carefully measured context of their perceived trading opportunities and costs; indeed, the theory has not been worked out fully for a risk-neutral commercial firm in the ever-changing situation of actual prices. Nor has the transaction cost perspective been extended to explain the presence of so many non-commercial traders, with so many different trading styles.

These differences in perspective extend to the analysis of markets for options on futures contracts, the one perspective emphasizing the construction of risk profiles through traded options, the other emphasizing arbitrage-like trading possibilities. For options, the arbitrage perspective has dominated. Because options in their current style began to be traded on organized exchanges only in the 1980s, less empirical evidence has been collected about them. One suspects that the further collection of evidence will be driven primarily by the implications of hypothesized purposes of options, and more discouraging yet, that the evidence will not influence theoretical treatments. In short, the subject of organized exchanges is dominated by economists' preconceptions.

Each organized exchange has its own history and current characteristics, just as each commodity has idiosyncrasies that influence how it is shipped, stored, and traded. Nevertheless, a number of characteristics appear to be common to commodity exchanges. While using coffee as the principal example, the first section of this chapter will emphasize these general characteristics. Similarly, the second section will identify broad types of traders, and review the empirical evidence about them. With this background, the third and fourth sections will present the risk-management and transaction-cost perspectives on futures and options markets. The fifth and final section will consider how well futures prices predict the subsequently realized price and similarly how well options prices predict the subsequently realized variability in the price. As it happens, economists' empirical tests for forecasting success have hidden within them particular theories about why organized exchanges exist. In other words, all the various subjects of these sections are intertwined, all reveal something about economists' approaches to models and evidence.

2. The nature of futures markets

Organized futures exchanges, notably the Chicago Board of Trade (CBOT), the New York Cotton Exchange, and the Liverpool Cotton Exchange, emerged in the third quarter of the nineteenth century, although some of their features can be traced back earlier [Williams (1982)]. The mid nineteenth century marked a revolution in steamships, railroads, bulk storage (an early use of steel-reinforced concrete was for vertical grain warehouses), and other innovations that expanded the economic range for shipments of commodities and increased the typical lot size far beyond that of individual producers or final consumers. The minimum lot for wheat, rather than the 2-bushel bags a farmer might transport by cart, became 5,000 bushels (a "bushel" was thereby re-defined as a commodity-specific unit of weight rather than the traditional unit of volume, to speed measurement), 5,000 bushels being the capacity of a canal boat carrying

grain in bulk. The mid nineteenth century also marked a revolution in communications. The telegraph allowed news about commodities to travel much faster than the commodities themselves. It also allowed frequent and detailed instructions, with the result that the local merchants who had aggregated farmers' quantities into the larger lots felt increasingly confident to entrust consignments to a relative stranger in a distant city. Those "factors" or "commission merchants" ("futures commission merchant" remains the name for a broker), no longer themselves needing to be present wherever the commodity was unloaded or stored, found it convenient to congregate, and to organize exchanges.

The success or failure of particular exchanges remains closely tied to the physical handling of the commodity and to the nature of information flows. The Chicago Mercantile Exchange's (CME) original butter and egg markets, dating from the early 1900s, died out by the 1960s. The production of both commodities had become much less seasonal, which reduced both the price variability and the need for intertemporal signals for guiding the disposal of inventories [Miracle (1973)]. Also in the 1960s, the CME benefited from the development of cold storage for pork bellies (used for bacon), which made possible the exchange's development of a new market [Powers (1967)]. A decline in the seasonality of pig births is now threatening that market, just as changes in the technology and industrial structure of the beef industry is reducing the volume on the CME's live cattle market. (The CME now handles primarily financial futures.)

Coffee, which will serve as the principal example throughout this chapter, illustrates well the interactions among economic geography, merchandising relationships, and organized exchanges. Coffee, grown in an increasingly large number of countries, is consumed mostly elsewhere: The percentage of coffee production, annually some 100 million 60-kg bags worldwide, entering international trade is larger than that of almost any other commodity. Coffee remains one of the last commodities to be handled in bags on pallets; the trend, however, is toward handling coffee in bulk in regular ocean-freight containers, the capacity of which implies a lot size of 20 tons (equivalent to 300 bags) and some \$40,000 value. Despite relatively high value (by weight, twenty times the value of wheat), coffee nevertheless feels transport costs to the extent of some fragmentation of its worldwide market. The market is also fragmented by coffee's heterogeneity. Its two main varieties, arabica and robusta, actually come from different plants; its various "growths", usually identified with a particular producing area, are finely distinguished by consumers. Inelastically supplied in the short run by its nature as a tree crop, exposed to seasonal cycles in production despite the geographic spread of production and despite low-cost storage, subject to not only freezes in Brazil but also efforts at withholding exports through the cartel-like International Coffee Agreement, and habit dependent on the demand side (is caffeine an addictive drug?), coffee has an especially variable price. Attempting to allocate the right type of coffee to the right location at the right time are some hundred merchandising firms worldwide, of many sizes and degrees of specialization in coffee. Coffee merchandisers that are based in producing areas are rarely producers too (that is, there has been no trend towards "grower-shippers" as in

some commodities). Coffee merchandisers that are based in consuming areas are usually separate from roasters, although roasters are increasingly integrating backwards. The roasting business has become increasingly concentrated worldwide (four transnational firms now hold more than 40 percent of capacity), but that trend co-exists with the rise of boutique roasters and with the presence of as many as several hundred independent roasters in Japan alone. Coffee currently has three active futures exchanges, all of which are located in importing centers. Trading has been most active on the Coffee, Sugar and Cocoa Exchange (CSCE) in New York, which traces its origins to the 1880s and whose “C” contract calls for delivery of arabica growths.¹ LIFFE, which, despite its origins in the 1980s as a financial futures exchange, recently encompassed the much older London markets for “softs” (commodities other than for hard metals, that is), trades a contract for robusta, now in a traditional “open-outcry” trading “pit” but probably soon by a continuous electronic version. Beginning in 1998, the Tokyo Grain Exchange (TGE), a fully electronic exchange since 1987, listed a contract for arabica and also one for robusta, trading these through its session system of discrete auctions. The CSCE and LIFFE offer options on their futures contracts, which trade continuously in pits adjacent to those for the futures contracts.

A distinction is often drawn between transactions in “physicals” and those in “derivatives”. When a Colombian coffee exporter exchanges a bill of lading for a specific container-load just then arriving in New York for a local roaster’s immediate payment in U.S. dollars, the transaction directly concerns the merchandising of coffee. When a Japanese trading house promises to pay to a German coffee importer in proportion to the extent that the New York price, for several types of coffee during the following July, averages over \$1.15 per pound for a notional 1,000 metric tons, the transaction derives from other physicals transactions. The distinction between physicals and derivatives is less about the time of the trade – transactions involving periods in the future can be physicals transactions – than about the involvement of something much like a financial instrument. A synonym for physicals is “actuals”, which term even more strongly suggests that derivatives are not concerned with the commodity itself. Nonetheless, it would be clearer usage were physicals and derivatives not defined as separate categories but as ends of a spectrum. Not only might the parties to a transaction view it differently, but over time types of transactions closer to the physicals end of the spectrum evolve into primarily derivatives transactions.

Futures markets are usually included as prime examples of markets for derivatives. They allow anonymous trading of standardized contracts guaranteed by the exchange in contrast to the direct negotiations between parties with specific reputations over the specific terms concerning grade, date, incidental fees, and so on, involved in a “forward market”. Indeed, “futures” would be even more emphatically classified as a derivative

¹ The C contract – “C” refers to a taste “sweet in the cup” – allows delivery by presentation of warehouse receipts issued by exchange-approved warehouses in New Orleans as well as New York (and recently Miami), a good example of the separation of trading from logistics.

were they to have a more sensible abbreviation as a name. In the mid nineteenth century, especially in the grain trade, the prevailing phrase was “a contract for future delivery”. “Delivered” then referred to something in store in a warehouse, in distinction to “on track”, “in transit”, “cost, insurance, and freight” paid, or “free on board”. (A corresponding contract for immediate delivery required the commodity to be “on the spot” and paid for in cash, since abbreviated to “spot” or “cash market”.) The better abbreviation for “a contract for future delivery” would have been a “contracts” market, since the commodity need not be in a warehouse.

To be useful to commercial firms, a “contracts” market needs to have standardized terms related to dominant commercial practices, such as lot size, but these terms need not be the most natural for any merchandising contract between two commercial firms, let alone all merchandising contracts. More important is the enforcement of the contracts. Were moral sanctions sufficient, were third-party guarantees common, or were courts quick and inexpensive at enforcing commercial dealings, organized exchanges would not exist.²

Organized futures exchanges have developed four related enforcement mechanisms. First, members of an exchange trade among themselves as principals personally responsible for a contract, even if they are acting as brokers for someone else.³ Second, an exchange mandates arbitration by standing committees of members, who, even if not entirely impartial, know about trading practices. Third, the members of an exchange guarantee contracts collectively. That is, once a transaction has been registered with the exchange’s “clearinghouse”, the two members no longer deal with each other as counterparties but with the clearinghouse. Fourth, an exchange’s clearinghouse “marks to market” any contract whenever the price moves. Day by day,⁴ the clearinghouse demands of the party against whom prices moved a deposit in cash for the price difference, or it closes out the member’s account (and the same procedures operate between mem-

² The confusions resulting from courts considering commercial contracts are well illustrated by the experience in the mid 1990s with multiyear “hedge-to-arrive” contracts between farmers and grain elevators, an analysis of which is offered by Lence et al. (1999).

³ Brokers’ taking on the role of principals may seem unimportant, but if it does not happen, a market will rarely attract additional volume. For instance today, many of the companies attempting to establish internet exchanges with commercial firms as members have found that brokers’ reluctance to trade as principals forces another layer of computer code and the risk that the incipient exchange cannot police its members. For instance in the 1870s, when futures commission merchants increasingly looked to “ring out” offsetting transactions, which made transactions on the new exchanges more convenient for almost everyone, clever lawyers for traders who had lost on particular trades would argue that those traders had not been consulted about the substitution of principals, as the law of agency requires. Fortunately, most courts saw the advantage of the practice of canceling essentially similar contracts ahead of time.

⁴ The clearinghouse can demand margin within the day, should prices move especially sharply. In principle, marking to market can occur at any reasonable interval, hourly or weekly. The price used for marking to market is known as the “settlement price”. Usually, the settlement price is the closing price, but for relatively inactive markets a committee makes a good guess based on the most recent trade and the trade for more active markets. In the nineteenth century, some exchanges used a mid-day price.

bers and their customers).⁵ Virtually always the trader finds it less unpleasant to meet the “margin call” than to default. The effect is the same as a daily re-negotiation of the contract to the current price.

These enforcement strategies together make futures contracts interchangeable and hence tradeable on their own right. If Trader A sells one lot of May coffee on January 13 to Trader B for \$1.15 per pound and later on January 19 buys one lot of May coffee at \$1.13 from Trader C, he does not hold those contracts open until May, subjecting his \$0.02 profit to the risk that either Trader B or C might default over the interval until May; they are cancelled out on January 19 by the clearinghouse, for each contract exists only as an entry on the books of the clearinghouse. Indeed, Trader A does not perceive of himself as trading with B or C (their histories might make them very different credit risks), let alone trading with their customers should B or C be brokers.

Because of the “counterparty risk” to forward contracts, or equivalently, because of the collective expenses from counteracting those risks, commodity exchanges developed clearinghouses. Clearinghouses further increased the usefulness of the particular contracts, to the point that most traders expect to “offset” their initial position rather than to make or take delivery. Knowing that they can offset later, some traders promise to deliver even when they have none of the commodity to deliver or even when they have no knowledge of how to make delivery. That is, clearinghouses are both cause and effect of the trading of contracts as if the contracts themselves were a commodity. And the trading of contracts themselves is both cause and effect of “short speculation”, namely the selling of something that one does not own in the hope of buying it later at a lower price, an action that seems so unnatural to those unfamiliar with organized exchanges.

The shift in emphasis towards trading contracts as if they themselves were a commodity can be seen in exchanges’ development of their options markets. Options give one party a choice, say to buy at a specified “strike price”, and give the other party, known as the “writer” of the option, an obligation should the holder of the option “exercise” it.⁶ Naturally, a writer of an option does not take on an obligation without some payment,

⁵ The daily flow of cash depending on price movements is known as “variation margin”. When a position is initiated, each of the two parties deposits “original margin”, which is drawn upon if variation margin calls are not met. Original margin is typically 5 percent of the value of the contract (an amount adjusted every so often by the exchange depending on the prevailing day-to-day variability of prices). Because prices rarely move that much each day, the clearinghouse is well protected from default [Gay et al. (1986)]. The degree to which the amount of original margin itself influences the volume of trading and the volatility of prices has been well studied, e.g., by Bear (1972), Peck and Budge (1987), and Adrangi and Chatrath (1999), although with no clear conclusion. The margin system increases the leverage and reduces the cost of capital for participants in futures markets compared to other methods of trading.

⁶ A “call” gives the holder of the option the choice to buy at the strike price, while a “put” gives the holder the right to sell at the strike price. Presumably, the holder of the option will exercise it only if, in the case of a call, the price of the “underlying” commodity has risen above the strike price, or, in the case of a put, the underlying’s price has fallen below the strike price.

known as the “premium”.⁷ Naturally, the holder of the option will not pay much as a premium without some assurance that the writer will honor his obligation if called upon to do so. Nor will the holder pay very much as a premium if the time involved is short, because an option presumes some degree of uncertainty will have been resolved. In the late nineteenth century and early twentieth century, some members of the CBOT traded what were known as “privileges”, although Illinois law had made trading of privileges illegal from 1874. Then, as now, the holder had the option to buy, or sell as the case might be, a futures contract. Then, unlike modern practice, the premium was set, usually at \$5 for 1,000 bushels, and the two parties bargained over the strike price (so that if there were a widespread expectation of especially uncertain prices, the market-determined strike price would differ more from the current price of the relevant futures contract). Then, especially different from modern practice, privileges gave the holder a right to exercise only the next day, most likely because the holder would not trust the writer much longer. Trading in privileges took place after regular hours, often outside the CBOT’s building, with the premium paid in cash, and no official record made of the transaction. (That any transactions occurred, since they were not enforceable at law, speaks to the enforcement power of CBOT membership itself – a reputation for default on privileges would limit a member’s other business.) Following a change in Illinois law in 1913, and before federal law restricted options trading in the late 1930s, trading in privileges (by 1913 also called “indemnities” or “deferred acceptances” – a change in name was one method to comply with the law prohibiting privileges) returned from the outside into the pits during regular hours, while the transactions were recorded and money handled through the CBOT’s clearinghouse. By the late 1920s, such trading in day-ahead options, and also week-ahead options, reached a volume on the order of 10 percent of the underlying grain futures contracts [Mehl (1934)]. When U.S. law looked favorably on options again in the 1970s (full-fledged trading began after 1982), the CBOT and other exchanges introduced a system, in line with practices in equity markets, of setting a few strike prices and letting the premiums for those be market-determined. That alteration in the system permitted a basic option contract for a particular strike price itself to remain constant, while any movement in its price, namely the premium, could be enforced in the style of margin and marking-to-market. The new system allowed trading many months ahead. Because of this much longer span of time before the exercise date, and because of the option contracts’ inherent interchangeability, many traders find it more convenient to offset their positions in options rather than to exercise them, making or losing money by the change in the prevailing premium. Thus, options on futures have become tradeable themselves.

⁷ In many instances, the premium might be part of another price, as in the mid nineteenth century transaction known as a “call o’ more”, in which, say, someone who bought 5,000 bushels of wheat at 80 cents per bushel had the right over the next week to buy another 5,000 bushels at 80 cents. The 80 cents would have been slightly above the prevailing price of wheat, to reflect that “embedded” option. The choices regarding day, location, and growth that the short can make under the CSCE coffee contract are other examples of embedded options, which presumably are reflected in the price of the futures contract.

By attracting considerable volume and a wide variety of traders, or, as Telser and Higinbotham (1977) have put it, by “facilitating trade among strangers”, active futures and options markets record prices that are widely accepted as representative and that are widely publicized. That very success works against an organized exchange, however. Should two commercial firms, or even two gamblers, trust each other sufficiently to refer to an exchange’s published prices, they could avoid the expense of membership, the cash reserves for margin calls, and their own trades’ effect on price. Should many avoid trading through the exchange, the exchange can no longer provide representative prices, ensure sufficient liquidity such that offset is easy, or even pay its staff. That tension lay behind the CBOT’s late-nineteenth-century campaign [recounted in Lurie (1979)] against “bucket shops”, which sent only the net of their orders to the pits, and lies behind the current controversy about “off-exchange instruments”, proposed by major investment banks as intermediaries to large commercial transactions. To economists, organized exchanges can be seen to have aspects of public goods, since one person’s use of a price registered on an exchange does not exclude others from responding to that signal. [Mulherin et al. (1992) examine the controversies over whether prices themselves are property.]

Futures contracts for a particular commodity on a particular exchange are interchangeable in every respect except for the period of delivery. Traders speak of the “May contract”, the “July contract”, etc., or synonymously, the “May expiration”. The terms of most futures contracts allow the party obligated to make delivery to do so on any business day of the month. Even if that fulfillment of the contract must occur on a single day, the convention remains to call the contract by the month. At any one moment, several distinct delivery months are traded, usually going as far ahead as eighteen months, but not every month is covered, and there are usually no more than eight. The delivery month that is about to end is called the “expiring” contract, the next the “nearby” contract, and those more than one year ahead the “deferred” contracts. A comparable usage is to call them the “first position”, the “second position”, and so on.⁸ Thus, the “futures market” of common usage contains within it several markets. At any one moment, there is a constellation of futures contracts, each of which has a distinct price.

Obviously, for a futures contract to come into existence, two parties must agree. The party committed to take delivery is the “long”; the party committed to make delivery is the “short”. Until those two parties offset their positions with each other (or much more likely, with others who had previously created futures contracts), the long going short with someone and the short going long with someone, the contract remains “open”. As part of its overnight “settlement” operations, a clearinghouse can track “open interest”, the total number of contracts open. Open interest can refer to a particular expiration, and track that series over its trading life. For example, Figure 1 shows the reverse time

⁸ Among the synonyms, “expiration” is perhaps the clearest term, given that “contract” can also refer to the number of lots (e.g., the trader has “five contracts in the July contract”) while “position” can refer to the style of trading (e.g., the trader has a “spread position between the third and fourth positions”).

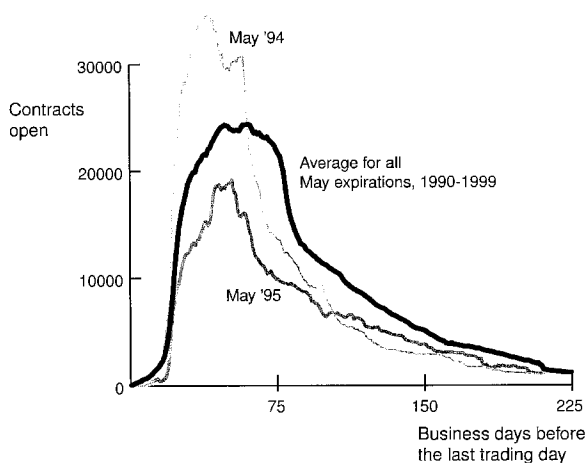


Figure 1. Pattern in the open interest of individual coffee futures expirations on the CSCE.

series for the open interest in the May '94 and the May '95 coffee expirations on the CSCE. Open interest can also refer to the sum across all expirations as of a particular day. For example, Figure 2(a) shows the day-by-day open interest across all eight CSCE expirations over the years 1989–1999 (the particular expirations necessarily came and went). The peak of some 60,000 contracts open, a peak reached a number of times during the eleven years, is equivalent to 16 million bags, which is some 15 percent of world annual production and 60 percent of U.S. annual imports, and represents a nominal value of some \$2 billion.

The time series in Figure 2(a) for CSCE open interest, although changing slowly, displays considerable variation over the eleven years. Economists' explanation of futures markets ought to explain that variation. The series in Figure 1 likewise show considerable variation. For example, the peak open interest in the May '94 expiration was nearly double the peak open interest in the May '95 expiration. There is, nonetheless, a similar pattern in the course of these two expirations' open interest, which can be seen especially clearly in Figure 1 in the series representing the average over all eleven May expirations 1989–1999. A year before the end of a May expiration's life, although trading has been possible for some 100 business days, the open interest is low, typically merely 1,500 lots. Although it rises steadily thereafter, the major increase comes only when the May expiration becomes the third position. Once the May expiration is the nearby contract (equivalently, the second position), i.e., during calendar March and April, its open interest is extinguished rapidly, so that at the start of the official delivery month, it is relatively small again. Economists' explanation of futures markets ought to explain this strong pattern too, since it is found on U.S. and U.K. exchanges for most commodities. On the TGE coffee market (and on other Japanese futures markets), in contrast, open interest peaks soon after the start of trading in an expiration, and from

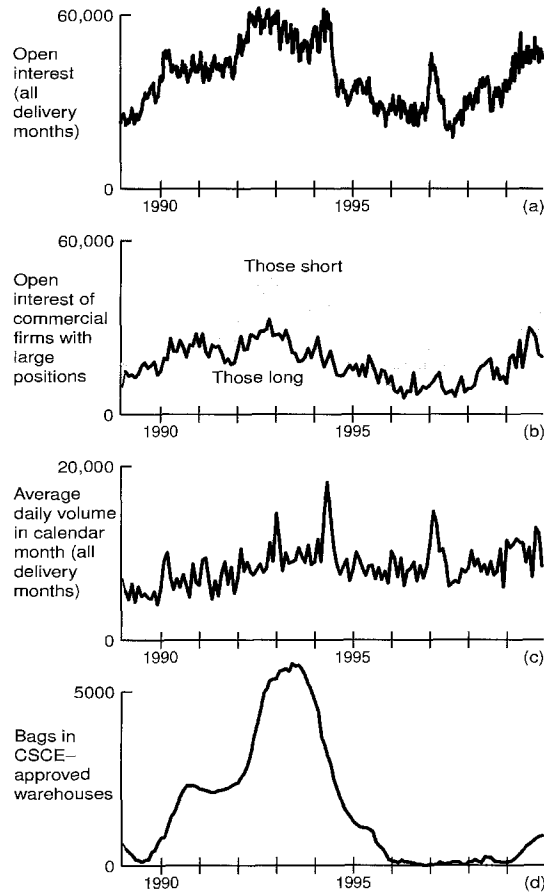


Figure 2. New York (CSCE) coffee trading, 1989–1999.

that early peak declines. Economists' explanations ought to account for that strong pattern too. The difference in these equally strong patterns presumably reflects the structure of brokerage commissions, the structure of position limits, and the degree and style of commercial firms' involvement.

Open interest and daily volume on formal, organized exchanges are highly visible statistics. For informal markets, relevant information about the number of transactions or the typical size of those trades is much harder to obtain, especially as a series over many years. Table 1 attempts such comparisons for a number of coffee markets, based on current practices as explained by some commercial firms. All the markets listed in Table 1 concern major importing or exporting centers for coffee,⁹ although it is not

⁹ Bremen should be taken to represent northwest Europe, including Rotterdam and Le Havre.

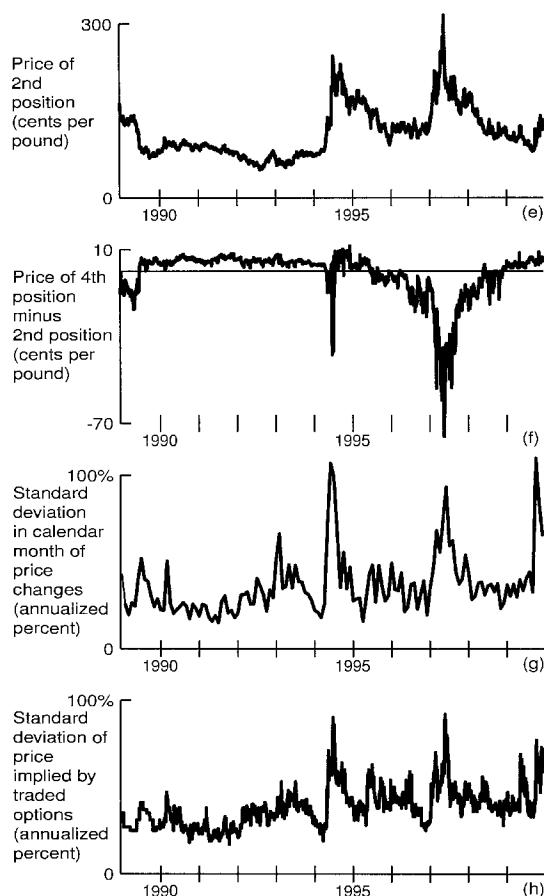


Figure 2 (continued). New York (CSCE) coffee trading, 1989–1999.

necessarily the case that a commercial firm based in one place necessarily trades just coffee bound for that one location. That there are a number of coffee markets reflects the degree of heterogeneity by space, time, and grade that fragments the worldwide coffee “market” of common usage.

As can be seen in Table 1, the three coffee futures markets have the most trades weekly, although the physicals markets typically have trades of larger quantities. On those futures markets, the typical trade is larger than one contract; for example, on the TGE speculators disproportionately take 5 or 10 lots (of 3.45 tons for arabica and 5 tons for robusta). Generally, the options markets conducted by the exchanges have fewer and smaller transactions than their sister futures markets.

Those unfamiliar with coffee markets may be surprised to see in Table 1 the dominance of forward trades among physicals. Most coffee does not begin a voyage (or even

Table 1
Trading activity in various coffee markets

	Trades weekly	Typical size (metric tons)
CSCE futures	8,000–10,000	50
CSCE options	3,000–4,000	25
Deliveries on CSCE futures ^a	10–200	100
EFPs involving CSCE futures	200–300	125
LIFFE futures	3,000–4,000	20
LIFFE options	1,000–1,500	10
TGE futures	2,000–3,000	25
New York spot	20–25	20
New York forward	50–70	125
Bremen spot	30–40	20
Bremen forward	30–50	125
Spot in Colombia	0–1	5
Forward in Colombia	30–50	125
Spot in Japan	200–300	5
Forward in Japan	30–50	125

^a Deliveries considered over the five months of contract expirations.

approach an export port) until some arrangement has been made for it. A typical merchandising firm, whether importer or exporter, would consider an active week to involve not even five such arrangements. Spot transactions in Bremen or New York are even less frequent, mainly to dispose of unwanted inventory. Spot transactions in Colombia occur on the rare occasions to fill out a shipment. The larger number of spot transactions in Japan reflects the large number of small roasters, who hold little inventory themselves. Usually weekly, they receive green beans from one of the few large importing firms. The relationships between a Japanese trading house and its affiliated roasters are so long-standing that the transactions might reasonably be classified as long-dated forward transactions, with a price adjusted periodically to outside conditions. Some of the larger Japanese roasters negotiate explicit forward contracts on the order of two to three months ahead.

The predominance of forward trading for physical coffee is far from unusual. For example, feed grains leaving the U.S. Gulf for Japan (a major export destination) are sold by the Japanese trading houses to their associated feed mills three or four months forward – farther forward, that is, than the trans-Pacific voyage itself takes, which practice implies that the Japanese trading houses are often transacting with U.S. grain exporting firms for Gulf delivery forward. That Gulf forward market is indeed quite active, usually more active than the Gulf spot market.

Forward trades in feed grains, as well as those in coffee, are expressed as differentials to prevailing futures prices. This style of trading with reference to a benchmark is known as “basis trading”. Indeed, for most commodities, almost all grades, locations, and peri-

ods “based on” a futures contract – hence the particular price differential itself is called the “basis”. For example, the basis for Salvadorian coffee for immediate (say, February) delivery in El Salvador might be 7.5 (cents per pound) “under” the March CSCE futures, while Colombian mild for delivery in New Orleans (NOLA) in March might be 3.0 “over” the March futures. Coffee traders talk in such shorthand (the part of the phrase “the March futures” would be understood and so dropped); when they negotiate, they do so about the basis, such as a NOLA roaster countering with “8.0 under” for Salvadorian spot, while all the while the benchmark futures price moves. Basis quotations tend to have a larger minimum price change than futures prices (0.50 cent per pound for most coffee growths rather than 0.05) and to move over days rather than minutes. Because a particular basis will move, traders speak of “basis risk”, even as they look to the futures market for most information about the web of prices. That is, physicals markets, such as those included in Table 1, do not exist independently of the derivatives markets. This fact exposes that “derivatives” is not the most informative term.

These facts about closely related markets call into question the approach taken by a large theoretical literature about the effects of futures trading. The questions asked, such as whether futures markets stabilize spot prices or whether they improve the allocation of seasonal production, remain legitimate. The problem is with the literature’s hypothetical example of incomplete markets. Turnovsky (1979), Kawai (1983), and Gilbert (1985), among many others, construct a model in which at first no futures market exists while a perfect spot market operates, perfect in the sense of no transaction costs, no grading disputes, no concerns about payment. Into that world, a similarly perfect futures market (comprising a single expiration) is imagined to be introduced. The economists’ preconception that a spot market could exist in perfection while a futures market does not exist determines the theoretical results they derive. Rather, if the nature of industries without organized futures markets (e.g., rice or almonds) is any guide, the hypothetical counterexample should include imperfect spot and forward markets, long-term relationships as an enforcement mechanism, prices not indicated to the public, prices that in any case anticipate later disputes about delivery conditions, grade, and payment. A model of such a complex heterogeneous situation is difficult to construct, but it would surely indicate a different effect of introducing an organized futures exchange than does the usual theoretical construct.

These facts about closely related markets also call into question a large empirical literature on the effects of futures trading. Gray (1963), Emerson and Tomek (1969), Powers (1970), Taylor and Leuthold (1974), and Cox (1976), among others, have looked at the behavior of spot prices before and after the introduction of futures trading in a particular commodity, especially addressing whether the prices had become more or less variable. Several of these authors, but not all, have appreciated that changes in underlying conditions, such as storage technology, government price supports, or consolidation in the processing industry, might alter not only the price variability but also the viability of the futures markets, clouding any before/after comparison. None of these authors has controlled for the likely change in the nature of the spot price quotations, however. In coffee, for instance, in the nineteenth century before futures trading, it was common to auction

lots upon their arrival at importing centers, at fixed times and places. Now such spot transactions are rare; published prices, which may be no more than informed guesses, surely do not represent the same growths and periodicity of the auctions. Economists should appreciate that the characteristics of the prices they can observe reflect the very set of markets they study.

3. Participants in futures markets

Longs collectively must equal shorts collectively. Someone's trading gains must equal some other participants' trading losses. The zero-sum nature of futures markets suggests that economists' standard tools, such as a "representative" participant in a single market, may not be especially helpful. Some heterogeneity among participants must be present, whether in merchandising experience, in views about the weather, in transaction costs, capital costs, or risk aversion; otherwise, no trades would take place. More than the futures market must be relevant, for those other markets would offer the scope for collective gains.

Because a position in futures contracts can be so easily offset, organized futures exchanges attract traders who have no regular connection to the underlying physical commodity, who are thus not "commercial". These traders are called "speculators", even though "non-commercial" would be a better term, since such traders' motives might include risk reduction, not to mention that commercials speculate. The presence of speculators on organized exchanges attracts controversy. Speculators' increased volume of trading adds to a market's liquidity, yet sometimes it seems to interested observers (consumers, whenever prices are perceived as moving abruptly higher, or producers, whenever prices are perceived as moving abruptly lower) that the non-commercial have undue influence. To economists, the presence of non-commercial raises issues such as whether speculation is stabilizing or whether speculators are risk averse.

When commercial firms use futures markets, they are said to be "hedgers" and their positions, whatever they are, are said to be "hedged".¹⁰ These words, with their suggestion of risk avoidance, are less suggestive of commercial firms' motives than administrative, accounting, and legal distinctions. Those classified as hedgers may deposit lower original margin, may treat gains (or losses) differently for tax purposes, and may exceed the position limits placed on speculators. Hedges are generally, and supposedly always, associated with commercial positions of some form. For instance, should a coffee exporter in Colombia hold a large inventory dockside, its short position in the nearby CSCE expiration for a corresponding quantity would be classified as a "short hedge". Should a roaster in Germany have committed to provide for a year a grocery

¹⁰ To be more precise, when commercial firms report their positions to regulatory agencies, they almost always call them hedges; this self-reporting is rarely scrutinized. In practice, therefore, commercial firms' trades are hedges officially. Conversely, even when a non-commercial takes on a futures position to reduce risk, it is not so classified officially.

chain's house brand but not yet have procured the green beans, its long position on LIFFE would be classified as a "long hedge". More precisely, the roaster's commitment with the grocery chain ought to include a specific price. Should the roaster take the long position on LIFFE anyway, thereby contracting to receive green robusta at a particular price, its long position would be classified as an "anticipatory hedge". An anticipatory hedge necessarily involves a business judgment regarding the course of prices over the next months, and so has a large element of speculation about the future. For that matter, a more conventional short hedge, one involving inventory that is, requires the business judgment about the relative movements among the prices of the various expirations in which the short position could be placed.

Commercial firms as hedgers are the fundamental participants in futures markets. Farmers rarely participate in futures markets, at least directly. Often the marketing arrangements that primary producers participate in with local processors, storage facilities, or merchandisers presume those commercials' direct participation in futures markets. (The applicability of the many theoretical treatments of futures markets that separate participants into "producers", "consumers", and "speculators" while making no mention of merchandisers should be viewed with some suspicion.)

Fluctuations in the open interest on a particular futures market mainly reflect changes in commercial firms' involvement. This pattern was first noticed by Irwin (1935) in wheat, was confirmed by Working (1960) for eleven commodities, was confirmed again by Peck (1980) for some other commodities, and is visible for coffee over 1989–1999 in Figure 2(b). All these studies and Figure 2(b) use data reported daily by traders with positions beyond some stipulated level to the Commodity Futures Trading Commission (CFTC), the U.S. regulatory agency. These "large trader reports" necessarily small commercials and speculators but they account for the majority of open interest for most commodities. In coffee over 1989–1999, the aggregate positions of the reporting commercials account for 69 percent of the month-to-month changes in total open interest. Their presence is much less closely associated with trading volume, however, as Figure 2(c) shows.

In most markets and at most times, commercial firms taken as a group are net short. This tendency can be seen in Figure 2(b) for coffee, which plots separately the aggregate position of reporting commercial longs and of reporting commercial shorts as published later by the CFTC for days near the first of each month. Only in 17 of the 132 months over 1989–1999 did longs predominate among reporting commercials in coffee. In some months, notably in 1992 and 1993, the reporting commercial shorts outweighed the reporting commercial longs by more than 20,000 lots, some 35 percent of open interest. It necessarily follows that non-commercials as a group were markedly long at those times.

Whenever commercial firms collectively are short in substantial quantities, typically also times when those commercial firms are substantially net short, inventories are substantially above average. This connection applies for all commodities ever studied. Figure 2(d) shows this connection for CSCE coffee warehouse stocks, which represent coffee stocks more widely. The correlation between the aggregate of reporting commer-

Table 2
Correlation among time series in coffee

	(a)	(b1)	(b2)	(b3)	(c)	(d)	(e)	(f)	(g)
(a) Total open interest									
(b1) Commercials reporting long	0.82								
(b2) Commercials reporting short	0.91	0.72							
(b3) Net among commercials	-0.53	-0.08	-0.75						
(c) Monthly volume	0.49	0.14	0.31	-0.31					
(d) Stocks in CSCE warehouses	0.80	0.68	0.83	-0.54	0.23				
(e) Price of CSCE 2nd position	-0.54	-0.65	-0.55	0.17	0.19	-0.54			
(f) Spread between 2nd and 4th	0.40	0.57	0.41	-0.52	-0.78	0.38	-0.67		
(g) Standard dev. of 2nd position	0.08	-0.11	-0.38	-0.52	0.46	-0.73	0.38	-0.47	
(h) Volatility implied by options	-0.84	-0.30	-0.19	-0.01	0.27	-0.18	0.58	-0.56	0.68

Simple correlations calculated from the 132 observations, near the first of the month, 1989–1999. “Net among commercials” = longs – shorts.

cial shorts and CSCE warehouse stocks is 0.83, as noted in Table 2, which reports all the simple correlations among the ten time series (measured monthly) in Figure 2.

The degree of short hedging is also closely correlated with prices. When short hedging is high, prices, as in Figure 2(e), are low.¹¹ This relationship might seem to suggest that short hedging directly causes low prices (more than a few farmers and politicians have leapt to that conclusion). Because coffee stocks are also high at those times (more than a few economists have leapt to the conclusion that high inventories cause low prices), it ought to be obvious that some deeper factors – the weather in Brazil is surely one of those factors for coffee – cause all three series, if not all ten series in Figure 2.

More interesting yet, the degree of short hedging is closely related to the price relationships within the constellation of futures delivery months. Traders speak of “spreads”. A spread exists between each possible pair of futures prices, and indeed, between the spot price and any of the futures prices – “immediate delivery” is part of the constellation at any one moment. Figure 2(f) displays the spread between the second and fourth CSCE coffee positions over 1989–1999. (Other pairs show spreads with

¹¹ The correlations among prices, the extent of commercials’ use of futures, and the composition of that use are present even for non-storable commodities, such as live cattle [Yun et al. (1995)].

much the same movement over time.) When the price of the more distant delivery month is above the nearer's price, the spread is said to be a "contango"; when the price of the more distant delivery month is below the nearer's price, the spread is said to be a "backwardation".¹² Contangoes are the more frequent in Figure 2(f), but the less frequent backwardations can be very large. "Backwardation" is just a fancy term for "a premium for earlier delivery". At times, especially when a small crop looks to be followed by a very large crop, a substantial premium will be paid for the earlier crop. A steep contango is not to be expected, however. If later delivery is at a great premium, the commodity can be stored from the earlier period, presuming it is a storable commodity like coffee.¹³

Working (1934) was the first to notice the close connection between spreads in futures prices and inventories, in his case the CBOT's wheat futures market and the nationwide end-of-crop-year carryover. This connection has since been found for every other commodity studied, including coffee [Thompson (1986)], although the connection between CSCE spreads or London spreads with worldwide stocks of coffee is not as close as in the case of wheat. For all commodities, the connection is nonlinear: When the spread is a contango, a unit increase in the spread is associated with a considerable increase in stocks; when the spread is a backwardation, a unit increase in the spread (a unit decrease in the extent of backwardation, that is) is associated with a small increase in stocks. For all commodities, some stocks are held even when the futures spread is in steep backwardation. Working (1948, 1949) generalized this relationship into what he called a "supply-of-storage curve", which supposedly is a smooth, stable function. He made sense of the observed tendency for some stocks to be held even when the apparent return to storage is negative by arguing that stockholders earn a "convenience yield" when stocks are few. His explanation has long been accepted on its face, although I, for one, have argued [Wright and Williams (1989), Brennan et al. (1997)] that the phenomenon that the concept of convenience yield is thought necessary to explain can be

¹² Contango and backwardation are terms of British origin. The grain markets on the CBOT developed a different usage. There a spread is referred to as a "carrying charge"; a contango corresponds to a "positive carrying charge"; a backwardation to an "inverse carrying charge", or sometimes just an "inverse". Although a positive carrying charge is an incentive to store the commodity – a spread greater than the full carrying charges of interest and warehousing fees represents a money machine – the usage from the grain trade can confuse a response to a spread with a description of the spread itself. Some economists misapply "backwardation", using it to refer to a futures price that is below the expected value of the subsequently realized spot price at that delivery date. Lest there be any doubt, a backwardation, or an inverse carrying charge for that matter, exists at one moment as a simple exercise in subtraction. Why backwardations exist is another matter.

¹³ When futures trading commenced in 1993 on the China Zhengzhou Commodity Exchange in mungbeans, amid inexperienced commercial firms and speculators, the more distant expirations were sometimes higher than the simultaneously traded nearby expirations by as much as double the known costs of warehouse fees and interest. Within two years, spreads were almost always no higher than the known costs of storage, much to the regret of traders who had noticed those early arbitrage opportunities too late [Williams et al. (1998)]. It is interesting that inexperienced traders take more time to learn about intertemporal arbitrage than spatial arbitrage, but it is behavior that proves the more general rule that experienced traders do not let spreads exceed known storage costs.

due to spatial or quality aggregation of stocks.¹⁴ Because a full treatment of the subject of convenience yield would be excessive here, suffice it to note two things: First, CSCE warehouse stocks do fall effectively to zero. Second, Working's principal point stands regardless. Commercial firms, nationwide or worldwide, look to the spreads in the principal futures market as the guide to their inventory decisions.

Despite the connection between aggregate stocks and commercial firms' short positions, most economists imagine that futures contracts have little direct connection to commercial firms' merchandising activities. Yes, the great majority of futures contracts are offset before actual delivery, but from that fact it does not follow that futures contracts do not connect to merchandising activities. During the last month of many CSCE coffee futures expirations, as many as 3,000 contracts culminate in delivery. That number, noted in Table 1, represents a large amount of coffee. Moreover in coffee, as on the CBOT grain markets [Peck and Williams (1991)], the quantity delivered expiration by expiration is very sensitive to the prevailing price relationships, which implies that deliveries on futures contracts are an intimate part of merchandising firms' activities.

A direct connection between physicals and derivatives is a transaction known as an "exchange for physicals" (EFP), also known as "against actuals". These trades have been little studied by economists [an exception is Mora (2000)], even though they are very common in almost every futures market, including coffee, as Table 1 indicates. An EFP presumes that a commercial with a short hedge has located another commercial who wants the short hedger's particular commodity and who is long the same delivery month. The two commercials, through their brokers, inform the exchange that they have offset each other's futures position – often at the day's closing price – while transferring ownership of the commodity.¹⁵ In coffee, EFPs are often the culmination of an earlier commercial connection. In January, say, a marketing firm in Colombia might negotiate to send 1000 bags of coffee to a Philadelphia-area roaster in March, with the price expressed as a differential to the CSCE March futures contract. The Colombian merchandiser goes short the March contract, the Philadelphia roaster goes long, with separate orders to the CSCE coffee pit (those positions might even have been established before January). When the coffee is being loaded (or perhaps as it approaches Philadelphia – the initial agreement usually gives one of the parties the option as to when to trigger the EFP), the two conduct an EFP for 4 contracts. Thus, EFPs, in coffee at least, are closely connected to forward contracts. Indeed, those forward contracts may be commercially viable because they employ the CSCE's enforcement mechanisms for all but the differential in price.

¹⁴ That is, the spreads between futures prices do not necessarily apply to coffee at a very different location or a very different growth from that easily delivered on the futures contracts. Indeed, that they are not delivered at the premium for early delivery suggests that they are inconveniently situated.

¹⁵ Because the parties to an EFP do not send their orders to the pit, they necessarily deprive others of a chance to profit from that flow of orders. Consequently, EFPs have been controversial, even though the anticipation of an EFP might have encouraged commercials to open the futures position in the first place.

Using the monthly data that large traders report to the CFTC (the Commodity Exchange Authority at the time), Houthakker (1957) calculated which group made money, whether the commercials, the large speculators, or the non-reporting traders, who are presumably mostly small speculators. For wheat, corn, and cotton, over 1937–1952 (with wheat and corn not trading during the war), he found that the hedgers collectively lost money in all three markets, especially in cotton, while small traders lost money in wheat and corn, but made much collectively in cotton. The large speculators appeared to be the most consistently profitable. Gray (1964) found that hedgers and large speculators made money in potato futures over 1952–1962, at the expense of small traders. Rockwell (1967) using more markets, more years (1947–1965), and semi-monthly observations, but still using the aggregates of classes of traders, found that small traders as a group had gross profits of essentially zero (and thus net losses after brokers' commissions). Large traders made profits, at the expense of hedgers as a group. Coffee over 1989–1999 falls within these patterns. An accounting of each group's month-by-month positions as in Figure 2(b) along with the month-by-month price movements (necessarily crude calculations) suggests that small coffee traders as a group made \$102 million over the eleven years, large speculators made \$68 million, while large hedgers as a group lost the \$170 million. Yet these sums, as substantial as they may seem, are not statistically significant; the month-to-month flows among the groups are simply too huge and too variable. For instance, by this accounting, large speculators as a group lost money in 70 of the 131 month-to-month changes.

More revealing about speculators than consideration of their aggregate behavior are studies of large numbers of individual speculators. In an early study [Stewart (1934) represents an even earlier study], Stewart (1949) examined the trading records over 1925–1934 of 9,000 customers of a nationwide brokerage firm catering to small speculators. Over 75 percent of these speculators lost money; in the aggregate they also lost money. Smidt (1965), having surveyed a number of amateur speculators, concluded that they split about evenly between those who attempted to detect that prices differed from some fundamental level (who are often called “fundamentalists”, as a result) and those who attempted to detect sustained movements in prices (who often employ charts of recent prices, and so are known as “chartists”). He estimated that half of such amateurs would cease trading within five years of starting an interest in futures speculation. In a recent study, for which brokers were surveyed about their continuing active customers, Canoles et al. (1998) found that such speculators are affluent risk-seeking individuals who enjoy having a position in the market and who count the number of their winning or losing trades more than their profits, which are usually negative over extended periods.

An especially important study is Hartzmark (1987), in which he utilized the day-by-day trades of 3,728 speculators in nine different futures markets who filed the large trader reports with the CFTC over the period July 1, 1977, through December 31, 1981. These are the raw data normally investigated as monthly aggregates. Surprisingly, although the large speculators as a group made money over the period, it was a small, statistically insignificant amount. (Commercials did marginally better, although a few of them accounted for the majority of their collective profits.) A slight majority of large

speculators lost money.¹⁶ In a related study, using the same data, Hartzmark (1991) found that the speculators' trading results are determined by luck rather than forecasting ability. Were traders adept at forecasting price changes, they would be long before a price increase and short before a price fall, and perhaps adjust the size of their positions by the firmness of their beliefs. On the contrary, it seems that there were even fewer traders exhibiting this type of forecasting skill than might have been expected by chance, evidently because a number of them follow similar trend-following strategies or subscribe to the same advising services.

Since the late 1970s an increasingly large component of speculation on U.S. exchanges has been through "commodity funds" or "commodity pools". Over 1,000 of these have existed at some point over 1980–1996. Smaller investors can buy shares in the funds or place money in the pools, in the style of mutual funds in equities. Large pension funds can place a share of their assets into commodities. Organized exchanges have spent much effort over the last twenty-five years trying to convince investors that commodity futures are another class of assets, along with equities, bonds, and real estate.

Many of the commodity funds and pools hire professional "commodity trading advisors". (Actually, the reverse happens more often; successful commodity trading advisors set up the funds and advertise for investors.) As with equity mutual funds, considerable theoretical and empirical questions arise about whether active management performs better than more passive strategies, such as holding long-term an index of commodities. Because these funds must make public their financial performance monthly (not their trading styles, however), it is possible to know much more about them than other speculators. In an early study, Irwin and Brorsen (1985) found that most funds covered their considerable management fees with trading profits, but that many lost money, often in the same year as the others (which suggests similarities in trading style). Edwards and Liew (1999), in a much more extensive study of a lengthier record, found much the same performance: slightly better than break-even. (The considerable entry into this business is probably one reason why trading performance is not extraordinary.) Murphy (1986) has documented that many commodity trading advisors favor "technical analysis", looking for relatively short-term trends they can follow. Because the funds are relatively large, some observers of futures markets worry that the similarities in the funds' trading styles create the very trends over a week or two that they seek to follow. Nevertheless, Irwin and Yoshimaru (1999) in an extensive study of the trading of large managed commodity pools over 1988–1999 find no such increase in price volatility.

Compared to most U.S. futures markets, speculators constitute a larger component of trading on the TGE and other Japanese exchanges. Why is not known, but it probably reflects less the behavior of speculators than commercials. Speculators in Japan fall

¹⁶ Using these daily disaggregated data, Hartzmark (1987) reconstructed aggregated monthly data. It seems that commercials do relatively well within months, evidently timing their trades well, which implies that the results Houthakker (1957) and Rockwell (1967) reported overstate the earnings of small speculators, modest as they appear to be.

on the usual spectrum of rank amateurs to long-time professionals. One category of speculator is prominent on the TGE but is not as common in the U.S.: the “house trader”, namely someone who trades on behalf of a brokerage firm itself. In TGE coffee in 1999, house traders accounted for some 20 percent of the trading volume. The TGE conducts futures trading as a series of auctions – indeed, conducted by the “Walrasian” auctioneer of standard micro theory who finds a price where supply equals demand – in which each of some 75 brokerage firms enters the net of all their customers’ orders, including the order of their house trader (commercial trade through brokers too). In arabica coffee, for example, every day, there are five cycles through the six delivery months. Some of the house traders are very active, adjusting the size and direction of their position auction session to auction session. Other house traders are passive, often taking the opposite position of their customers’ net orders, whatever that happens to be. (If all brokerage firms acted this way, much as did the late-nineteenth-century bucket shops, no orders would go through to the auction.) Because the customers of these brokerage firms happen to be mostly inexperienced speculators and because inexperienced speculators seem to be most comfortable on the long side of the market, these house traders are often short for weeks or months on end. Whatever their trading styles, almost every house trader, over 1991–1999 over all TGE markets, achieved profits little different from zero.

“Scalpers”, common on U.S. and U.K. exchanges, are another type of trader classified as a speculator, but primarily in the sense that they are non-commercials. Scalpers do make money, and much more consistently. The typical scalper is an independent trader, always present in the trading pits, who holds his futures positions for a matter of minutes and who rarely holds a position overnight.¹⁷ A scalper is often the one to initiate a trade, in the sense of calling out (and hand signaling) a willingness to buy, say, 10 lots at 115.35 cents per pound, which offer is one “tick” of 0.05 cents per pound below the most recently recorded transaction. Should a broker have just received an order to sell quickly 10 lots at the best available price, the broker signals “done” to the scalper. The scalper often then begins to call out a willingness to sell up to 10 lots at 115.40. He might instead stand quietly, hoping that a flood of buy orders will soon arrive and that he can sell to one of the better arrivals. He might also sense, depending on what broker just dealt with him, that more sell orders are on the way, in which case he might look to “scratch” much of his ten-lot purchase with someone else at 115.35.¹⁸ A scalper would be happy

¹⁷ Or rather, because there is no official designation, it might be said that scalping is defined as a trading style, as distinct from “day trading”, which involves positions held several hours within a day, or from “position trading”, which involves positions held for weeks or months, and which does not require a presence in the pits. Scalping blends into day trading.

¹⁸ According to a study of CME scalpers by Manaster and Mann (1996), individual scalpers control their inventory, avoiding becoming either too long or too short. Yet the correlation between their current position and the price at which they appear willing to transact is positive, whereas the correlation should be negative if scalpers use the prospective trade’s price to control the size of their position. It would seem that scalpers actively take their positions and that they can sense short-term trends.

to stand in the pit servicing alternating hurried buy and sell orders one tick apart, since such orders would rarely arrive simultaneously, but he must also be a speculator in the sense of anticipating the order flow over the next few minutes. The typical scalper thus aims to trade in the “dips and bulges”, to use Working’s (1967) phrase from the first study of scalping [in the precursor (1954a), he used the word “jiggles”]. Working followed several cooperative scalpers for several weeks of their trading. Recently, more comprehensive data have become available, especially about the CME [e.g., Kuserk and Locke (1993)]. The typical scalper makes thirty or forty trades a day, losing on many, and on average making just less than one tick per trade, such a thin slice being the nineteenth century inspiration for the name scalper.

Collectively, scalpers are the market-makers in continuous futures markets. Equity markets, corporate bond markets, and foreign exchange markets all have traders who quote a “bid” at which they will buy and simultaneously an “ask” at which they will sell, in which case they are said to “make a market”. No individual scalper calls out both a buying price and a selling price, nor necessarily even displays a willingness to transact.¹⁹ In a pit as active as CSCE coffee, perhaps twenty members trade as scalpers. Without coordination, at least one scalper will be calling out an offer to buy and at least one other an offer to sell. Scalpers can account for as much as 50 percent of daily volume. Thus, collectively scalpers provide the liquidity and depth to the market, which gives those not on the floor the confidence to place orders such as “buy immediately” (a skilled “floor broker” will, of course, interpret “immediately” according to his own sense of the order flow) and the confidence that should they reverse that order weeks later they will find someone willing to buy close to the most recent price. Were it not for scalpers, U.S. and U.K. futures markets would not be “continuous double auction” markets.

In continuous markets such as CSCE coffee, the interaction of outside orders, whether “limit orders” or “market orders”, with the practices of scalpers produces a transaction-by-transaction price series with negative serial correlation [Martell and Helms (1978)]. At first glance, such a predictable component to price changes would imply that some attentive trader could make a profit. Yet any mechanical trading filter would not cover the costs of executing the suggested trades. At second glance, the negative serial correlation at very short frequencies indicates the market is functioning well, for many scalpers must be present. Indeed, the tendency for price reversals at the interval of seconds or minutes can be used to estimate the “execution costs” for orders by those not on the floor. Such execution costs, which might also be called the “price effect” of an outside order, represent the order’s indirect costs, while brokerage commissions are among the direct costs of an outside order. The estimates of execution costs, made by Locke and Venkatesh (1997) for CME markets and by Thompson and Waller (1987) for coffee

¹⁹ On the new continuous electronic exchanges, such as those in China, some traders regularly have pending orders both to buy and to sell, at different prices. This incipient practice is much closer to straightforward market-making.

specifically, and derived from the “price change register” (the prices reported by exchange employees to the outside world) are on the order of one or two ticks per trade, in line with the estimates of scalpers’ profits from their own trading histories.

Given that scalpers make money consistently, albeit very little per trade, everyone else collectively must lose that sum. Who precisely has those losses is not known, because the second-by-second trading of others is aggregated into that of particular floor brokers. Given that larger longer-term speculators do not make much money, neither can commercials lose much money, if any, over long stretches of time.

The zero-sum game of futures trading also speaks to the issue of whether speculation stabilizes prices. If a futures market attracted only speculators, speculation could not be profitable on average. Since it is commercial firms whose inventories respond to spreads, any effect of speculation must be indirect. If a futures market attracted only commercials, short hedging could not predominate. It must follow that a principal consequence, intended or not, of speculation on organized exchanges must be to facilitate hedging. Gray (1967) has offered evidence that hedging costs, in terms of the price effects of the trading, are lower on those markets that have more speculation.

4. Trading in the presence of risk aversion

The symbiosis of commercials and non-commercials, otherwise known as hedgers and speculators, depends fundamentally on commercials. Working (1954b) offers a compelling example that the Kansas City Board of Trade’s attempt to make its wheat futures contract more attractive to speculators drove hedgers to other wheat futures markets, and speculators departed following the hedgers. What then is the motive behind commercials’ use of futures markets? Most economists propose that the primary motive reflects commercials’ risk aversion, aversion, that is, to inherently volatile prices. Economists’ risk-management perspective has three strands, namely the theory of normal backwardation, the theory of hedging pressure, and the portfolio theory of hedging. In the most modern models, economists use a blend of these three: Portfolio theory is used to derive the behavior of an individual commercial firm; aggregation to market-level equilibrium accords with the idea of hedging pressure; one implication of the market-level equilibrium accords with the older theory of normal backwardation.

In the 1930s and early 1940s, several British theory-oriented economists, among them Keynes (1930), Kaldor (1939), Dow (1940), and Blau (1944), described futures markets as insurance markets for price risk. Blau (1944, p. 10) succinctly stated their position: “The system of futures trading is based on the fact that cash and futures prices move together. Clearly, the effectiveness of hedging (i.e., the effectiveness of neutralising price risks in the cash market by assuming opposite risks in the futures market) must be impaired to the extent to which the movements of cash and futures prices diverge”. Although maintaining that futures markets resemble markets for insurance, Blau recognized that futures markets could not operate like standard insurance markets. By pooling the independent risks of many individuals to fire, theft, or death, an insurance company can closely anticipate the number who actually suffer a loss, and thereby substantially

reduce its own risk. Unlike with fire or theft, commercials gain or lose together on their inventories (or lack thereof), because the gain or loss is determined by a price common to all. Should those commercials wanting to be short just balance those wanting to be long, all would be fine. Otherwise, those wanting price insurance must transfer their risk to other participants in the futures market.

What induces speculators to take on the risk of a position in futures? Keynes (1930, p. 143) argued, when stocks are of average size, "the spot price must exceed the forward price by the amount which the producer is ready to sacrifice in order to 'hedge' himself, i.e., to avoid the risk of price fluctuations during his production period. Thus in normal conditions the spot price exceeds the forward price, i.e., there is a backwardation". The speculator earns a premium for bearing risk because futures prices are biased downward as estimates of the prices that will prevail at the time of the contracts' expirations. The farther ahead the futures contract, the more the downward bias, since the price insurance is offered for longer. And according to Keynes, the typical risk premium should be on the order of 10 percent per annum, due to the considerable risks speculators take on.²⁰

Keynes's theory of normal backwardation can be generalized into the hedging-pressure theory with two observations [and some mathematics, e.g., Stein (1986)]: First, commercial longs outweigh commercial shorts on some occasions, in which circumstances futures prices should be biased upwards by the need to attract speculative shorts in to the market. Second, the more commercial shorts outweigh the commercial longs, the more speculative longs need to be attracted into the market. These two observations suggest that the bias should reflect the sign and magnitude (and probably a linear function as a reasonable approximation) of the net of commercials' positions. The bias reflects what might be called the supply of naive speculative services. Only if the supply of (net) speculative services is infinitely elastic at the price expected for the expiring futures will the hedging imbalance not result in a bias within the futures price before its expiration, or at least from a simple view of the balance in futures markets.²¹ Should

²⁰ Keynes's theory – not that it was developed in any modern sense of mathematical rigor – refers to the size of the risk premium as comparable to the typical backwardation observed; it is thus a theory of why backwardations are common. Economists can twist terminology, and in so doing subtly change the predictions of a theory. Some economists have used "backwardation" to mean the supposed "bias" in futures prices. That switch in meaning leaves no expression to describe the common situation of nearby prices exceeding those simultaneously quoted for later delivery months (not to mention that the word "bias" is a sufficient description). More pernicious, the altered meaning of backwardation implies that it is normal to have a bias, whatever its magnitude, rather than that the bias should be as large as the backwardation under normal market conditions, which was Keynes's meaning.

²¹ The presence of the considerable number of speculative shorts is awkward for the theories of normal backwardation and hedging pressure. Given that commercial shorts outnumber commercial longs, the speculative shorts must suffer the downward bias in futures prices too. Thus, they cannot be following some naive strategy of collecting the risk premium. And if they are not naive, why should the speculative longs be naive? In coffee over 1989–1999, it happens that the amount of short speculation in the aggregate (as defined by those not reporting themselves as large commercials short) is below average whenever the hedging imbalance is more short than usual, although the reduction is not large. The presence of speculative shorts in above-average quantities when commercials were unusually short in the aggregate would be very difficult to reconcile with the hedging-pressure theory.

commercials forecast price movements better than naive speculators, a subject considered at greater length in the final section here, the commercials might profit regardless, although that pattern would make it all the more difficult to explain the small speculators' presence.

At the crux of the theory of normal backwardation is the observation that hedgers are net short as a group, most of the time. From this fact comes both the belief that hedgers are seeking insurance and the prediction that speculators must be paid a risk premium to provide it. It is the apparent selling pressure from short hedgers that causes the supposed downward bias in the futures price; the subsequent buying pressure whenever the hedgers offset their positions bids the price back up, with speculators profiting from the advance. If a speculator maintains a long position consistently, which speculators as a group do inasmuch as hedgers are net short as a group, he will earn a profit on average from the general tendency of futures prices to rise as the contracts mature. The generalization to the hedging pressure theory would say that if speculators were to maintain a position opposite to hedgers, which speculators must necessarily do as a group, they would earn a risk premium in direction and in proportion to the position they maintain.

If any consensus has emerged, it is that no significant downward bias exists in futures prices. By implication, speculators are not attracted to futures markets to earn a risk premium through a naive trading strategy. Telser (1958, 1960) studied the wheat and cotton markets and claimed to have found no bias, although Cootner (1960), in reworking Telser's data, concluded that some bias was present. Gray (1960, 1961), attempting to balance the two, concluded that there was effectively no bias in large markets like corn, although smaller, relatively inactive futures markets might be biased. Kolb (1992), in the most comprehensive study to date, of 29 commodities over the period 1958 (or when they were first listed on an exchange) through 1988, found minimal evidence of futures prices rising from the first trading of particular expirations through their final day of trading.²² Bessembinder (1993), in a comparable study involving slightly different commodities and periods, also uncovered little evidence of bias in futures prices.

Similarly meager evidence of a downward bias is present in coffee over 1989–1999. Figure 3 provides a time series of observations expiration by expiration, from which a histogram of price changes can be constructed and which identifies some statistical complications. Each observation in Figure 3 represents the change in the price of a particular futures contract from eleven months earlier. (Studies such as that by Kolb use day-by-day changes, but daily evidence cumulates to something such as Figure 3.) The mean change for the fifty contracts shown in Figure 3 is 3.88 cents per pound (or 3 percent per annum, at average prices). This number is at least positive, as predicted by the theory of normal backwardation. But with the incredible volatility in the series, 3.88 cents is not significantly different from zero (by conventional *t*-tests, which ignore the non-symmetric frequency distribution). With the marked skewness in the price changes,²³

²² The exceptions were for non-storable commodities, feeder cattle, live beef, and live hogs.

²³ Because stocks can be held, thus supporting prices, while production from the next crop year cannot be brought into the present, thus putting little bound on the highest current price, the distribution of year-to-year prices for a storable commodity should be skewed [Wright and Williams (1982)].

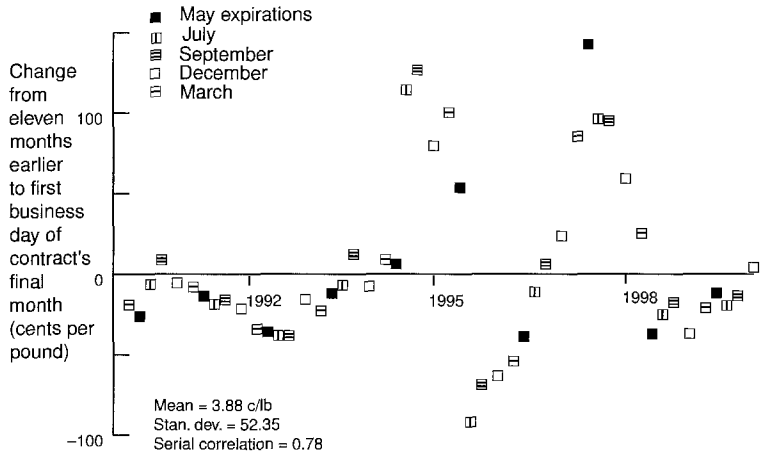


Figure 3. Price movements over the eleven months before expiration of CSCE coffee futures contracts, 1990–1999.

32 of the 50 contracts had a loss. With the pronounced serial correlation in the observations, because the constellation of many delivery months tends to move together, the effective sample size is smaller than it seems to be, closer to merely one observation per year.²⁴ Neither Kolb nor Bessembinder worried about these statistical complications, which would have weakened further their weak evidence of bias in futures prices.

The test for downward bias such as conducted by Kolb or Bessembinder or as conducted in Figure 3 treats all observations as equivalent, whether or not there was substantial short hedging. To account for the extent of short hedging is to test the “hedging-pressure” theory. When both Houthakker (1957) and Rockwell (1967), in their studies previously mentioned, calculated the period-by-period profits of the aggregates of traders reporting to the Commodity Exchange Authority, they were implicitly testing whether hedging pressure increased the average profit potential for speculators and the average loss for hedgers. Houthakker found that large hedgers did lose money on average; Rockwell somewhat the same, but to a lesser extent, and that the successful traders were the large speculators, not the small speculators who would be the ones presumed to follow a naive trading strategy. Gray (1979) found that a naive trading strategy taking positions opposite to net hedging would have lost money over 1960–1977 in corn and soybeans. Neither Houthakker nor Rockwell considered the statistical significance of their results; neither result is very strong statistically. In a more statistically oriented and more recent study of five commodities, including coffee, Chatrath et al. (1997) found that the commitments of large commercials did not influence subsequent movements in futures prices.

²⁴ Differences in the variances of the five delivery months might be another complication – the standard deviation for the ten December expirations in Figure 3 is 60 percent of that for the ten July expirations.

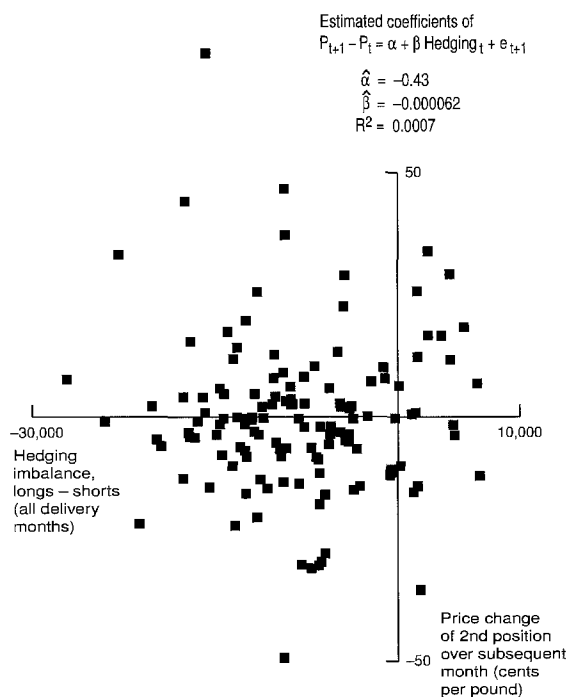


Figure 4. Relationship between coffee hedging imbalance and price changes, monthly, 1989–1999.

The style and typical results of these tests for an effect from hedging pressure can be seen for coffee in Figure 4. In this scatter diagram, the first-of-month net position of large commercials (the net of the series in Figure 2(b)) is related to the change in the price of the second futures position over that month, with adjustments for those months when a contract expires.²⁵ According to the hedging-pressure theory, in a straightforward OLS regression, the hedging imbalance should be statistically and economically significantly related to the change in the futures price and the intercept should equal zero. According to the regression results reported in Figure 4, for coffee over 1989–1999, the intercept is effectively zero. And so is the slope coefficient, contrary to the hedging-pressure theory.²⁶

²⁵ The series for hedging imbalance covers all delivery months, so it should not be as closely related as the series for the hedging in the second position itself.

²⁶ Fort and Quirk (1988) argue that the higher correlation between cash and futures prices when stocks are abundant (equivalently when prices are low) encourages short hedging. This argument suggests that the spread, say between the second and third position, might also be an explanatory variable along with hedging imbalance in the regression in Figure 4. Neither variable, however, explains the change in the price, notwithstanding that the price level, the spread, and the hedging imbalance are all contemporaneously related, as Table 2 indicates.

Studies of hedging pressure have searched for bias by considering what a trader with a position tracking the aggregates of traders reporting to the CFTC would have earned given the actual behavior of futures prices. They did not examine the trading history of individual hedgers or speculators. In that regard, Hartzmark's study (1987), previously mentioned, offers much more direct evidence. To repeat, he found that hedgers on average did not lose money, while the large speculators made no money on average, evidence sharply refuting Keynes's theory of normal backwardation. (He did not examine whether the probability that individual commercials made money over some short time interval was itself a function of the collective amount of hedging, a test that would have said even more about the hedging-pressure theory.)

Dusak (1973) approached the question of bias and risk premiums from a different direction, that of what a speculator would have to earn to induce him into the futures market. She concluded that a speculator does not need to be enticed with much of a risk premium, if any. Her point of departure is the observation embraced by modern finance theorists: Speculators need be compensated only for what is called systematic risk, because all other risk can be diversified away.²⁷ Thus, the amount of bias expected in futures prices equals the extent to which futures prices move systematically with a broad portfolio of assets in the economy.²⁸ Dusak determined that there is no systematic relationship between movements in futures prices and movements in a broad market portfolio. For corn, wheat, and soybeans, her estimates of the "beta", namely the extent to which some asset's price moves with a one-unit change in the broad portfolio, were all on the order of 0.05. Major equities, in contrast, have a beta of at least 0.60; the market portfolio by construction a beta of 1.0. Carter et al. (1983) questioned whether Dusak had constructed the broad market portfolio properly, with the inadvertent result that she understated the systematic risk of positions in futures markets, because commodities themselves, farmland, and agricultural processing plants are not well represented within firms with traded equity; they found evidence of somewhat higher betas. Marcus (1984) in turn argued that Carter et al. had overstated the share of commodity-related assets, thus finding higher systematic risk. Kolb (1996), using the most months of data and the largest number of commodities, although using a broad portfolio consisting only of equities, has found little evidence that futures prices move with a broad portfolio. If Kolb's result of very low betas can be taken as definitive, there is no reason to expect

²⁷ A related argument is that speculators, if they truly sought only to earn a risk premium, would hold long positions in many futures markets, since that would reduce their exposure to the vagaries of a single market. As it happens, the largest speculators tend to specialize.

²⁸ The "capital asset pricing model" (CAPM) begins with the observation that, were an asset added in equal proportion to a portfolio of many other assets, its contribution to the variance of the new portfolio would reflect its covariances with the other elements of the portfolio. If it had a low covariance on average, even zero, it would add little to the portfolio's variance despite its intrinsic riskiness, as measured by its own variance. The average covariance can be found by regressing the asset's price changes (some daily or monthly series, usually converted to percentage changes) on the equivalent series for the broad portfolio, since the regression coefficient reflects that covariance. Because of the common Greek notation for coefficients in OLS regressions, economists invoking the CAPM speak of an asset's "beta".

futures prices to include a risk premium; that is to say, there is no reason to expect futures prices to be biased.²⁹

Some doubt may always persist about the presence of a risk premium in futures prices. Bjornson and Carter (1997) detected that month-to-month movements in futures prices are related to time-varying macroeconomic variables besides a general index of equity prices, which suggests not all commodity risk is diversifiable. Similarly, the pronounced seasonality in the variability of futures prices complicates any statistical procedure.³⁰ Yet, if any bias exists, the difficulty in spotting it suggests that it must be small. Surely a bias as large as the 10 percent per annum Keynes imagined would be easily discernible in futures prices if it exists. Likewise, differences in hedging balance as large as that in coffee over 1989–1999 ought to make it possible to discern any connection between hedging pressure and a bias in futures prices.

Although the theory of normal backwardation, not to mention the hedging-pressure theory, receives little empirical support, economists who have tested it, including those skeptical of the theory, have persisted in viewing the theory's validity as an empirical issue about the behavior of futures prices over time. They have never questioned its underlying logic. A slight expansion in the supposed number of periods from two to three reveals an internal contradiction regarding the assumption about speculators' naive behavior. A slight expansion of the number of delivery months in futures from one to two reveals an internal contradiction in the supposed pattern of the bias. Slight alterations in the method of transacting between hedger and speculator that do not change the effect of the transactions radically change the theory's perspective on the motives for the transactions.

Keynes's simple theory, but also the modern mathematical treatments, imagine two periods, one in which a substantial number of short hedgers entice naive speculators into the futures market – the futures price that first period equilibrates with a large implicit risk premium – and the second in which all positions are liquidated at the unbiased price. Imagine a yet earlier period in which there is some short hedging pressure of the same contract for delivery in the final period, such that the equilibrium risk premium in that earlier period would be small, by the usual arguments about hedging pressure. Imagine that everyone knows of the substantial hedging pressure that will appear in the next period. Under these circumstances, the speculators who accommodated in the yet earlier period are stupid, not merely naive. Put differently, a speculator, even one solely interested in earning a risk premium, would attempt to forecast hedging pressure. Commercials would also rationally attempt to forecast hedging pressure, to avoid being

²⁹ A variant of the CAPM proposes that an asset's risk premium should be related to its movements in relation to consumption rather than to assets such as equities. Jagannathan (1985) examined two-month movements in corn, wheat, and soybeans in relation to a broad measure of U.S. consumption and found that they did reveal the expected risk premium.

³⁰ As Murphy (1987) has shown, seasonality variability should not affect the expected return due to the holding of a futures position. First of all, much of the seasonality is predictable. Second, the remainder is an easily diversifiable risk.

part of a flood of orders. In such multiple-period situations, it is not at all clear that there should be a connection between current hedging pressure and price changes.

For almost every commodity, including coffee, the constellation of prices, including the price for immediate delivery, is often in contango among all but the most distant pairs. Such price relationships coincide with considerable short hedging and considerable inventories. With short and long hedging so out of balance, it should be precisely these periods in which the largest risk premium would have to be paid to attract the additional long speculation. Keynes attempted to explain away this contradiction by arguing that in times of full carrying charges the futures price and the current spot price are both biased downward (i.e., so they appear as full carrying charges). Keynes's explanation is inadequate. If the spot price itself is biased downward, what happens to the supposition that futures price one period ahead is a biased predictor of the realized spot price? That spot price will be unnaturally low too. Furthermore, what determines the periods in which the current spot price is no longer biased downward? Clearly, a major inconsistency in the risk-management perspective arises from the presence of full carrying charges over several delivery months simultaneously with long and short hedging being out of balance.

The line of reasoning in the theory of normal backwardation would be suspect if the trades between the coffee exporter and speculator were conducted in a slightly different manner to achieve the same economic effect. Imagine that instead of buying coffee outright, a coffee exporter makes a repurchase agreement with a farmer. "Repos" and the broader category "swaps" increasingly dominate trading of government bonds and currencies, and are the type of off-exchange instrument that investment banks want to make available in commodity markets. The effect of a repurchase agreement is that the coffee exporter has the use of the farmer's coffee over the period of the agreement just as if he had received it on loan, while the farmer has the use of the coffee exporter's money, just as if he had received it on loan. Once the initial step of the repurchase agreement has passed, it will appear that the farmer has an obligation to buy coffee from the exporter while the exporter has the obligation to deliver coffee to the farmer. Despite these appearances, the repurchase part of the agreement exists to return the coffee and money to their original owners. Suppose, however, that the farmer decides that he no longer wants to own his coffee. He could sell it in advance of its return, say to a speculator. Rather than receive coffee from the coffee exporter and deliver it in turn to the speculator, the farmer would find it much easier to instruct the coffee exporter to deliver the coffee directly to the speculator and to instruct the speculator to return the money owed to the exporter on the farmer's behalf. Under that arrangement, the coffee exporter and speculator need have nothing to do with one another; their only contact is an effort to reduce the handling costs of delivering coffee back to the farmer and then his redelivery to the speculator. The transaction at the heart of the theory of normal backwardation and hedging-pressure theory, namely the coffee exporter's short sale to a speculative long, disappears. Because nothing of substance has changed with this reformulation of the transactions, the theories cannot have captured the motivation for them.

Despite these flaws as a theory and despite the weak or non-existent empirical evidence, the idea of a bias in futures prices persists. Why? At one level, the idea seems intuitive: Were speculators not to earn something on average, they would perform their economic function without any reward [Houthakker (1979)]. Had so many commercials not gone short, the futures price would have been higher. Yet others, whether speculators or commercials, can anticipate both the placement and removal of those hedges. More important, the idea presumes that commercials would have conducted trades in other markets, e.g., acquire inventory, regardless of their trades in the futures market.

At a deeper level, the persistence of the theories of normal backwardation and hedging pressure reflects the sequencing of economists' research. Not long after Keynes wrote his few pages amounting to the theory of normal backwardation, strong evidence emerged, from reports required of large traders in U.S. markets, that commercial shorts were disproportionately present when price relationships were in contango rather than backwardation. Not long after economists conducted the first research on hedging pressure, the capital asset pricing model began to dominate the discussion of risk. Not long after economists conducted the most extensive tests of trends in futures prices, repos and swaps became the predominant way of trading in financial markets and were modeled there by economists not from the perspective of risk management. Were all these orderings reversed, it is doubtful that the theory of normal backwardation would have emerged.

The other major theory presuming a role for risk aversion in futures markets, the portfolio theory of hedging, contains internal inconsistencies as well. The problem is not with portfolio theory itself but with its application to commercials' trading. The major postulate of portfolio analysis in general is that among assets with the same average return, people prefer those assets whose returns are least risky. Of course, a higher expected return might induce people to hold a riskier asset. The tradeoff between risk and return induces people to combine several assets into a portfolio, because generally speaking a mixture of assets will be less risky than any one single asset.

After the formulation of portfolio theory in the 1950s, one of its first applications was to the question of hedging by dealers in commodities. Johnson (1960) and Stein (1961) contended that commercials consider a blend of two assets, a physical commodity and a short position in futures. (The theory generalizes to include long hedging.) Equivalently, commercials consider a blend of hedged inventory, which earns a low but relatively steady rate of return, and unhedged inventory, which has a higher but riskier return. Depending on his preference toward risk, a dealer or processor hedges some proportion of his inventory with the sale of a futures contract.

With two assets, the mathematics of portfolio theory is simple, an application of the properties of linear combinations of random variables discussed in introductory statistics courses. The mean μ_P of a random variable $P = aX + bY$ is $a\mu_X + b\mu_Y$, while the variance $\sigma_{PP} = a^2\sigma_{XX} + b^2\sigma_{YY} + 2ab\sigma_{XY}$. Regarding hedging, X corresponds to the inventory of physical coffee and Y to the position in the futures market. If the amount of inventory is divided into the lot size of the futures contract, a can be treated as 1.0, while the natural range of b is between 0.0 and -1.0 . By varying a single parameter b ,

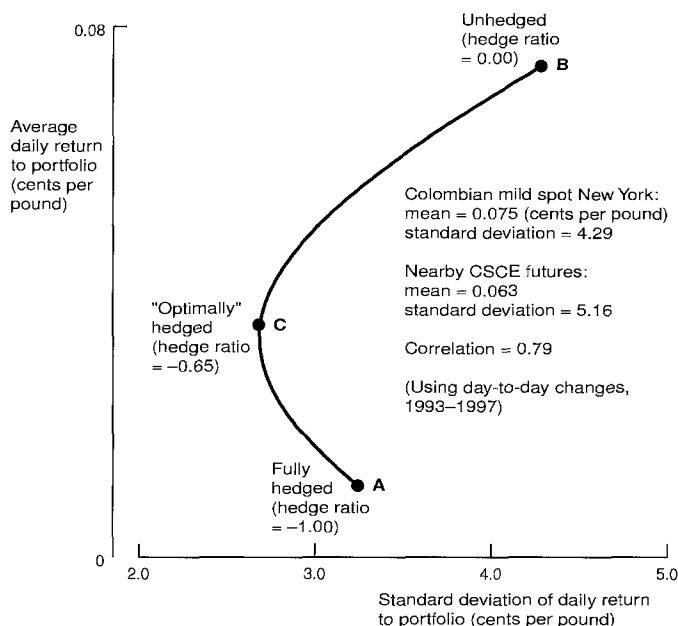


Figure 5. Portfolio hedging of Colombian mild in New York.

one can trace out the combination of the mean and variance of the portfolio with that proportion b hedged, a "portfolio frontier" as it is known in the finance literature.³¹

Figure 5 portrays graphically the portfolio frontier for an inventory of Colombian mild in New York, using estimates of the means, variances, and correlation from spot and nearby futures prices. At Point A in Figure 5, all the inventory in the portfolio is hedged, which is to say, the short position in futures contracts corresponds to all the inventory. At Point B, all the portfolio is in unhedged inventory, which is to say, no futures contracts have been sold. The curve connecting these two extremes represents the expected return and the variance of the return (converted to the standard deviation so the units are comparable) of the various proportions hedged. A point halfway along the curve corresponds to 50 percent hedged. The shape of that curve depends upon the correlation between the returns to the two assets; the more positive is the correlation, the more the curve is bowed to the left (because the futures position is negative). The correlation of 0.79 between Colombian mild in New York and the nearby futures is relatively high, so the portfolio frontier in Figure 5 is relatively bowed.³² If the indifference

³¹ This formulation presumes that the amount of inventory is predetermined. If it is endogenous instead, the portfolio frontier would be different, as noted by Kahl (1983) and Bond and Thompson (1985). Among other considerations, a third asset would need to be included, or there will be an ambiguity about whether both hedged and unhedged inventory would be "dominated" in terms of risk and return.

³² The R^2 is often taken to measure the "effectiveness" of the hedging instrument.

curves corresponding to a commercial firm's preferences toward risk were superimposed on the figure, the portfolio that particular firm would select would be some point along the frontier.³³ Quadratic risk preferences, a common assumption, leads to the selection of the "optimal hedge" corresponding to Point C on Figure 5. Point C is also the "risk-minimizing hedge". The hedge ratio of -0.65 (65 percent hedged, that is) differs from -1.0 , and in that difference the theory of optimal hedging suggests a strategy for commercials other than the straightforward one of complete hedging.

This representation of the degree of hedging as the selection within a portfolio, regarding which aversion to risk is fundamental, has come to dominate research on futures markets. Ward and Fletcher (1971) used the portfolio theory of hedging in an article on live beef, Peck (1975) in one on eggs, Leuthold and Mokler (1979) in one on cattle feeding, Rolfo (1980) in one on cocoa, Berck (1981) in one on cotton, Anderson and Danthine (1981) in one on commodities like sorghum related to a commodity, corn, with a futures market, and Lapan and Moschini (1994) in one on soybeans. Anderson and Danthine (1983a, 1983b) and Britto (1984) have worked to extend these models of a single firm to the equilibrium resulting from the combined actions of many such firms. The portfolio theory of hedging has been a spectacular growth industry.

The hedge ratio at Point C in Figure 5 is the estimated coefficient from a simple regression of the day-to-day changes in the price of Colombian mild against the day-to-day changes in the price of the nearby futures price. The particular estimated hedge ratio, -0.65 , of course, depends on the particular five years of data; it would be closer to -1.0 were the early 1990s included too. Similarly, the estimated hedge ratio would be more nearly -1.0 if only the first months of the year (the major period of exports from Colombia) were used, or if week-to-week changes were used,³⁴ or if price levels rather than changes were used, as was the practice before Brown's critique (1985). In other words, the practical implications of the theory of optimal hedging are highly sensitive to econometric specification and estimation technique. Lence and Hayes (1994) counsel that such estimation uncertainty itself should be incorporated into the decision about hedging. Elam (1991) suggests that correcting for the autocorrelation in the residuals will improve the estimation. Myers and Thompson (1989) and McNew and Fackler (1994) propose to improve estimation by allowing for conditional heteroskedasticity, such as that due to seasonality or price levels themselves. Myers (1991) expands that adjustment to the autoregressive conditional heteroskedastic framework increasingly

³³ Given the estimated positive mean return to a futures position, those points below Point C towards Point A are "dominated" in the sense that another portfolio offers higher average return and lower variance.

³⁴ The data for Figure 5, ostensibly representing a daily series for Colombian mild in New York, are a typical spot price series. Even casual inspection of the series reveals that the minimum price change is 0.5 cents, ten times the tick in CSCE futures. Often for several weeks, the reported price will not change, although futures prices will have moved considerably. Rather than the futures price having the higher variance, most likely, no transactions in Colombian mild were observed over those periods, so the last price was kept in the records. Indeed, the whole series may be little more than informed guesses; as mentioned in regard to Table 1, spot transactions in New York are not common. Such conditions for spot price reporting should give pause to economists applying optimal hedging models.

common in the finance literature. Lence (1995) is nonetheless skeptical of the efforts at improving econometric implementation of the theory of optimal hedging. Using simulations, he has found that hedge ratios within the likely range of any econometric technique make little difference in terms of the measure of expected utility at the heart of the tradeoff between risk and return. He has found that relaxing the assumptions of quadratic risk or, most interesting, zero transaction costs, makes much more difference.

As with the theories of normal backwardation and hedging pressure, the portfolio theory of hedging has a number of unrecognized problems purely as a theory, apart from any empirical issues. It is unduly sensitive to a slight change in perspective or starting position. It presumes that a bias exists in futures prices. It does not consider the results if the inventory involved were deliverable on a futures contract. It does not treat explicitly why the prices of the two assets move differently, even though that price difference has an economic interpretation. Rausser (1980) made a number of these criticisms about a specific application to barley, and Williams (1986) about a specific application to wheat; they can be recast here in the context of coffee.

Because of the sensitivity of the results to the starting point, it seems best to begin with the simplest case possible. Imagine a roaster in New York whose inventory of coffee is a growth routinely delivered on CSCE futures contracts. Suppose further that whenever this roaster sells a futures contract against part of his inventory, he makes delivery on that contract. Think of the roaster as being in the storage business, owning a warehouse. Equivalently, the owner of the coffee could be an exporter in Central America, who is placing a container of a deliverable growth on a freighter bound for New York. Think of the exporter as being in the loading and shipping business. The standard version of the portfolio theory of hedging begins with the complications that the coffee is not a deliverable growth or can be sent to New York only by altering normal shipping routes. Instead of leading to broader results, however, starting with these complications hides several misconceptions in the theory.

Contrary to the presentation in Figure 5, the variance of the return to hedged deliverable coffee should be zero over the horizon culminating in delivery. A simple example indicates the source of the confusion. Suppose today, January 1, the hedge is placed in March futures. Imagine that the price of coffee for immediate delivery is 12 cents per pound below the price of the March futures contract. Quite clearly on the day of delivery in March, the spread between spot and futures prices must be 0 cents, since on that date both represent contracts for the immediate delivery of the same growth of coffee. All the movement in the spread between them was the convergence of the spot and futures prices. The portfolio theory of hedging mistakenly assigns the movement resulting from this inevitable convergence as a risk to hedging operations. It is not a risk, being fully predictable. Gray (1984) has made this point emphatically in his criticism of the portfolio theory of hedging.

Often a perfect hedge is claimed, as by Blau (1944), for the period of time during which the spot and futures prices track each other with a perfect correlation of $+1.0$. But because the spot price and the futures price must converge, they cannot track one another perfectly. Consider the case where the futures price does not move from \$1.50

cents per pound. The spot price, whatever it began at some months before, say \$1.30, is ultimately \$1.50. The correlation between spot and futures prices is 0.0, yet there is no risk to the hedging operation.

One might well ask why hedged and unhedged inventories are drawn in Figure 5 such that unhedged inventory enjoys a higher expected rate of return. It does so only if futures prices are biased downward. As noted by Benninga et al. (1984), implicitly the portfolio theory of hedging relies on the theory of normal backwardation, which is a shaky foundation indeed. Because unhedged inventory equals hedged inventory plus a long position in futures, the two rates of return differ by the expected return on a long position in the futures market. As it happened, over 1993–1997, a long position in coffee made money, but not nearly so much over 1989–1999, as Figure 3 indicated. If the true expected return on a routine long futures position is zero, the expected returns on hedged and unhedged coffee are the same, and Points A and B in Figure 5 should be drawn at the same level, rather than with Point B higher than Point A. In any econometric implementation, the estimates of variances and correlation will differ from those given in Figure 5 should the hypothesis of zero mean return be imposed as a restriction.

Because the return to hedged inventory has no variance when the inventory is of the deliverable grade, the diagram of expected return and the variance of the return should be drawn in the equivalent of Figure 5 to be a straight line touching the vertical axis. The height of that horizontal line depends on the spread between the spot and futures prices at the time that the hedge was placed. (Most likely, the hedging operation earns a positive return, indicating that initially the spot price was below the futures price.) Second, the expected return to unhedged coffee is the same as the return to hedged coffee, because the long position implicit in unhedged coffee only earns something above zero on average if there is a downward bias in futures prices. Given this reformulation of the possible portfolios involving deliverable coffee ranging from all hedged to all unhedged, according to the portfolio model itself, any firm the least bit risk averse will choose always to be hedged completely.

Commercials with inventories of the deliverable grade who choose to hedge less than completely are taking on risks that they, like speculators, could avoid entirely. This argument is related to that of Holthausen (1979) and Feder et al. (1980). They demonstrate that a firm with no uncertainty in its output, such as a copper mine, should base its production decisions solely on the futures price, that is, that it should act as if it has sold all its output forward. Any speculation based on expectations concerning price is a separate decision. This result is a classic application of a separation theorem, as between consumption and production if trade is possible or between consumption and investment if capital markets are perfect. In this instance, the result depends on the absence of any basis risk, which causes a change in the spread between the commodity produced and the commodity for delivery on the futures contract.

An economic interpretation is usually, if not always, present in the price spreads contained within optimal hedging models. (These spreads, it should be clear, concern simultaneously observed prices for different commodities or services, rather than the behavior of a single series over discrete units of time.) Colombian mild is an awkward

example of this idea, because no direct economic activity can transform less valuable growths into Colombian mild. Yet the spread between the price for immediate dockside in Central America (more common CSCE growths) and the nearby CSCE futures price has a clear economic interpretation: the coffee shipping service. Other examples include the difference between soybeans and soy meal and oil prices: the crushing service; the difference between nearby corn futures and forward corn at the U.S. Gulf: the Mississippi barge service; the difference between wheat and flour: the milling service; and the difference between the spot price in Chicago and the nearby futures: the storage service. Sometimes the price difference may represent several services, but that combination has an economic interpretation, nonetheless. Moreover, the economic interpretation concerns not the behavior of a single firm, as imagined by an optimal hedging model, but the whole service industry.

Classic portfolio theory, developed with equity markets in mind, interprets the actions of an investor with shares in Intel and shares in Ford Motor as diversification, since the two companies are not related in any substantive sense. Were the investor observed to be long Intel and short Dell Computer, the interpretation would not concern portfolio diversification at all. The investor would be seen as effectively taking a position, indeed, a speculative position, on the computer assembly business, probably out of a belief that its margins are likely to fall. Positions in substantively connected assets in commodity have even more direct interpretations than that of the computer assembly business represented by long Intel and short Dell.

The econometric model of the hidden industry represented by the price spread considered by the optimal hedging model should make sense. Those price spreads are not mere statistical residuals in linear equations. In a direct industry-level model of coffee shipping, a central concern would be the supply elasticity of empty containers to Central America and backhaul prospects, not to mention the capacity constraints and flexibility of loading rates in ports in Central America. In a direct industry-level model of barge rates, a central concern would be the simultaneity of prices, which would lead to an extended discussion of bias, identification, instruments, system methods of estimation, and so on. In a direct industry-level model of corn storage, the spatial distribution of facilities would be important, as would the interaction with storage of other grains [Paul (1970)], not to mention the regional speed of entry and exit. That such difficult subjects involving industry-level models are ignored in the optimal hedging literature does not mean they are not present.

5. Trading in the presence of transaction costs

In contrast to the substantial literature taking the risk-management perspective on futures markets, the transaction costs perspective or what might also be called the arbitrage perspective has been developed much less extensively. Working (1953a, 1953b) made the seminal contribution. Working's observations that actual hedgers seem to have concerns other than risk minimization, namely making profits, is often mentioned by

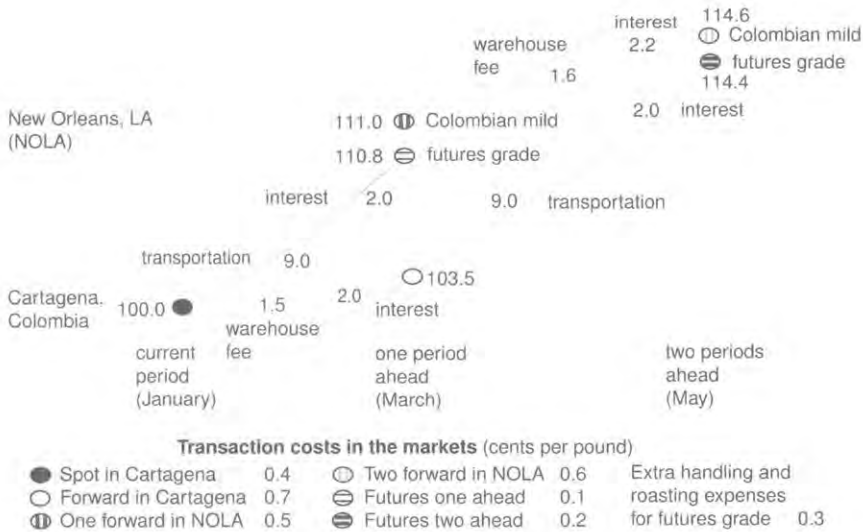


Figure 6. Illustrative spatial-temporal-quality equilibrium in a set of coffee markets.

economists who nonetheless proceed to emphasize risk aversion. I, however, have questioned [Williams (1986, 1987)] whether risk aversion is even necessary to explain the salient features of futures markets. To my writings can be added Peck (1985), who emphasized storage arbitrage, and Brorsen (1995), who considered the trading strategies of risk-neutral commercial firms that face nonlinear borrowing costs. Models from the risk-management perspective simplify the complex world by ignoring transaction costs and restricting the choices before a firm while retaining a nonlinear objective function and substantial uncertainty. Models from the arbitrage perspective simplify the complex world by supposing the firm has a linear objective function and operates where uncertainty is incidental, while retaining explicit transaction costs and a multitude of possible trading strategies. In the risk-management perspective, the crucial nonlinearity is in the utility function; in the transaction-costs perspective, it is in the costs themselves.

Because models from the transaction-costs perspective of futures markets are relatively rare, an extended example may be useful here. Figure 6 considers a situation with two locations, two grades, and three periods, and distinct markets for all. Instead of simple labels such as Location A and Period 3, let us use labels from coffee, although the situation will still be stylized. The two locations are Cartagena on the coast in northern Colombia, an important coffee export center, and New Orleans, a coffee import center (besides being the most important grain export center). In Cartagena a physicals market operates for immediate, that is, January, delivery, as well as forward for March delivery, while in New Orleans (NOLA) there are March and May forward markets. In a real situation, no doubt, there would also be some trading for January NOLA and May Cartagena, but the subset in Figure 6 emphasizes the spatial connections, for transporta-

tion takes a full period, namely, two months. There is also a futures market, with March or May delivery dates. By the terms of the futures contract, the seller can deliver any of several growths; as Colombian is a premium growth, the short in a futures contract receives less than in the physicals market while the long must pay extra in handling or roasting. At the prices given in Figure 6, neither sellers nor buyers would use the futures market, apart from any considerations of transaction costs.

The situation in Figure 6 by construction is in equilibrium. Coffee flows from Cartagena to arrive in New Orleans in both March and May. That is, the price differences exactly cover the transportation charges, warehouse fees, and interest.³⁵ No arbitrage opportunities exist, in the sense of a profitable purchase in Cartagena for storage or for shipment to New Orleans. Equivalently, someone with coffee in Cartagena in January is indifferent among selling it immediately, selling it March forward in Cartagena, NOLA March, or NOLA May, just as a New Orleans roaster needing Colombian in May is indifferent among buying NOLA Colombian May, Cartagena March while arranging transport, or even Cartagena January while arranging for storage and then transportation. That is, each trader has a number of optimal trading strategies, which Table 3, column 1 identifies with a star.

How would transaction costs disturb the situation in Figure 6? Let the exogenous transaction costs listed in Figure 6 all be explicit and all be paid both by the seller and by the buyer. Let the transaction costs include all expenses attributable to search and enforcement; for example, the transaction costs for forward physicals transactions include a bank's charges for providing the buyer with a letter of credit or an escrow account for the seller's deposit of a letter of a warehouse receipt or a bill of lading, and for futures transactions include any capital tied up in the margin system. The transaction costs for forward trading are larger in Cartagena than New Orleans, while both are larger than in the futures market. Within the futures market, the nearby March contract has the lower effective transaction costs. All these costs, although in line with actual coffee trading, are a construction of the exercise, just as are the posted prices. How do their relative magnitudes affect trading strategies?

At the posted prices in Figure 6, the transaction costs preclude any arbitrage as conventionally imagined. The transaction costs do not preclude another type of arbitrage, however. Indeed, they reinforce the importance of "natural-position arbitrage".³⁶ A roaster who needs green coffee in New Orleans in March – why the roaster needs

³⁵ Because these charges are not functions of the amount shipped or stored, and are the same for each period, no equilibrium can exist such that coffee comes to New Orleans in March to be stored until May, given that interest would have to be paid on the transportation charges. This fact of life, in brief, is the economic pressure for storage in producing areas. The disadvantage to storage in the importing location is made greater in Figure 6 by a higher warehousing fee there.

³⁶ Deardorff (1979) calls this type of arbitrage "one-way", in contrast to conventional arbitrage, which is "two-way". Another expression is "owner's arbitrage". By whatever name, the importance of such arbitrage depends on the number of such traders and their starting positions. That is, the supply of natural-position arbitrage is not infinitely elastic over all quantities, as conventional arbitrage surely is.

Table 3
Trading strategies in the presence of transaction costs

Strategy	No trading costs	Trading costs	Costs but lower interest
<i>Marketing firm in Cartagena, with Colombian on hand in January</i>			
(1) Sell Cartagena spot	100.0*	99.6	99.6
(2) Sell Cartagena March forward	100.0*	99.3	99.5
(3) Sell Colombian NOLA March, ship now	100.0*	99.5	99.7
(4) Go short March futures, ship now	99.8	99.7*	99.9
(5) Sell Colombian NOLA May, ship now, store in NOLA	99.8	99.2	99.6
(6) Sell Colombian NOLA May, store in Cartagena, ship in March	100.0*	99.4	99.8
(7) Go short May futures, ship now, store in NOLA	99.6	99.4	99.8
(8) Go short May futures, store in Cartagena, ship in March	99.8	99.6	100.0*
<i>Roaster in NOLA, needing green coffee in March</i>			
(1) Buy Colombian NOLA March	111.0*	111.5	111.5
(2) Go long March futures, pay extras	111.1	111.2*	111.2*
(3) Buy Cartagena spot, ship now	111.0*	111.4	111.2*
<i>Roaster in NOLA, needing green coffee in May</i>			
(1) Buy Colombian NOLA May	114.6*	115.2	115.2
(2) Go long May futures, pay extras	114.7	114.9*	114.9
(3) Buy Colombian NOLA March, store	114.8	115.3	115.1
(4) Go long March futures, store, pay extras	114.9	115.0	114.8
(5) Buy Cartagena spot, ship now, store in NOLA	114.8	115.2	114.8
(6) Buy Cartagena spot, store in Cartagena, ship in March	114.6*	115.0	114.6*
(7) Buy Cartagena March forward, ship in March	114.6*	115.3	115.1

beans in March is not an issue, although the need for beans is natural in such a business – finds the cheapest method in the face of different transaction costs, to buy through the March futures contract, despite the extra processing charges, as column 2 in the upper section of Table 3 identifies. A roaster who needs green beans in May finds it best to go long in the May futures contract. The advantage of this approach is merely 0.1 (cents per pound) over the next best alternative, but the roaster might as well take that small advantage. Similarly, a marketing firm with coffee to sell in Cartagena has one superior approach, delivery on a March futures contract in New Orleans, whereas without transaction costs, it would be indifferent among four approaches to disposing of its coffee.

Although Figure 6 may seem unduly complicated, it is much simpler than the situations faced by actual coffee traders. Traders become adept at finding such small cost advantages (or they cease to be in the business). Traders need to look incessantly, for such advantages may be fleeting. Their own trades will alter the prevailing prices, making another style of trades the most advantageous. And other considerations will now and then complicate the analysis. For example, if a roaster in New Orleans or a marketing firm in Cartagena is flush with funds, such that its interest expenses are 0.2 cents per pound less than the costs shown in Figure 6 (the 0.2 for two months, when annualized, would represent the different interest rates at which banks would take deposits versus lend out funds), it will tend to transact differently. A natural position in money will tend to make roasters buy the coffee for earlier delivery, while making a firm with coffee in Cartagena to sell for later delivery, as column 3 in Table 3 makes clear.³⁷

One lesson from the situation in Figure 6 and Table 3 is that it is difficult to infer traders' motives from their actions. Say an economist observes a New Orleans roaster going long the nearby March futures contract. Does the roaster want the lower grade delivered on futures contracts or Colombian mild? The economist cannot observe all the transaction costs the roaster perceives. Does the roaster want the green coffee then, or in two months' time? Or is that trade influenced by an attractive financing opportunity? The economist needs to see the whole set of trades the firm conducts simultaneously, yet few are even as visible as the futures trade. Does the roaster face especially high transaction costs in the Cartagena market because it defaulted on some previous transactions? The economist needs to consult the other potential trading parties to measure those transaction costs. Say an economist observes a coffee marketer in Cartagena going short the May futures contract. The economist is unlikely to know the particular dealer's interest rate – it would be unusual for an economist to know the interest rate even for the average dealer in Colombia – and so cannot infer the dealer's motive for contracting to deliver farther ahead than most others, although the economist, depending on his preconceptions about futures markets, might leap to the conclusion that the marketing firm was especially risk averse.

Were the relative transaction costs in Figure 6 slightly different, the optimal trading strategies in Table 3 could be substantially different, perhaps not involving futures contracts at all. Were the posted prices in Figure 6 slightly different (yet still within the range precluding conventional arbitrage), the optimal trading strategies in Table 3 could be substantially different, although a price shift to the advantage of a roaster tends to drive someone with a natural position in coffee in Cartagena to the opposite set of transactions. Put differently, commercial firms' demand curves for transactions of various types are interlocking and highly nonlinear, indeed knife-edge, functions of transaction costs, interest rate differentials, and forward transport differentials. Those demand relationships are also not structural equations. A large literature, e.g., Rutledge (1972)

³⁷ Posted prices and transaction costs in Figure 6 are not such that a firm with solely a natural position in money but no natural position in coffee, such as an investment bank, would lend money indirectly through coffee, but the possibility should keep those investment banks with uncommitted funds alert.

and Giles et al. (1985), nonetheless represents commercial firms' hedging demands as smooth structural functions of prices.

A second lesson from Figure 6 and Table 3 is that trading tends to go to the market with the lowest transaction costs. This lesson may seem obvious, but it is not obvious that all of the firms in the physical coffee market will tend to gravitate to the nearby futures contract, which in the situation (by construction) does not involve the desirable growth, Colombian mild. In situations in which the transaction costs are endogenous, say being appreciably lower if many trades are conducted per unit time, particular markets' power of attraction will be self-reinforcing. Futures markets' high volume (recall Table 1) results from a virtuous circle. This self-reinforcing of transaction costs explains why one organized exchange almost always has all the trading volume in one commodity (the exceptions usually being in different time zones, as is the case for coffee).

Figure 6 and Table 3 suggest a third lesson: Trades done for indirect motives, attracted to futures markets, will tend to move prices there first. A decision by a marketing firm in Cartagena to sell a substantial amount of coffee quickly will lead it to place a large sell order in the March futures contract. Even though that market is exceptionally liquid, such a large order may well affect prices available to the next commercial firms who contemplate trade because of some natural position. In real markets, scalpers might adjust their bid and offers down one tick; in Figure 6, that would be equivalent to a new posted price for March futures of 110.7. That slightly lower price for March futures, all other prices yet unaltered, would encourage a roaster in New Orleans flush with funds but needing coffee in March, to go long the futures contract rather than transact in the Cartagena spot market. Should those posting prices in Cartagena notice a fall-off in inquiries, let alone trades, they might lower the spot price in Cartagena. In such sequences of trades resulting from natural-position arbitrage is a mechanism for "price discovery". At a prevailing set of prices, trades, reflecting "news" in some way or they would have been consummated before, gravitate toward the market with the lowest transaction costs; the resulting small change in price probably alters the calculations for others, which trigger some trades in the set of related markets, thereby transmitting the news, perhaps even to the market where it would first have appeared had there been no transaction costs. Such ripple effects have been widely noted. In every set of markets studied [e.g., by Garbade and Silber (1983), Oellermann and Farris (1985), and Schroeder and Goodwin (1991)], changes in futures prices have been found to lead changes in prices in related physicals markets.

However plausible, this argument cannot be classified as a full theory of price discovery. Such a theory would need to account for the reason behind the price effect and for commercial firms' efforts to minimize those price effects by breaking a large trade into smaller lots. Also traders might try to anticipate arbitrage opportunities. (Models with expectations and uncertainty are inherently more difficult than the static Figure 6.) If say a NOLA roaster procures a monthly supply of green beans the first Friday of every month from the lowest-cost source that day, should prices on the preceding Thursday offer an extraordinary bargain through some version of the myriad combinations of

trades equivalent to buying coffee in New Orleans, the trader would surely take such an opportunity. The trader's reasons would be that of an arbitrageur, not a risk avoider.

In Figure 6, the relatively high transaction costs in the NOLA forward market for Colombian mild induce a natural seller to use the futures market instead. Those transaction costs are so high in part because of the difficulty of enforcing a forward contract over two months and because of the difficulty of locating a specialized buyer quickly. Over the several weeks until late February, the firm in Cartagena, whose coffee by that point is approaching New Orleans, while making and receiving routine inquiries from clients, may locate a roaster in New Orleans who wants Colombian mild (indeed, given sufficient time, that match is nearly certain). Having found each other by routine contacts, their search costs are low; having the coffee nearly in New Orleans (and in the care of a third-party who has issued a bill of lading), the effective cost of enforcing any short-term forward contract is low. If only the Cartagena marketer had not committed the coffee to the futures market! Yet, because futures contracts are traded in their own right, the Cartagena marketer can simply offset its March short position, established in January, by going long in late February. The Cartagena marketer pays an additional transaction fee to offset its futures position, to be sure, but that fee is very small compared to the expense of re-negotiating a forward contract.³⁸ The Cartagena marketing firm "lifts its hedge", in the terminology of the trade. Despite the terminology, the marketing firm had not entered into the futures contract out of risk aversion, but as a "temporary substitute for a merchandising contract to be arranged later", to use Working's (1962) phrasing.³⁹

A fourth lesson from Figure 6 is the importance of spreads. By construction, Figure 6 has prices for coffee in various locations, periods, and grades that closely match the costs of transportation or storage. Conventional arbitrageurs compare the differential between coffee prices at two locations to the cost of transportation; the price level is irrelevant. Natural-position arbitrageurs especially compare price differences, because those reveal the best strategy for constructing equivalent trades; the "flat price" of coffee is irrelevant to that stage of their decisions. Furthermore, as prices change, the overall price level changes more than the price differentials (that is, interest rates and transport rates stay relatively stable, largely because they depend on much more than coffee).

³⁸ Should the roaster in New Orleans also want to offset a long futures position – according to Table 3, the nearby contract would have been its least-cost way of obtaining green beans – the two commercial firms can avoid sending their orders to the floor, where, unless they would have to pay a half-tick or so to a scalper, they could inform the exchange that they have offset "ex pit", that is, that they have conducted an EFP.

³⁹ A similar explanation can be offered about commercial firms' widespread practice of "rolling their hedges" forward. The Cartagena marketing firm, having gone short the March futures contract, could well find, as the weeks pass, that a glut of coffee in New Orleans has depressed the nearby price of Colombian mild relative to the March futures and both relative to the May futures. Under these new pricing conditions, depending on the firm's interest rate, it may find it profitable to buy back its March futures and sell May futures – to roll its hedge. In anticipation of such possibilities, the marketing firm might not have shipped the coffee from Cartagena, where warehousing fees are lower.

Thus, all the information about coffee prices in Figure 6 could be given more conveniently as price differences against some benchmark, which alone would indicate the level of prices. The obvious benchmark against which to measure the other prices is the price in the most active market, which in Figure 6, as in most real situations, is the nearby futures contract. In short, the style of thought among arbitrageurs explains the common practice of basis trading.⁴⁰

Commercial firms make money from predictable changes in the basis, as Working (1953b) first argued. A Cartagena marketing firm, whose coffee is worth 10.8 under, loads it on a container vessel while going short the March futures contract. If the Cartagena firm delivers on the futures contract, which at expiration has a basis of 0.0 with itself by definition, its coffee's basis has appreciated 10.8 (cents per pound), no matter what has happened to the benchmark futures price over the two months. If the Cartagena exporter finds over the interval a NOLA roaster wanting Colombian mild in particular, at a basis of 0.2 over, so much the better. If Colombian mild in New Orleans has appreciated to 0.6 above the March futures, better yet for the Cartagena exporter, but that unpredictable component cannot be relied upon.

Figure 7 applies Working's idea of the predictability of changes in the basis to the series for New York Colombian mild previously used in Figure 5. Each observation represents a sequence of computations. First, the price for a futures contract two months before expiration is subtracted from that day's spot price for Colombian mild (such a price difference being a "basis"). Second, a similar calculation is made on the fifteenth day of the delivery month – were Colombian mild the growth regularly delivered on CSCE futures contracts, that basis would be zero. As Colombian mild usually trades at a premium, most of these calculations yield a positive number. Third, the change in the basis over the two months is computed. As can be seen in Figure 7, the earlier basis predicts well the change in the basis; the R^2 is 0.62.⁴¹ Given that the change in the basis represents the return to storing the commodity, Figure 7 suggests that the return to storing (or shipping) Colombian mild is itself predictable.⁴² Those coffee exporters, importers, or roasters who owned Colombian mild and who were short CSCE futures could act as if such storage decisions were essentially arbitrages. Such merchandising

⁴⁰ Pashigian (1988) has argued that the visibility of basis quotations allows country grain elevators to collude more easily. He offered evidence that farmers' opposition to grain futures markets in the 1920s and 1930s, usually attributed to a dislike of speculators, was most vociferous in regions with concentrated ownership of elevators.

⁴¹ Working's original study (1953b) of Kansas City wheat futures over 1922–1952, specifically the change in the basis from September to December, found an R^2 of 0.70. Fama and French (1987) presented evidence (upon a slight reformulation of their regressions) that such predictable relationships are common across many commodities.

⁴² Given that the basis over 1995–1997 was usually predicting a decline in the premium for spot Colombian mild, the dominant signal was for no one to hold such stocks in New York. Indeed, over that period, stocks of any growth were negligible, as Figure 2(d) showed previously. The basis for Colombian mild in Cartagena during the main exporting season, a hypothetical series given that spot trades in Cartagena are so few, would reveal more about the predictable returns to storage.

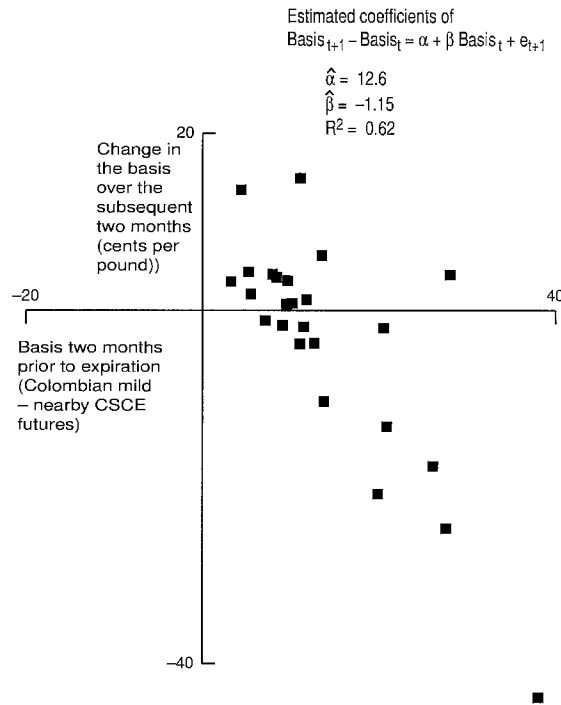


Figure 7. The basis for Colombian mild as a predictor of the change in the basis, 1993–1997.

firms would thus have sufficient reason to use futures as part of these arbitrage-like sets of trades even if they were risk-neutral.

From the perspective of arbitrage, it matters little whether commercial firms are risk-neutral or risk-averse, since any would be happy to collect riskless profits. Usually to economists, an appeal to an arbitrage argument is sufficient. If the main features of commercial firms' use of futures markets can be explained as arbitrage, why look further for explanations? Yet those economists who view futures markets from the risk-management perspective remain unconvinced, perhaps because they see Working's arbitraging merchandiser as accepting a trading cost the firm could avoid. Yes, they would agree, the commercial firm, by buying the commodity in a local market and carrying it through space and time, profits by the predictable change in the basis. But, they would note, the firm could earn that profit whether or not it goes short in the futures market. If it goes short and later offsets its futures position, as it would often do, it incurs two transaction costs, which it could easily have avoided. Hence, they would conclude, it must incur those costs because it is risk averse. That criticism of Working's arbitrage perspective presumes, however, that any other method of selling the commodity is costless. Once the commercial firm has acquired the commodity locally, seeing an arbitrage opportunity, what matters are the relative transaction costs (and selling prices) of sell-

ing it in any of the myriad ways. As the example of the Cartagena merchandiser has established, the low transaction costs in the futures market will often encourage sales to be made there, even if those trades through futures contracts will often be superseded by explicit merchandising agreements. In sum, Working's arbitrage perspective regarding the predictability of spreads expanded to include the actions of a natural-position arbitrageur in the presence of transaction costs looks sufficient to explain commercial firms' use of futures markets.

6. Futures prices as forecasts

An economist new to futures markets might reasonably imagine, from their name alone, that they are principally allow participants to express opinions about the uncertain future. Surprisingly, the risk-management perspective and the transaction-cost perspective both emphasize the present, namely by considering why market participants take positions in currently active markets. Both perspectives mention participants' expectations mostly in passing. The two perspectives are, however, more concerned with the future than they first seem. Current actions – inventory decisions are the most obvious – connect the present to the future, and vice versa. With the future uncertain, current actions inevitably express opinions about the future, even if only implicitly. A commercial firm, motivated to go short the nearby futures contract to manage risk, would surely trade differently if it had knowledge of the future. A commercial firm, long a deferred futures contract as part of an arbitrage operation, could adjust that trade (or its companion trades) if it had a strong opinion about the future. A speculator's fate is necessarily determined by future movements in prices. The better any trader forecasts, the more successful he is, although from that fact it does not necessarily follow that the most successful traders forecast well. In sum, it is obvious to investigate how well participants in futures markets individually and collectively forecast the future. What are not obvious are the many conceptual difficulties resulting from the feedback of the forecasts on market participants' actions.

Regarding this topic of forecasting power, theoretical alternatives to actual futures markets are especially helpful explicit comparisons. Often economists make an implicit comparison, and not necessarily always the same one. One explicit comparison is to an idealized world in which no uncertainty exists; all is stable, although the crop is harvested once a year while consumption is continuous. The futures prices in that idealized world would provide perfect forecasts of the subsequently realized spot prices; farmers would plant according to the first new-crop futures price. Another explicit comparison is to a similar idealized world, but one with uncertainty from "shocks" to the new crop through the weather. All market participants know the probability of these weather shocks but not the specific shock. They are also risk neutral, in the sense of being concerned only with expected profits. The condition of risk neutrality does not imply that uncertainty has no effect. Because a plentiful harvest can be smoothed over several years whereas a poor harvest cannot be relieved except by past storage, any current constellation of prices reflects that physical constraint. Any current constellation

of prices reflects the cumulative effects of past uncertainty and the prospects of future uncertainty. By construction in such an idealized world, the amount stored is the socially rational amount given the future uncertainty. By construction, the futures prices are the best possible forecasts of subsequent spot prices. By construction, farmers plant according to the first new-crop futures price. Such an idealized world is the implication of the stochastic dynamic programming models of optimal stockpiling, e.g., Gardner (1979), Miranda and Helmberger (1988), and Williams and Wright (1991).

These two idealized worlds can first be used to consider what would be the constellation of futures prices from a particular current situation. In the idealized world with certainty, the equilibrium constellation of prices for various delivery dates would look like a sawtooth, with within-crop-year spreads all exactly covering interest and warehousing fees while the last old-crop – first new-crop spread would be in backwardation [Samuelson (1957)]. This sawtooth would repeat year after year, especially if the current situation were a crop of typical size. Whether the commodity were sufficiently storable to last past one crop year would not matter, since none would be carried over. Inter-crop-year carryovers are, however, a natural feature in the idealized world under uncertainty. A very large crop currently would be spread out over several years, in expectation. That is, there might be current situations in which the constellation of prices rises at nearly full carrying charges across several crop years, while there might also be situations in which the constellation of futures prices falls sharply, because the current crop is small. The constellation of prices would adjust following each weather shock, yet the previous equilibria will have taken account of the possibility of those adjustments. Some of those shocks might lead to extreme current situations, but the long-run average price (that is, a very distant futures price) would be stable, as under certainty. That a very far-ahead futures price is the long-run average price implies that constellations of futures prices in an idealized world of weather uncertainty will be smoother than the sawtooths under certainty, especially across crop years. More distant spreads will be less than full carrying charges, because when the earlier of those distant periods becomes the current period, the current situation might indicate low spot price, high stocks, and a corresponding spread at full carrying charges, or it might indicate a high spot price, no stocks, and a backwardation; the expected value of this forward spread is necessarily less than the maximum of full carrying charges. [Bresnahan and Spiller (1986) have emphasized this property of forward spreads in an uncertain world.]

Constellations of coffee prices, shown in Figure 8 once a year in early May for the first five expirations traded on that date, accord closely with the patterns present in the idealized world under uncertainty. All but one year out of the eleven shown – 1995, which followed a freeze that damaged some trees rather than just the maturing crop – the constellations (including the sixth, seventh, and eighth positions not illustrated because they overlap with the annual observations) attenuated to a stable long-run price. (Why this should be much the same nominal price rather than a real price is a puzzle.) When the current spot price, as represented by the price of the expiring May contract, is above that long-run price, the pattern is one of backwardation (and few stocks); when the current spot was below that long-run average price, the pattern was one of contango (and

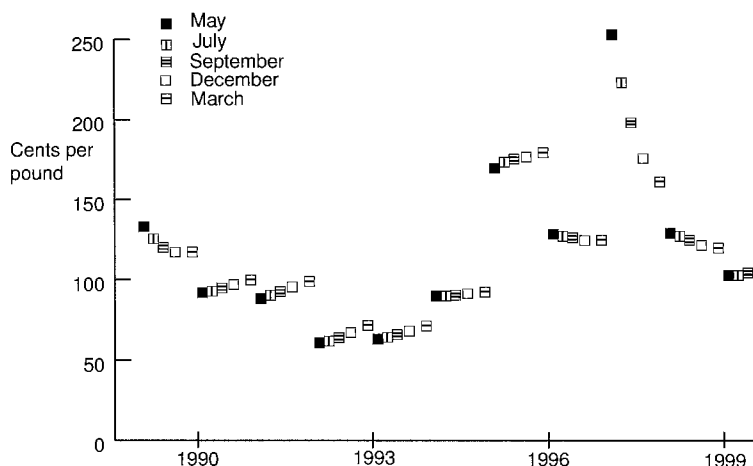


Figure 8. Constellations of CSCE coffee futures prices, first business day in May, 1989–1999.

considerable stocks). The backwardations can be extreme, as in 1997; the situations with contango and low prices are necessarily less extreme by the arbitrage that determines spreads. All constellations attenuated to the perceived long run, which is not necessarily the conditions under average weather.

Figure 8 makes clear why coffee futures expirations go out in time only eighteen months, with little volume in even some of those. A series of five-year-ahead coffee futures contracts would have remained essentially constant until they came within a year or so of expiration. Yes, there is much more uncertainty about five years ahead than one year ahead, but that uncertainty is resolved as a series of independent shocks affecting nearby conditions primarily. Evidently, the principal uncertainty in coffee, not to mention most other commodities, concerns serially uncorrelated annual weather, not once and for all changes that very distant futures contracts might help reflect.⁴³

The pattern of attenuation, and with it the time ahead futures contracts trade, depends not just on the type of shocks the commodity receives but also on the flexibility of technological responses. If the commodity is not easily stored, such as potatoes, any current shock is reflected in old-crop futures prices; put differently, the attenuation to the long-run average is evident in the constellation of futures prices within one year or less.

⁴³ Gardner (1989) has considered whether a strategy of placing a quantity equivalent to five years' production in the most distant expiration available and rolling over the requisite proportion as more distant expirations became available would give stable returns equivalent to a full constellation of futures contracts five years ahead. He concluded that the strategy would mimic very deferred futures contracts, although the transaction costs would mount excessively. Kenyon and Beckman (1997) have extended Gardner's analysis to the case where a producer of corn or soybeans initiates such long-dated positions only if he thinks prices are unusually high. (Such a strategy falls in the category of anticipatory hedging.)

If the commodity has a high elasticity of supply, although planting and maturity of the crop takes several months, any shock before plantings can be partially absorbed through changes in plantings. For example, if the last corn crop was poor, stocks are drawn down and the acreage planted increased. Were that flexibility in planting not possible (say due to government set-aside programs), storage and the current consumption would need to absorb more of the previous weather shock, which would be manifest in a lower spot price and a slower attenuation within the constellation of futures prices.⁴⁴ Coffee, because it is relatively easily stored and because it is a tree crop, has one of the slower attenuations among commodities.

Tomek and Gray (1970) have previously made this point about the stabilizing role of storage as reflected in futures prices. They also emphasized that the constellation of prices reflects known current and nearby conditions; in that sense, futures prices are not about distant unknown conditions but about allocating current supplies. Put more starkly, they would have argued that the constellations of futures prices would be much the same were everything to be certain from that moment forward. Indeed, were the commodity currently abundant and new supplies stable henceforth, as in the idealized certainty world, the constellation of futures prices would display contango for the several years over which the excess would be smoothed; were the commodity currently scarce and new supplies stable henceforth, a pronounced backwardation would be the equilibrium.

The idealized world under certainty thus confirms Tomek's and Gray's important insight that futures prices are more concerned with current conditions than future conditions. The idealized world under uncertainty suggests that such a conclusion be tempered, however. If in 1992, a time of abundant coffee and spreads in contango throughout the constellation of futures prices, the prospect of freezes in Brazil had disappeared through some genetic advance, the equilibrium spot price of coffee and the rest of the constellation would have been even lower. That is, the prospect of future uncertainty and not just current conditions influences prices. More important, the current conditions themselves result from uncertainty. Why was coffee so abundant in 1992? Because there had been no severe freeze for some years. Current conditions, in coffee in Figure 8 as in other commodities, show the extreme range that brings to bear futures markets' allocative role because of the inherent uncertainty. In sum, the greater the range of current conditions and the less flexibility in response, the more scope for futures markets.

Figure 8 speaks to another issue raised in the literature on futures markets: Do futures prices become more variable as the contract they represent approaches expiration? Samuelson (1965) first raised this question, in a theoretical argument imagining a particular autoregressive random process for the spot price, the mathematical expectation of which, at different periods ahead, equaled hypothetical futures prices. (Under this formulation, if the futures prices' variances did not increase as the expiration approached,

⁴⁴ A related subject concerns "overshooting" such as discussed in Rausser and Walraven (1990). Because bulk commodities are much more freely traded than most other goods, when there is a monetary or macroeconomic shock, short-term commodity prices might bear a disproportionate share of the adjustment.

the spot price itself followed a random walk and had infinite variance.) Rutledge (1976) tested Samuelson's hypothesis on daily data for a single expiration in four commodities. He found that two of the commodities, silver and cocoa, had higher variance as the expiration approached, but two, wheat and soybean oil, did not. Samuelson (1976), although he did not take exception to Rutledge's empirical approach, felt that if these commodities' prices were studied for a longer stretch of time, their tendency to return to a stable long-run mean would become more evident. Samuelson would find Figure 8 reassuring. Year-to-year, the nearby May coffee contract is more variable than the more distant March contract (or the one-year-ahead May contract not shown in Figure 8). Figure 8 not only adds more years of data but it changes the statistical inquiry from inspecting the behavior of separate expirations over their lives to the behavior of constellations of prices. That attenuation is the dominant pattern emerges as much more visible in the constellations of prices themselves.

The idealized world under uncertainty, with optimal storage deduced with numerical stochastic dynamic programming, exposes a deeper problem with Samuelson's original formulation and consequent empirical work. The spot price process's autoregressive and attenuation properties are endogenous, just as are the degree of seasonality, the degree of heteroskedasticity, and the degree of skewness. That is, the statistical properties of constellations of prices, including their properties as forecasts, alter with underlying parameters, such as the physical storage cost, the supply elasticity, and the variance of the weather. Moreover, the futures price is not just a linear function of past prices, and by extension, a linear filter of the exogenous random process, the weather. As a result, the degree of attenuation will itself be a function of the spot price, differing substantially when the constellation of prices displays backwardation rather than contango.

In Figure 8, changes from May to May in the level and pattern of coffee futures prices coincide principally with freezes in Brazil. Another influence is the International Coffee Agreement (ICA). One of the more successful cartel-like agreements concerning internationally traded commodities [Finlayson and Zacher (1988) and Bates (1997)], the agreement fell apart over several weeks in June and July 1989. How coffee futures prices moved over June and July 1989 illustrates features, including some puzzling ones, common in futures markets.

Figure 9 shows daily coffee prices over two weeks, one week in early June and the other in early July 1989. In each of these two weeks, a major event happened regarding negotiations extending the ICA scheduled to expire in September 1989. In the weeks before June 8, the constellation of prices looked much like those on June 8 and 9. Similarly, the constellation was fairly stable from June 14 through June 30, while the pattern seen on July 7 lasted for several weeks.⁴⁵ The two price breaks together represented

⁴⁵ Following July 7, prices for all delivery months fell a few cents more, then rose slightly, then fell slowly over the course of the summer, a decline that would be sensible inasmuch as each passing day meant that a freeze had not happened in Brazil. The possibility of new negotiations had an influence throughout the late summer. When it became evident in September that the ICA had truly lapsed, prices of the nearby contract fell as low as 70 cents per pound.

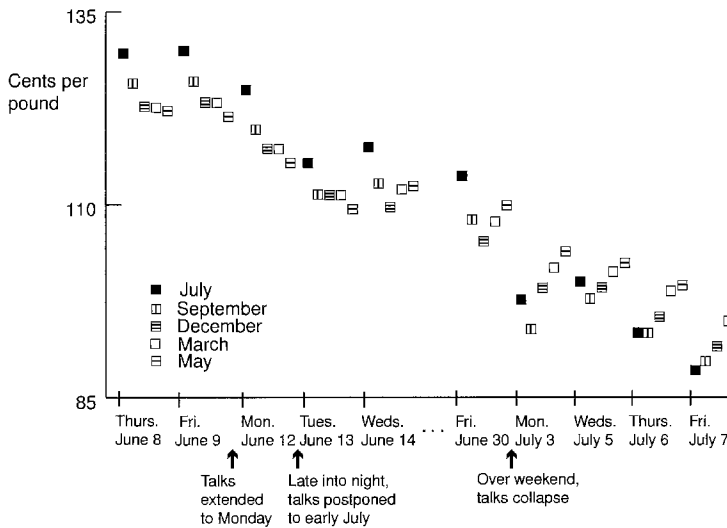


Figure 9. Constellations of closing CSCE futures prices during negotiations over the International Coffee Agreement in 1989.

a 32 percent fall in the price of the July '89 expiration, a large change even to those familiar with the extreme variability in commodity prices.

The ICA restricted exports quarter by quarter, supposedly keeping prices within a band between 110 and 130 cents. The restriction of exports created shortages of coffee at importing centers while building up stocks within producing countries. The restriction of exports led to a constellation of futures prices on June 8 with a pronounced backwardation, as well as the attendant low level of stocks in CSCE warehouses seen previously in Figure 2(d). Given that a backwardation signals a temporary shortage, the constellation of futures prices on June 8 was suggesting a collective suspicion that the quarterly restrictions might not last or might not be so strict in the future. Were the export restrictions in prospect viewed as consistently effective, the various expirations would have had the same price.⁴⁶

The negotiations held on June 8 and 9 had been expected to be problematic. The U.S., the largest consuming country, had been insisting that the next ICA preclude producers from selling to those not signing the ICA at prices below those applied to ICA signatories.⁴⁷ Colombia, whose growth had become increasingly desired by consumers com-

⁴⁶ Export restrictions expected to be even tighter would have been manifest as a contango among all pairs of expirations.

⁴⁷ The U.S. was party to the negotiations because the ICA was an unusual producer-support program in which many consuming countries pledged not to help members of the cartel cheat, by requiring that all imports bear an official stamp. The U.S. had become annoyed that the producers were selling at much lower prices elsewhere, price discriminating between segmented markets.

pared to lower-quality arabicas from Brazil, had been pressuring Brazil for a greater share of the export quota. Brazil wanted no changes in the system. The hardening of these negotiating positions meant that the talks, in London, did not conclude as scheduled on Friday, June 9, but had to be extended to Monday, June 12, and late on June 12, had to be rescheduled for the first weekend in July. The futures market reacted very quickly to this negotiating impasse. Prices fell on Monday, June 12, and even more so on June 13, indeed falling that day at the start of trading to a level that remained more or less stable until the talks resumed in early July. Thus, the coffee futures prices incorporated the possibility of the failure of the negotiations. Because of this property, futures prices in general are said to be “anticipatory”.

Whether the coffee futures market on June 13, 1989, plausibly estimated the possibility of a lapse in the International Coffee Agreement is more difficult to surmise, by the uniqueness of the events. Only if every year, following similar circumstances in June, were talks held in July, some years a success and other years a failure, could an objective calculation be made of the possibility of failure, an objective calculation that could be compared to that implicit possibility within the prices on June 13, 1989. Since these conditions of controlled experiments are usually lacking, it is nearly impossible to demonstrate beyond reasonable doubt either that futures price *ex ante* are clearly implausible or that they are clearly plausible. *Ex post*, they will look wrong for certain.

In a few futures markets, conditions for replication and objectivity are met. These instances suggest that futures prices do indeed anticipate well, although not as well as possible. In a study of frozen concentrated orange juice (not one of the most active futures market, to be sure), Roll (1984) found that during winter months, closing prices in the afternoon anticipated well the possibility of a freeze in the production zone in Florida. Indeed, the futures market provided slightly better forecasts than did the U.S. Weather Service a few hours later. Sumner and Mueller (1989) examined the reaction of corn and soybean futures prices to USDA forecasts of harvests, forecasts made monthly over the summer for a number of years. These forecasts are reasonably accurate on their own. Hence if the futures prices did not react to their release it was because market participants had already deduced the information rather than knew to ignore it. Sumner and Mueller found, however, that corn and soybeans were unusually variable on the day following the USDA's release, which fact suggests that the USDA's forecasts contained information not previously known to market participants. [Baur and Orazem (1994) have reported similar results for USDA forecasts regarding harvests of oranges.] Sumner and Mueller inspected the variance of price changes rather than the direction of price changes, because prices might rise in response to a forecast of a large crop had market participants imagined that the crop would be even larger. That is, they could not measure the extent of the surprise in the USDA forecast. In the cattle and hog industries, market analysts release their own forecasts of the number of cattle and hogs on feed simultaneously two days before the USDA does. The “surprise” in the USDA's announcements can thus be measured by the change from the median private forecast from two days before (not that announcements of private forecasters' views necessarily move prices either, since they could have been disseminated or deduced by traders

themselves earlier – it is rather that they measure expectations besides what can be observed in prices). Grunewald et al. (1993) found that a surprise component in USDA announcements moves cattle futures prices just as Colling and Irwin (1990) found that a surprise component in USDA announcements moves hog futures prices. Carter and Galopin (1993) note, however, that the hog price movements observed by Colling and Irwin are so small and so unreliable that a (hypothetical) trader who had access to the announcements a day before the market as a whole would not find it profitable, transaction costs included, to trade on the information. All these studies find that if USDA announcements contain a surprise, the new information is incorporated into prices very quickly.⁴⁸

Because futures prices react quickly to news, sometimes in a matter of seconds or minutes, futures markets are “efficient”, in the sense used in the finance literature. The “efficient market hypothesis” has been well studied in equity, bond, foreign exchange, and commodity markets. Pruitt et al. (1987), which investigates various commodity markets’ reaction to the day-by-day events involving the Chernobyl nuclear power reactor in 1986, is a good example of a study of a specific event. Cargill and Rausser (1975) is a good example of inspecting day-to-day price movements themselves for patterns. Although some predictable components of price movements can be found in some markets for some periods of time, e.g., as in Brinegar (1970), the evidence is very strong that there are no pronounced cycles, runs, reversals, or trends in prices, for they would have been noticed by traders and the implied profits competed away. (Of course, an economist finding some pattern that would make trading profitable might not publish that evidence.) An implication is that prices for a particular expiration move much as a random walk. To be precise, that proposition derives from two ideas, one that prices quickly reflect what can be anticipated and the other that surprises arrive, by their nature, at random.

The evidence of futures prices moving as a random walk leads many people, including some economists [as early as Taussig (1921), economists wondered why commercials’ sales would not lead others to sell rather than buy], to conclude that futures prices are themselves indeterminate or inexplicable. On the contrary, the large price breaks in coffee in June and July 1989 in Figure 9 are closely tied to the negotiations over the ICA. Likewise, the year-to-year movements in the constellation of coffee prices seen in Figure 8 reflect the ICA and even more the weather in Brazil.

Even though many price moves can be explained, it can hardly be said that all price changes can be explained, even with *ex post* knowledge of how events unfolded. Between the two 10-cent price drops of early June and early July 1989, the small price changes on the order of 1 cent per day are not easily aligned with news about the ICA or any other specific source for that matter. Likewise, coffee prices can move by 0.5 cents

⁴⁸ All these studies examine the price change from the close of trading following which the USDA makes its announcement to the close of trading the next day, and so on. If the futures market is fully efficient at processing information, any surprises in the announcements should be incorporated in the opening price the next day.

from one hour to the next even during the Brazilian summer. Supposedly, such short-scale price changes reflect surprises, but surprises about what? Barnhart (1988, 1989) studied the reaction of commodity prices, including coffee, to surprises in macroeconomic and monetary variables. He found that those surprises, especially in monetary variables, did influence commodity prices in the sensible direction. Nonetheless, the proportion of the day-to-day variation attributed to those causes was on the order of 2 percent.⁴⁹

Speculators are frequently blamed for inexplicable price moves. Three specific accusations have led to exceptional data on individuals' trading. First, because of politically noticeable price movements in wheat during 1924–1926, the Grain Futures Administration, the CFTC's predecessor, investigated the daily trading of dozens of large speculators and hedgers, as well as a substantial sample of small speculators [Duval and Hoffman (1928) is the last in a series of published studies]. Although it was thought that some large speculators had enticed small speculators into the market (supposedly later to leave them holding positions at the inflated prices at which the large speculators had sold out), the Grain Futures Administration found that the small traders tended to trade opposite the large speculators. They found that prices tended to change day to day in the direction that the large speculators traded.⁵⁰ [Petzel (1981), with more modern statistical techniques, found no evidence that the large speculators tended to move the prices to their advantage; if anything, the large speculators were merely along for the ride.] Second, because of a sharp break in cotton prices over three days in October 1946, which were believed to have been caused by a few large speculators, the Commodity Exchange Authority (1947) reconstructed the trading of nearly every market participant. They found the price decline to have been accelerated and extended by hasty liquidation by speculators, who had been primarily on the long side of the market. Two very large longs' selling contributed, but this selling was a forced liquidation on the third day (for failure to meet a margin call) caused by the price break itself. Hedgers and, surprisingly, many small speculators proved to be the buyers who had stabilized the market. Many traders were active throughout those days and weeks, yet the market proved to be much less able to absorb large orders than expected. Third, because of a sharp run-up in the July '73 corn expiration in its last hours of trading and the resulting allegations of manipulation, expert witnesses, including Hieronymus (1981), were able to investigate the trading of those remaining in the market to the end. It emerged that virtually all the remaining traders were commercials, although many of them, in no condition to make or take delivery, were speculating, despite their self-reported classification as hedgers.

In coffee, June 12, June 13, and July 3, 1989, were also days of high volume, perhaps 50 percent above levels in the weeks before and after. Likewise, in other periods in coffee, sharp price moves have been accompanied by higher volume; in Table 2, the correlation between the standard deviation of price changes within a month is positively

⁴⁹ Such low explanatory power may partly reflect the simple linear models of price changes.

⁵⁰ These findings led to the recommendation of position limits on speculators.

correlated with that month's trading volume. In this respect, coffee is like many other commodities, according to Cornell (1981). Such contemporaneous positive correlation between price variability and volume is found even at the daily level, for all commodities studied by Kocagil and Shachmurove (1998). Presumably, data measured at even shorter intervals, such as five or ten minutes, would show a correlation between volume and the absolute value of price moves. This correlation does not imply causality in any meaningful sense, however. Clearly, in the case of coffee in 1989, the news about the ICA caused both the price change and the increased trading volume.

It may not seem surprising that major price moves are associated with substantial volume. Yet prices could move with little volume. If everyone, regardless of whether long or short, calculated that the collapse of the ICA on July 3 implied a 15 cent drop, it might have been that the new bids and asks centered 15 cents lower than previously without a single trade. Evidently in coffee in 1989, while no one could have imagined that the collapse of the ICA meant anything but a price decline, the exact magnitude of that decline was in dispute. Those differences in opinion presumably encouraged trading. Another interpretation might be that the price decline made for arbitrage opportunities involving related markets, which would have adjusted more slowly. Without volume statistics from those related physicals markets, a full picture of the news's effect on trading is not possible, unfortunately.

A final feature of futures prices can be seen in Figure 9: Anticipations about the future affect prices in the present, sometimes considerably. The ICA negotiations concerned an extension of the existing agreement beyond September 1989. The negotiating impasse in June affected not only those delivery months in the period of the proposed agreement but also the September '89 and July '89 expirations, whose prices fell considerably too.⁵¹

In the case of coffee, the future is connected to the present principally by storage. Yet other mechanisms can be at work, such as adjustments in the speed of harvesting, washing the coffee berries, loading, shipping, and unloading. These other intertemporal connections are more important for commodities such as live hogs or feeder cattle. In general, if the commodity is in temporary abundance, such that spreads are in contango, news about future availability, such as improved prospects for the next harvest, cause virtually equal movements in spot, nearby, and intermediate prices, as the contango relationships within the constellation will not change. If the commodity is in temporary shortage, such that spreads are in steep backwardation, news of improved prospects for the next harvest affect the distant expirations disproportionately, perhaps the expiring

⁵¹ When the talks collapsed in early July, the existing export restrictions were suspended, which explains why the July '89 expiration fell disproportionately then. The new price level and the new price relationships had to reflect the worldwide abundance of stocks. The greater fall of the nearby July '89 expiration compared to the May '90 expiration, or, put differently, the movement in the spreads from backwardation to contango, makes clear that the ICA itself was mainly affecting short-term price relationships, notwithstanding its supposed long-run goal of price stabilization. That the story concerns nearby spreads should be noted by those economists who study buffer-stock schemes, government storage programs, etc.

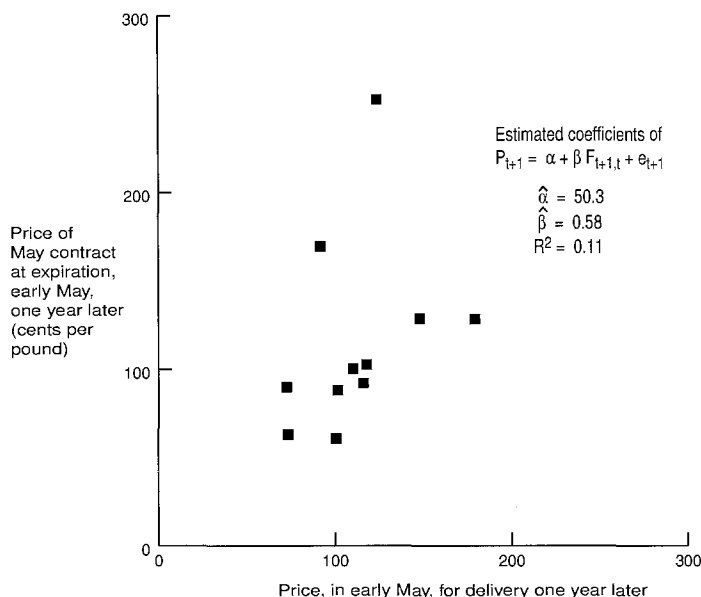


Figure 10. Forecasting success of CSCE May coffee futures, 1989–1999.

contract's price not at all. Even though the backwardation will become steeper, the existing steep backwardation probably had already given a strong signal to delay demand or speed up processing and shipping. As Tomek and Gray (1970, p. 373) emphasize, "[t]he element of expectations is imparted to the whole temporal constellation of price quotations, and futures prices reflect essentially no prophecy that is not reflected in the cash [i.e., current spot] price and is in that sense already fulfilled".

Given that futures prices anticipate the future, at least to some extent, the question naturally arises about futures prices' success. How well do they forecast the future? This question has been well investigated, and usually with a straightforward test in a standard OLS regression. A futures price for a contract expiring on $t + 1$ observed on t , namely $F_{t+1,t}$, becomes a realized price P_{t+1} , differing from the forecast by a forecast error e_{t+1} . In Figure 10 are plotted eleven pairs $F_{t+1,t}$, P_{t+1} for coffee measured one year apart in early May.⁵² If in a regression $P_{t+1} = \alpha + \beta F_{t+1,t} + e_{t+1}$, the intercept α is close to 0.0, the slope coefficient β close to 1.0 and the R^2 high, the forecast performance of the futures prices is impressive indeed.

⁵² This notation presupposes an equidistant measurement of futures and spot prices, as when one observation is made each year. Generalizations to data collected two months before expiration are obvious. Kahl and Tomek (1986) have cautioned against constructing a series of one-year-ahead forecasts involving March expirations, another series of one-year-ahead forecasts involving May expirations, and so on, because the connections within constellations of futures prices imply that those series overlap considerably.

The one-year-ahead May coffee futures prices do not achieve impressive forecast performance. As can be seen in Figure 10, the R^2 is low, the estimated intercept considerably above 0.0, and the slope coefficient substantially below 1.0.⁵³ Measured in March, and so two months rather than one year from expiration, the May futures prices are much better predictors of the realized price in early May.

This forecast performance of coffee futures prices over 1989–1999 is typical of other periods and commodities. Kofi (1973) did find the R^2 for coffee futures forecasting eight months ahead to be 0.79 and the unbiasedness property of $\alpha = 0.0$ and $\beta = 1.0$ upheld over 1953–1962, but he found a less impressive forecasting performance for potatoes, cocoa, wheat, corn, and soybeans over 1953–1969. Rajaraman (1986) found much the same result for 1973–1982 for coffee, in both the New York and London futures markets. Kenyon et al. (1993) found that for corn and soybeans even that unimpressive forecasting performance declined after 1973. Bigman et al. (1983) found for wheat over 1975–1980 that while the forecasting power one week before expiration was impressive, even twenty weeks before the R^2 was 0.40 and the estimated slope coefficient 0.65 (for soybeans it was even lower at 0.47). Hazuka (1984) found more forecast power for some non-storable than for some storable commodities, at the range of one month ahead. Leuthold (1974), for live beef cattle involving the 36 contracts maturing from April 1965 through February 1971, found the R^2 for forecasts one month ahead to be 0.85 but for eight months ahead to be merely 0.04. Koppenhaver (1983) found those results for live cattle extended through 1983. Gray (1972) found a similar low forecasting power for potatoes futures expiring after harvest quoted before planting. [Actually, the first such analysis Emery (1896) performed for post-Civil War cotton and wheat.]

Having inspected a number of regressions of this type, Stein (1981, p. 227) concludes that for futures prices “more than four months to delivery, the R^2 of the regression is negligible. Consequently, the forward price at ‘planting’ time is a biased and worthless predictor of the price at the ‘harvest’”. Stein, however, does not consider how high the R^2 could be under the best of circumstances.⁵⁴ It should not ordinarily be expected to be anywhere near 1.0, the maximum statistical value.

By construction in the idealized world with uncertainty, the futures price for delivery the next period is the best possible estimate of the price at the next harvest. Nevertheless, for reasonable combinations of parameters in this idealized world, the highest R^2 in a forecasting regression is merely 0.30, and it can be as low as 0.10 [Williams and Wright (1991)]. Were the test applied to the idealized model’s futures prices for

⁵³ The joint hypothesis of $\alpha = 0$ and $\beta = 1$ is not rejected at conventional levels of statistical significance, however, because there is so much “unexplained” randomness in the realized price.

⁵⁴ Brannen and Ulveling (1984) approach the subject from another direction: What would have been the forecasting performance of a current spot price of subsequent spot price before and after the introduction of futures trading. They find for several commodities that the forecast performance by the physicals market improved with the introduction of futures trading, perhaps because the futures market made more information available. (Changes in marketing conditions that arose simultaneously with futures trading might be another explanation.)

two periods ahead, the highest attainable R^2 would be even lower. Compared to these R^2 's attainable by the best possible futures prices, the forecasting performance of actual futures prices does not look so bad. Prediction of subsequent spot prices is inherently difficult.

The degree of predictability depends on the commodity involved – the specific demand and supply parameters, storage costs, and so on. If the commodity cannot be stored, the R^2 would be zero in this situation. Gray (1972) made that point regarding his study of potatoes: With no potatoes carried over and nothing yet known about planting conditions, the harvest-time futures price should be essentially the same every year (as it was). Storage disperses excess availability from one crop year to the next, reducing the deviation from the long-run average of price in period t but increasing it in period $t + 1$. It is this storage-induced component of P_{t+1} that is “explained” by the futures price, and consequently the lower the cost of storage, the higher the proportion of the variance explained.⁵⁵

The higher is the supply elasticity, the lower is the attainable R^2 . This relationship may be surprising. More elastic supply, by helping to absorb the shocks from good or bad weather up to the time of planting, reduces the predictable moves back to the stochastic steady state. Thus elastic supply, by facilitating adjustment to previous shocks, reduces that component of the variance of the spot price that could be explained by information in period t . While this effect diminishes the variance (of the spot price) to be explained, it also diminishes the proportion explained by the futures price.

The lessons can be put together to call into question whether a higher R^2 in a forecasting regression even indicates greater rationality, the presumption behind the whole formulation of the test. Consider a case where producers are irrational. Although they could adjust their planting intensity period to period (the true one-period-lagged supply elasticity is, say, 1.0), they persist in forecasting the next price as equal to the long-run average (the effective one-period-lagged supply elasticity is 0.0). Private storers, meanwhile, are rational, including an understanding of the effective supply elasticity.⁵⁶ The forecasting power of the futures price as measured by the R^2 would be higher if supply were of this irrational form than if supply were rational. Therefore, it seems premature to interpret empirical results from regressions of the form used in Figure 10 without some understanding of parameters like storage costs and supply elasticity. Moreover, to judge the social value of the futures price (and market) by the R^2 is a mistake. The more responsive is supply to that very futures price – that is, the more useful the futures price is in guiding planting decisions – the lower will be its forecasting power inferred from the R^2 .

⁵⁵ It is also worth emphasizing that the lower are the physical storage costs, the lower is the variance of the spot price to be explained. The variance of the spot price is endogenous, as noted earlier regarding tests for changing variance in futures prices.

⁵⁶ Peck (1976) presents such a hybrid model, with rational expectations for speculators and adaptive expectations for producers.

A related literature considers whether the prices of options predict well the future variability of prices. Or the issue might also be put as to whether the *ex ante* premiums are sensible prices for the options. A direct test of the plausibility of prices might be to compare an option premium with its value again a month later, except that a premium should be expected to change with time, and as a highly nonlinear function of the strike price and the intervening movement in the price of the underlying asset. A more appropriate test is to compare the premium to a prediction implied by a model of option pricing.

An explanation of such tests requires a digression regarding the relationship among options, volatility, and models. As mentioned earlier, were prices not volatile, no one would pay a premium to have an option to buy the commodity at a price above the prevailing price. With an assumption about the variance of price, an economist or trader can deduce, as in Black (1976), an explicit formula for the value of the option as a function of the price variance, the time to expiration, and the strike price. Given the assumption about the variance, arbitrage arguments alone reveal the explicit formula, although arbitrage arguments in the perfect situation of no transaction costs. (Similar approaches provide a numerical rather than an analytical solution.)

One complication concerning options on commodity futures is that the variance is not plausibly constant, as it is plausibly for equities, for which the standard options models were developed. Anderson (1985), Kenyon et al. (1987), and Hudson and Coble (1999) have documented the pronounced seasonality in the day-to-day variability of prices, whether wheat, soybeans, corn, cocoa, live cattle, hogs, or cotton. The variability of prices is perhaps twice as high in key growing months as in winter months, such as June and July for corn and soybeans. In the case of coffee, prices are typically more volatile during June, July, and August, the Brazilian winter, although the difference is not as pronounced as for the field crops. As Table 2 indicated, the day-to-day volatility of coffee prices is higher when the price is high (and stocks low, etc.), which Streeter and Tomek (1992) found to be the case for soybeans. Crain and Lee (1996) have found the day-to-day volatility of wheat prices to be related to regime of government programs; the effectiveness of the ICA was similarly an influence on the volatility of coffee prices. Nevertheless, over periods of several months, the variance of a commodity's price is likely to be more-or-less stable.

Thus, it is reasonable to compare actual option premiums to those implied by a model, such as Black's, and a plausible estimate, from recent history, of the variance of price. Hausser and Neff (1985) have found that actual premiums closely match those implied by a plausible option model for soybeans and hogs, as Wilson et al. (1988) have found for wheat, corn, and soybeans. The small discrepancies may have been due to mispricing by market participants, to a mistaken estimate of the price variance, or to particular assumptions in the model; by the nature of the comparison it is impossible to tell which.

A slightly different approach is to combine the actual premium with the formula deduced through the option-pricing model to derive the element missing in the model, namely the variance of the price. As this estimate of the variance is implied by the

premium and the model, it is known as the “implied volatility”. The implied volatility ought to be sensible, or the actual premium is not sensible (or the model is not sensible). Figure 2(h) plots the time series of implied volatility for coffee, over 1989–1999, based on the most heavily traded option on the nearest futures contract. That series displays a plausible value, one near to the mean standard deviation in Figure 2(g), and higher values during the Brazilian winter. According to Table 2, the implied volatility is correlated with the other series in coffee in a plausible direction. Its value at the start of one month predicts the observed standard deviation of prices the subsequent month, with an R^2 of 0.20. Similar results have been found by Fackler and King (1990) for corn, soybeans, cattle, and hogs, and by Sherrick (1990) for soybeans. These two “calibration” exercises, conducted not long after options on futures began to be traded on organized exchanges, were limited by small samples and attendant statistical problems, but they too suggest that option premiums anticipate future price variability.

An extensive literature pits futures prices against various econometric techniques in contests of forecasting ability: Are traders or econometricians the better seers? For example, Rausser and Carter (1983) compared the three futures prices in the soybean complex and Garcia et al. (1988) live cattle futures prices to univariate and multivariate autoregressive moving-average (ARMA) models employing spot prices. Leuthold and Hartmann (1979) contrasted hog futures prices to a two-equation econometric model related to the well-known cobweb specification. Also for hogs, Brandt (1985) compared futures prices to ARMA forecasts from spot prices, a quarterly reduced-form econometric specification fit with spot prices, and expert opinion from a university outreach program.⁵⁷ Just and Rausser (1981) investigated the forecasting ability of futures markets for wheat, corn, cotton, the soybean complex, live cattle, and hogs relative to quarterly large-scale structural econometric models fit to spot prices.⁵⁸ In these forecasting comparisons, rarely does the futures market win convincingly, especially against a whole group of econometric techniques. For that matter, the econometric approaches, although sometimes the winner, do not win convincingly.⁵⁹

The effective tie in forecasting skill between futures markets and econometric models should be expected, however. Traders can use those very econometric models, not to mention that the econometricians can peek at the futures prices. In any case, the data for the econometric models and the futures prices are not independent. Especially for

⁵⁷ Marquardt (1979) earlier had compared “outlook letters” from universities and government agencies to futures prices in cattle, hogs, corn, soybeans, and wheat and found the futures prices to be the better forecasts, although not strongly so.

⁵⁸ To this list can be added a type of study examining the informational efficiency of futures markets, such as Epps and Kukanza (1985) for grains. Because the errors from efficient forecasts should be uncorrelated with anything known at the time of the forecasts, forecast errors can be regressed on stocks, past prices, etc., to test for informational efficiency. A structural model is implicit.

⁵⁹ If econometric techniques are not obviously superior, it is hard to justify paying large fees for forecasts from large-scale econometric models. Evidently, before Rausser and Just (1979) presented their comparison to the forecasting skill of futures markets, the large macro-oriented forecasting firms were marketing their services to futures traders.

storable commodities, futures prices are by their very nature related to the concurrent spot price, an observation made years ago by Working (1942). In a quarterly setting of an annual crop, the spot price will be a linear function (apart from the proportional factor of interest expenses) of the futures price and vice versa. Hence, the likely ARMA forecast, namely the current spot price plus a constant, would be none other than the futures price for delivery one quarter ahead. Only across crop years and then only when there is no carryout, will the current spot price and current futures price make different predictions about the next spot price. Thus, even as "storability" imparts ARMA-like features to the behavior of spot prices, it makes the distinction between ARMA forecasts and a rational futures price more difficult to draw.

The connections within constellations of prices at one moment in time contrive a logical inconsistency in the presumption that ARMA or structural econometric models employing spot prices could be better forecasts than the futures price. If the futures price is irrational, say because of an overreaction to news about the next harvest, then the current spot price too is irrational. Nothing ensures that sophisticated econometric models based on irrational spot prices should be superior to an irrational futures market. Put differently, storage and similar intertemporal connections cause a feedback of expectations on the current situation. Commodities with futures markets are fundamentally different forecasting environments than assumed for standard econometric applications, whether ARMA time-series techniques or structural models.

Most important is the problem arising from a connection between the error term e_{t+1} and subsequent values for the futures price, the right-hand-side variable. For $\hat{\beta}$ under OLS to be an unbiased estimate of β , $E[F_{t+1,t}, e_{t+1+j}]$ must equal zero for all j . The correlation, in expectation, for $j = 0$ is zero as required, but for $j = -1$, the correlation is positive. $\hat{\beta}$ should be biased downward. (OLS is consistent in such circumstances, however; the bias disappears in sufficiently large samples.)⁶⁰ Consider what happens when a harvest is unexpectedly large. The spot price is low and, more to the point, is lower than the futures price, as of the previous period, for delivery at that date: e_t is negative. The equilibrium with that large harvest also features a low futures price as of period t , for delivery in period $t + 1$. That futures price is the value for the right-hand-side variable for the next observation in the forecasting regression. Thus, the right-hand-side variable is related to the previous error, contrary to the conditions appropriate for OLS. The statistical problem is much like that of a lagged dependent variable, where even if the error term is not serially correlated, slope coefficients estimated from small samples will be biased toward zero. On statistical grounds, therefore, for a storable commodity some bias should be expected in the conventional procedure.

⁶⁰ Elam and Dixon (1988) have recognized this problem within the literature on bias and efficiency of futures prices as one of serial correlation in the right-hand-side variable. Brenner and Kroner (1995) make a similar point about "cointegration" tests. They all discuss the problem in the context of spot prices that follow a random walk, however. Even if spot prices do not follow a random walk (they look to be mean reverting, after all), the error term in the regression is related to futures prices for subsequent delivery dates, because of the nature of storage.

The word “bias” should bring to mind the earlier discussion of Keynes’s theory of normal backwardation and the hedging-pressure theory. Indeed, were the intercept α in the forecasting regressions estimated to be statistically and economically significantly above 0.0, the natural interpretation would be as a risk premium. The discussion of forecast power of futures prices thus exposes three more problems with the conventional tests for a risk premium. First, the effective sample sizes are not that large, really not much more than annual data. Second, subsequent hedging pressure is correlated with the previous price change (if prices fall, commercial shorts become more numerous), in which case previous “error terms” are correlated with the right-hand-side variables. Third, because forecast power should be expected to be low, tests for risk premiums should be inconclusive.

Chang (1985) examined the “large trader reports” used to test the hedging-pressure theory for non-commercial traders’ forecasting skill. He applied a minimalist definition of forecasting skill: Depending on the net holdings of large speculators, presumably more times than not prices, should move in the direction of their holdings. Over the period 1951–1980, he found some such evidence of large speculators’ forecasting skill in wheat, but none in corn and soybeans, where more often than not the price moved against the large speculators. Coffee over 1989–1999 also does not provide even this minimalist evidence of forecasting skill by large speculators. Over the whole 132 months, 100 months the large speculators were long as a group at the start of the month, yet 60 of the subsequent month-to-month price changes were negative. Following the 32 months the large speculators were net short, on 18 occasions the subsequent price change was positive. By this minimalist test, the reporting commercials had forecasting skill while the small non-reporting coffee traders did not.

Faced with so little indication of forecasting skill among large speculators [Hartzmark’s (1991) study, previously mentioned, would have been a strong corroboration], Chang concluded that non-commercials must be present in futures markets to collect a risk premium. Yet the explicit evidence supporting the theory of normal backwardation or the hedging-pressure theory is weak at best. Why then do speculators participate in futures markets? Even though speculators make little money on average, it may be that a constant turnover allows for a stable pool of possible speculators. Yet the evidence, at least regarding speculation in the aggregate, does not accord with that interpretation. As seen in Figure 2 and Table 2, whenever prices decline, open interest tends to increase, and commercials tend to go further short. That is, just after non-commercials have lost money while long as a group, they go further long. Such behavior is difficult to reconcile with any model of learning about one’s own forecasting skill or indeed with any model of behavior under risk aversion. If those non-commercial longs profit from the next price move, necessarily the commercial shorts do not. If even some speculators appear to have forecasting skill, necessarily some other market participants must appear to have the reverse of that forecasting skill. In short, the zero-sum nature of futures markets makes difficult any explanation of how they achieve the forecast implicit in the constellation of prices.

The anticipatory nature of futures prices also constrains any theory of futures markets. For example, the arrival of weather news in bursts causes more trading volume and larger price changes than at other times. Although the effect on trading volume might linger for days or weeks, the effect on price must be nearly instantaneous. Otherwise volume would predict the direction of price changes, including the prices of options, and so traders could profit by tracking volume. [Not surprisingly, Kocagil and Shachmurove (1998), mentioned previously, found no evidence that the daily series of volume anticipated price changes.] Given that price variability is seasonal, any risk premium deriving from hedgers' demand for "price insurance" should also be seasonal, as Beck (1993) has noted. (She found evidence of seasonal risk premiums in only one of four commodities she studied.) In that instance, the anticipatory nature of futures prices helped to refine a test of a theory of futures markets.

7. Conclusion

Economists have written a multitude of papers on organized commodity exchanges over the years. Carter (1999) has surveyed what he calls the "large literature base" since the previous major survey by Gray and Rutledge (1971), who even then were remarking on the breadth and depth of economists' interest in organized exchanges. In other fields, the sheer number of papers would suggest substantial progress in understanding the subject. Yet these many papers, whether theoretical or empirical, mainly treat the same subjects again and again, albeit with a gloss of ever more mathematics and econometrics. [Frankly, the topics and puzzles emphasized in this chapter are much the same as in Hoffman's (1941) well-considered essay on wheat and corn futures markets.] That sixty years of research has brought so few definitive answers largely reflects several inherent difficulties, difficulties present in other areas of economics to be sure, but especially pronounced when economists study organized futures and options exchanges.

The first inherent difficulty in studying organized exchanges arises from the data available. Organized exchanges publicize prices at extraordinarily short intervals. Yet quantities are generally recorded at longer intervals, and by the exchanges' very success in promoting anonymous trading, are generally observed at levels of aggregation far beyond individual traders. Those traders' positions in closely related markets are rarely observed, yet it is the combination and sequence of related trades that could best differentiate among the various theories about why commercial firms use futures and options markets. The exchanges' very success in making their prices the benchmarks reduces the price information available about other grades, locations, and periods. The exchanges' very success arises from traders' differing opinions about freezes, plantings, rainfall, harvest times, etc., but those natural sources of randomness make it difficult to conclude *ex post* whether some strategy *ex ante* was in any economic sense rational, let alone optimal.

The second inherent difficulty arises from organized exchanges being industry-level phenomenon. Rarely is more than one exchange active in a particular commodity. As

Table 2 made clear in the case of coffee, the volume of trading on an exchange, the open interest, the extent and structure of commercial use, the level and pattern of prices, the warehouse stocks, the prices of options, the variability of prices, not to mention the amount of deliveries, the number of Exchanges for Physicals, the level of original margin, the number of scalpers, and the activity of commodity funds, are all in a simultaneously determined system. At the interval of seconds or minutes, some among the simultaneous series must precede the others – that condition is the idea behind “price discovery” – but the anticipations of those relationships can feed back on the other endogenous variables: Effects need not follow their causes. Moreover, organized exchanges’ very success derives from a non-linear feedback of the trading volume and the representativeness of prices. Economists are most comfortable studying industry-level systems, such as the market for fresh tomatoes, in which the quantity variables have natural interpretation in equilibrium and in which the assumption of a representative producer or consumer does not seem crucial to the analysis. Of course, a market-level analysis of the fresh tomato industry may raise many issues about industrial structure over time, but one can plausibly speak of the equilibrium quantity of tomatoes in some period and one can plausibly ignore intermediaries. Organized exchanges are not such relatively straightforward industry-level systems. Examined closely, the prices on organized exchanges are never stable; the typical trade more plausibly represents an action moving the market towards equilibrium, however fleeting that equilibrium may be. Organized exchanges, by their very success, attract a whole range of players not in the fresh tomato industry, such as speculators. Those speculators include both newcomers and long-established professionals. Such heterogeneity is crucial, for it gives impetus to trading.

The third inherent difficulty in studying organized exchanges concerns the relevant counterfactuals or hypotheticals that economists employ in their models. By training, economists seek simple models, such as those with two periods rather than many. Yet a multiperiod model contradicts much of the analysis in two-period models of futures markets. Economists are comfortable imagining well-functioning markets, and so posit the addition of futures markets to perfect spot markets. Yet a futures market emerges in circumstances of poorly functioning spot and forward markets. Economists treat legal constructs as unimportant details. Yet organized exchanges are first and foremost substitutes for courts. Economists aggregate by place and quality, referring, for example, to the “world” coffee market. Yet it does not follow that the transportation costs, cleaning costs, transaction costs, and other frictions are irrelevant to the nature of organized exchanges. Economists usually conduct their analysis imagining a world of certainty, and if they invoke uncertainty, they do so by training with reference to risk aversion and insurance. Yet it does not follow that a model in between, one with uncertainty but no risk aversion, in the presence of frictions, does not make the natural comparison. Economists’ conventional techniques more often than not undercut their analysis of organized futures and options exchanges.

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STORAGE AND PRICE STABILIZATION

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Abstract

Commodity storage models, developed first within agricultural economics in the tradition of Gustafson (1958), are valuable in helping us understand how prices of storable commodity markets behave, and how they respond to policy interventions. They show that the policy-relevant dynamic effects of storage-increasing policies are quite different from comparative statics, and generally less favorable to consumers. They help us understand the implications of price controls, price supports, buffer stocks, speculative attack, and “convenience yield,” and have great potential for assessing various econometric methodologies used for studying market efficiency and bias, and supply response. However, more attention should be paid to appropriate commodity market interventions in times of rapid productivity change, and in extremely depressed markets such as those of the 1930s, that influenced the course of agricultural policy in the United States over the next half-century.

Keywords

storage, buffer stock, dynamics, price stabilization

JEL classification: Q11

1. Introduction

In subsistence economies, food has a dominant share of individual consumption, and fluctuations in agricultural output are a direct threat to the health and indeed life of consumers. The success of major ancient civilizations was in many cases dependent upon effective means of ensuring stable food consumption, including irrigation systems, transportation networks, spatially diversified familial linkages, community-based consumption sharing and the selection of crop varieties with reliable yields to reduce production fluctuations or diversify their effects. For many civilizations, food storage policy has also been important for smoothing of subsistence consumption, as the biblical story of Joseph illustrates for ancient Egypt. Another example is ancient China, where the “ever-normal granary”, instituted in the Han Dynasty in 54 B.C., was an important element of public policy [Liu and Fei (1979)]. Private storage has been more generally fundamental to subsistence, both for intra-year and inter-year smoothing. This is still true in some areas of the world. A recent survey of farmers in the Shaanxi Province of China showed that they store an average of over two years’ supply of carryover grain (nearly a third of their assets) in their homes to buffer consumption [Park (1996)].

When market infrastructure is poor and farmers’ production roughly equals their household consumption, price fluctuations are not as important to them as yield variation. But as economies develop and food consumption increases beyond subsistence, Engel’s Law dictates that the food consumption share falls. Farmers become specialized market-oriented producers, or switch to other activities. As the income elasticity declines, food demand tends to become more price inelastic. Price fluctuations typically tend to be relatively severe due to inelastic demand and (short-run) supply, and substantial production risk. The direct link of yield to welfare is broken. Farmers and consumers become two distinct groups, with divergent interests in price fluctuations. Farmers recognize that inelastic demand can imply that high-yield years are not favorable to them if price is allowed to clear the market.

The collapse of commodity demand in the 1920s, the persistence of high production in the Great Depression of the 1930s, and the World War II experience with controls led to proposals for the acquisition of stocks by the government (as in the U.S.’s New Deal) or by producer cartels to “stabilize” prices, as well as to proposals for supply controls and marketing quotas. Distrust of market rationality, especially in the short run, was widespread, and stabilizing interventions were supported by economists across the philosophical spectrum including Prebisch (1950), Singer (1950), Keynes (1938, 1942), Kahn [see Palma (1994)]. Fisher (1920), and Hayek (1943) advocated a commodity reserve currency that would lead to a stable price for a basket of storable commodities.

The strategy of public buffer stock proposals was that stocks would be purchased at low prices and released later when prices rose. Evaluation of such proposals was difficult because policy had leapt ahead of analytical capacity. The positive price effects of the initial acquisition, the immediate focus of the proposals, could be confidently

predicted. But the net effect of the overall program, including later release, was a task beyond the economic and computational state of the art prior to the 1950s.

The commodity demand boost associated with the onset of the Second World War made earlier buffer stock acquisitions highly beneficial *ex post* and made the benefits of such public interventions seem self-evident. Though Keynes' advocacy of International Commodity Control [Keynes (1942)] was unsuccessful, storage-based programs remained a standard feature of commodity price policies in United States agriculture and were later adopted in the European Community, and in numerous international initiatives for intervention in commodity markets, including the proposals by the United Nations Conference on Trade and Development (UNCTAD) for a New International Economic Order (NIEO) [UNCTAD (1974)]. Public storage initiatives were typically characterized as price "stabilization" schemes, although it was often questionable whether price stability dominated price level as the main objective.¹

Since the 1950s economists have developed a greater respect for the rationality of private market participants relative to that of government bureaucrats. The modern theory of finance emphasizes the capacity of private markets to handle risks without government help.

Study of the significance for producers and consumers of disturbances, made manifest as price instability, originated within agricultural economics. But advances in modern financial economics (largely achieved outside of agricultural economics and now only slowly permeating the field) and agency theory (of which studies of sharecropping were important progenitors) have engendered an increasingly sophisticated view of the effects of agricultural price fluctuations on producers and consumers. Developments in theory and methodology, including important innovations originating within agricultural economics, have made it possible to analyze markets for storable commodities and the implications of market interventions.

This chapter does not attempt a comprehensive survey of the voluminous literature in this area. In Section 2 the focus is on the economics of markets with variable prices. Attention then turns to alternate means of stabilization, beginning in Section 3 with ideal stabilization defined as (mean-preserving) elimination of market disturbances, then introducing the importance of capitalization in assessing the effects of such stabilization in Section 4. After a brief discussion of the role of general inter-market arbitrage in Section 5, commodity storage is introduced in Section 6, which presents a formal model and outlines the numerical approach to its solution. The nature of competitive storage behavior and its implication for market dynamics are discussed in Section 7, followed by an analysis of simple market interventions in Section 8. In Section 9, the implications of market power for storage are discussed, and in Section 10 we consider the nature of (constrained) optimal public interventions. Section 11 covers extensions of the model to a spatial-temporal context and the implications for understanding the confusing literature on "convenience yield" and "backwardation". A brief review of recent tests of the

¹ See Gilbert (1996) for a postmortem on many international agreements.

model follow in Section 12, and some promising work extending the model is discussed in Section 13. Conclusions bring up the rear.

2. The welfare effects of price variability

2.1. Analysis of price stabilization

Interventions in commodity markets are typically characterized as price “stabilization” programs. Price stabilization intuitively appears to be beneficial to market participants. Yet the first formal analysis of the welfare difference between fixed and variable price by Waugh (1944) implied that price stabilization would make consumers worse off. Waugh was motivated by the problem of the effects on consumers of stochastic interruption of food shipments to wartime Britain due to enemy action. But his analysis focused on a simpler issue: Is a consumer better off consuming a commodity at a price that varies between a high price (P_{high}) and a low price (P_{low}), or consuming at the mean of these two prices, $\bar{P}$?

Using a linear demand curve with finite negative slope, Waugh showed that the Marshallian consumer surplus gained when price was (P_{low}) rather than $\bar{P}$ was greater than the consumer surplus lost when price was (P_{high}) rather than $\bar{P}$. The consumer can take advantage of the low price of a good by purchasing more of it and can reduce the effects of the high price by reducing consumption of it and purchasing more of some other goods. For mean-preserving spreads in price, Waugh’s result reflects the concavity of the expenditure function in commodity price and is quite robust under risk neutrality for consumer demand with a finite negative slope. It does not depend on the linearity of demand, the accuracy of Marshallian consumer surplus, or the presence of risk as distinct from foreseeable variation. (Waugh’s result can, however, be reversed in a model with random price fluctuations, if the consumer is sufficiently averse to risk.) To confirm these assertions, consider the case of an individual who has intertemporally additively separable utility, and a fixed endowment each period.

Figure 1 shows a nonlinear demand curve of an individual. If price is fixed at $\bar{P}$, and consumption is $q(\bar{P})$, the Marshallian surplus is the area under the demand curve above $\bar{P}$. If price is $P_{\text{low}} = \bar{P} - \delta$, $\delta > 0$, then consumer surplus increases by the vertically striped area. If price is instead $P_{\text{high}} = \bar{P} + \delta$, consumer surplus decreases from its value at $\bar{P}$, by the horizontally striped area. Assuming the demand curve has finite negative slope, the average of the surpluses at P_{high} and P_{low} exceeds the surplus at $\bar{P}$.

Obviously, if P_{high} and P_{low} have equal probability of 0.5, then expected surplus is higher than surplus at $\bar{P}$. If price fluctuates between P_{high} in even periods and P_{low} in odd periods, the average (undiscounted) surplus is higher under variable prices. Since the Hicksian demand through $\bar{P}$ also is negatively sloped, a similar diagram would show that the average *ex post* equivalent variation of price stabilization is negative in general.

A similar exercise with the (restricted) profit function shows that the competitive producer also gains from price variability when the marginal utility of income is constant. Convexity of the profit function (upward-sloping supply) means that average profit under price variability exceeds profit at the mean price, a result first noted by Walter Oi (1961). These results generalize to the effects on expected surplus of random price fluctuations with expected price $\bar{P}$. As long as marginal utility of income does not fall too fast as surplus increases, consumers or producers gain from such randomness of exogenous prices.

These results rightly imply that price stabilization is not necessarily beneficial for a consumer or a producer. Waugh was prompted by his own analysis to go further and ask whether a policy of price destabilization might be desirable for the economy as a whole. This is an entirely different question. In a long-delayed response to Waugh (the original was lost in the war-time mail), Samuelson (1971) pointed out that price instability is not fundamental; it must be generated by shifts in demand and/or supply. If there are no fundamental disturbances shifting demand and supply, generating instability by a public program of market intervention does not improve aggregate welfare, estimated by Marshallian measures of gains and losses that are all equally weighted.

The analysis of market stabilization since Waugh has progressed to the extent that it has moved beyond the limitations of the pioneering literature, as discussed below. To the extent that the exposition succeeds in keeping things simple, it should make the important points seem obvious. Experience has shown that they are not necessarily obvious otherwise, even for the very best theorists in the profession who have ventured into this area [see for example Mirrlees (1988)].

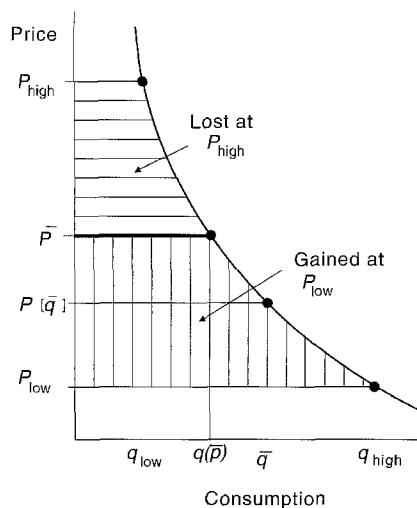


Figure 1. Consumer surplus with variable prices and quantities.

2.2. Focus shift: from prices to real variables

Studies that focus on price stabilization as the policy lever, starting with Waugh and Oi, ignore the means of achieving this objective, and indeed its feasibility. Some authors, especially in the field of international price stabilization, have noted the fact that stabilization at the arithmetic mean of price depends in general on the choice of numéraire. Indeed, Flemming et al. (1977) advocate stabilization at the geometric mean of price, based on the analytical attractiveness of numéraire-independence.

Massell (1969) moved closer to reality by considering a model in which the disturbances were explicitly related to shifts in demand or supply. Figure 2 shows one type of linear case he considered. If the supply curve alternates between curves S_1 and S_2 , and the demand curve is D_0 , then stabilization of price at P_0 when supply is S_2 means that producer surplus increases by area $KDCE$ and consumer surplus falls by area $KBCE$. When supply is S_1 , stabilization reduces producer surplus by area $JAHK$, but increases consumer surplus by area $JABK$. On average, the producer gain exceeds the consumer loss by area BDC .

Note that the above program is not unambiguously stabilizing. It destabilizes producer surplus and quantity produced, though it stabilizes consumer surplus. True stabilization could be achieved were a means to be found to costlessly stabilize the supply at the dashed curve S_0 . Would this be beneficial as measured by net social surplus? The answer is no; on average, all parties lose. Social surplus, represented by triangle MBF

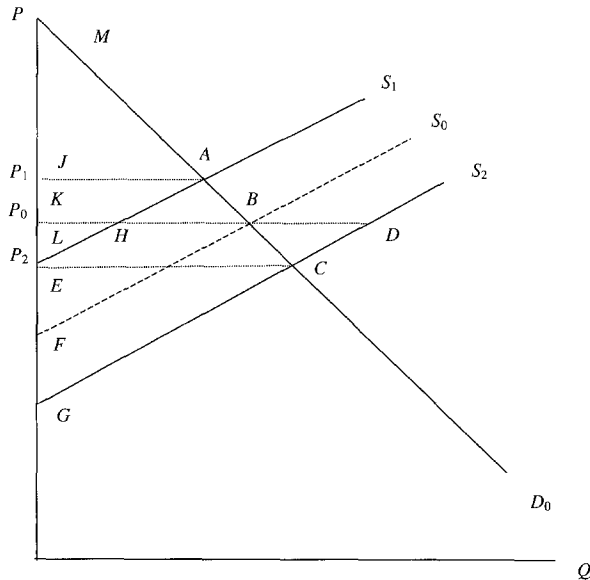


Figure 2. The effects of price stabilization when supply is variable.

under stabilization, is less than the average of triangles *MAL* and *MCG*, the values under high and low supply. Moreover, it is easy to check that both consumers and producers lose relative to the average under supply instability.

As a counterpart to Samuelson's warning against generating instability, this result shows that removing natural instability is not necessarily desirable. It is better to follow Massell's result and reallocate some supplies from the market in a state of surplus to the market in a state of shortage, if that can be achieved at a low enough cost. Similar lessons can be learned from symmetric demand shifts with fixed supply.

The Waugh-Oi-Massell analyses are a useful introduction, but their simplicity is deceptive and dangerous for policymakers. In fact, the model is not capable of addressing issues of risk, expectations, the need for policy intervention and the nature of that intervention. Even a shift from linear to nonlinear demand can reverse Massell's results.

2.3. Nonlinearity of demand

The assumption that demand and supply are linear is crucial for Massell's results. First, results above on efficiency can change if the supply function in some states intercepts the quantity axis (and is thus nonlinear). Second, linearity means no distinction between mean quantity and the quantity at mean price. Turning back to Figure 1, it is obvious that mean price is not the price at mean quantity $\bar{q}$, given a nonlinear demand curve. As noted by Howell (1945), fixing quantity at its mean would raise mean consumer surplus in this example, whereas stabilization at mean price reduces it, in line with Waugh's general result for the linear case. We shall see below that feasible stabilization need not preserve either mean.

2.4. Lagged supply response

The model assumes that the equilibrium instantly adjusts to market disturbances. There is no need for agents to form price expectations to achieve efficient resource allocation. Risk aversion does not affect efficiency at all, since the results of all decisions are certain at the time they are made. Thus the need to commit resources long before outcomes are known, a major feature of the decision processes in commodity markets, is ignored.

Recognition of a lag between commitment and realization is an essential modification that raises a number of crucial issues. First, risk aversion may affect the producer's welfare and allocative efficiency when production is lagged, as shown by Sandmo (1971). Second (and less recognized in this literature), the producer cannot be modeled as having a utility function defined on current income alone. Since she is investing, she must be involved in intertemporal arbitrage that should be considered as a means of smoothing consumption when income is variable.

2.5. The formation of price expectations

The need to pre-commit resources when production responds with a lag makes the formation of price expectations a relevant issue. Analysis of inefficient adaptive models

of private behavior could lead to the conclusion that government interventions can be efficient essentially because they introduce the benefits of superior price forecasting. This notion was a prominent feature of the influential policy prescription of Prebisch (1950) and Singer (1950) that governments intervene to guide developing economies away from primary production via trade policy, and of the thoughts of Keynes (1942) on the benefits of commodity market intervention in the short run.

Nowadays the rational expectations hypothesis of Muth (1961) is considered the pioneering work in modeling endogenous expectations. What is remarkable is that the fundamental idea of internally consistent expectations was formulated and applied earlier, in the agricultural economics literature. This was achieved by Gustafson (1958), who modeled storage as a market-stabilizing device in his brilliant, obscurely published and unheralded USDA bulletin, completed three years prior to publication of Muth's hypothesis, and without Muth's simplifying assumption that stocks can be negative. Expectations were relevant for Gustafson [as for Williams (1936), Working and Keynes many years earlier] because he was explicitly considering intertemporal arbitrage. In the absence of serial correlation, storage is necessary to induce variation in price expectations and thus make them meaningful sources of intertemporal variation in production.

2.6. Welfare criteria

The use of Marshallian surplus measures was more analytically suspect at the time the pioneering literature was written than it is today. For consumption stabilization at the arithmetic mean $\bar{q}$, expected equivalent variation under the expected utility hypothesis is, up to a second order approximation,

$$\frac{1}{2} \bar{q}_i \frac{P_i(\bar{q}; e)}{\eta_{ii}} \left[\frac{\gamma_i}{\eta_{ii}} (\eta_{ie} - \rho) + C_i - 1 \right] \Delta \sigma_q^2, \quad (1)$$

where $P_i(\bar{q}, e)$ is the inverse demand evaluated at mean quantity,

$$C_i \equiv -q_i \frac{\partial^2 P_i(\bar{q}_i, e)}{\partial P_i(\bar{q}_i, e)^2},$$

a coefficient of relative curvature of demand, and $A\sigma_{q_i}^2$ is the reduction in the square of the coefficient of variation of consumption σ_{q_i} , the standard deviation normalized by the mean [see Wright and Williams (1988a)]. η_{ii} is the price elasticity of Marshallian demand (measured at mean quantity), η_{ie} is the income elasticity, and ρ is the Pratt-Arrow coefficient of relative risk aversion. Assuming the budget share γ_i is sufficiently small, the value of C determines the sign of the expected consumer gain. For linear demand, ($C = 0$), the consumer loses from quantity stabilization, consistent with the result of Waugh for price stabilization for general demand curves. For linear demand, expected price $\bar{P} = P(\bar{q}, e)$ and $\Delta \sigma_{q_i}^2 = \eta_{ii}^2 (\bar{q}_i / P_i)^2 \Delta \sigma_{P_i}^2$. Substituting these expressions in Equation (1), that equation becomes identical to that of Turnovsky et al.

(1980) for arithmetic mean-preserving price stability. But for constant elasticity demand, $C = (1 - 1/\eta_{ii})^{-1}$, if demand is inelastic, ($0 > \eta_{ii} > -1$), the consumer gains from consumption stabilization.

Commenting on the latter result, as derived in an example in Newbery and Stiglitz (1981), Kanbur's review article states: "The demonstration that stabilization schemes which take up existing supplies will lead to a transfer of income from producers to consumers is a striking result ..." (1984, p. 342), which he notes was anticipated in work by Harry Johnson (1976) and Michael Lipton (1970). The sensitivity of the result to demand specification has been long in the learning. The further result that the true dynamic incidence when there are "existing supplies" is much more likely to favor landowners, as well as the holders of those supplies, as noted below, is likewise taking time to permeate the literature.

In the approximation (1), the term $\gamma_i(\eta_{ie} - \rho)$ incorporates the effect of the change in the individual's marginal utility of income. For developed economies, the budget share of any given commodity is typically so low that this effect is negligible. For example, in the United States, all food has a share of expenditure of only around 10 percent (and much less at the farm gate), and the share of any one commodity is much smaller. Even in developing countries, most consumers do not consume any one commodity that has a budget share as high as 10 percent, and those that do tend to be commodity producers as well. General equilibrium considerations and the correlation of prices of different commodities then tend to be more important for accuracy than the issue of demand compensation [Wright and Williams (1988a, pp. 622–624)].

Other criteria have occasionally been chosen for evaluating market stabilization. For example, price or income stability *per se* has been advocated or adopted in many studies including Arzac and Wilkinson (1979), Cochrane (1980), Dixon and Chen (1982), and Ghosh et al. (1987). The value of price stabilizing intervention to prevent macroeconomic disruptions, a serious issue addressed in Kanbur (1984) and Timmer (1989), has proved to be difficult to analyze with any rigor in the absence of a complete and satisfactory macroeconomic model. The most severe problem seems to arise after prior interventions have left domestic food prices (and often wages) far out of line with competitive market-clearing prices. Many a less developed country (Indonesia in 1998 is a recent example) has seen riots provoked by abrupt food price increases caused by increases, mandated by the International Monetary Fund, in "stabilized" food prices.

Similarly, an exchange rate that is "fixed" to avoid macroeconomic disruption can cause severe disruption when a devaluation can no longer be avoided. In both cases, a full analysis of the policy must include the effects of its inevitable adjustment or abandonment. These will depend upon the means of stabilization. Indeed analysis of some notion of price stabilization divorced from a model including both the source of instability and the means of stabilization has no necessary relevance to any policy issue regarding stabilization policy, as the next section shows.

3. Ideal production stabilization

Market instability might arise from many sources, but it must eventually stem from fluctuations in consumer preferences or endowments or in some aspect of supply including distribution. Fluctuations in preferences are obviously important in some products like clothing, beverages and entertainment. Whether induced by advertising or reflecting stochastic underlying tastes, such instability raises challenges for welfare analysis not yet addressed in the market stabilization literature. Fluctuations in consumer endowments are not important for commodities with typically low income elasticities (that is, the vast majority of primary commodities in wealthy countries). Here we focus on production instability.

The effects of shifting instantaneous supply were considered above in a Massell-type model. In that context, instability was beneficial to both consumers and producers. Now we reconsider this issue using a modification of that pioneering model that makes risk and expectations relevant.

The demand and supply equations are

$$\begin{aligned} q(P_t) &= A - aP_t + u_t, \\ h(P_t^r) &= (B + bP_t^r)(1 + v_t). \end{aligned} \tag{2}$$

Consumer demand $q(P_t)$ is linear and, for simplicity, independent of income. Production, the “harvest” $h(P_t^r)$, is linear in the incentive variable P_t^r , which is effective at the time of “planting”, period $t - 1$, before the realizations of the independent and identically disturbed (i.i.d.) disturbances u_t and v_t are known. The disturbance v_t is multiplicative rather than additive; as a first approximation it seems reasonable to assume that acreage with higher mean harvest suffers proportionally higher harvest disturbances. This specification has the added bonus of straightforward decentralization: every producer can share the same proportion of the aggregate disturbance on average and at the margin. (How shares in the alternative additive aggregate disturbance should be distributed at the margin, a question crucial for incentives, is not obvious.)

Ideal stabilization is defined as fixing of v_t at 0, by some means not explicitly modeled. Random sources of disturbance such as weather are perhaps stabilized (for example, by irrigation), or the effects are removed by choosing a technology (such as crop varieties resistant to droughts and floods) insensitive to the disturbances. Storage is assumed away, so market clearing implies

$$q(P_t) = h(P_t^r) \quad \text{for all } t.$$

In period t , the representative competitive producer i has output h_t and revenue $r_t^i = P_t h_t^i$. Substitution for P_t from the demand equation (2) yields

$$r_t^i = \frac{1}{a} [A - (B + bP_t^r)(1 + v_t) + u_t] [\bar{h}^i (1 + v_t)],$$

where $\bar{h}_t^i = E_{t-1}(h_t^i)$, planned production of producer i . In period $t - 1$, when production commitments are made for period t , expected revenue is

$$E_{t-1}(\pi_t^i) = \frac{1}{a} [A - (B + bP_t^r)(1 + \sigma_v^2)] \bar{h}_t^i.$$

Notice that the competitive producer recognizes the correlation of his own output with aggregate output and hence with price. The marginal incentive for the risk-neutral producer [what Newbery (1990, p. 1045) calls the “action certainty equivalent price, the price which yields the same choice of inputs in the absence of risk as that chosen under risk”] is defined as

$$\begin{aligned} P_t^r &= \frac{\partial E_{t-1}(\pi_t^i)}{\partial \bar{h}_t^i} \\ &= \frac{1}{a} [A - (B + bP_t^r)(1 + \sigma_v^2)] \\ &= \frac{A - B(1 + \sigma_v^2)}{a + b(1 + \sigma_v^2)}. \end{aligned}$$

This is true for all t ; planned output is constant in this model. Note that P_t^r differs from expected price:

$$\begin{aligned} E_{t-1}(P_t) &= \frac{1}{a} [A - B - bP_t^r] \\ &= \frac{1}{a} \left[A - \frac{aB - bA}{a + b(1 + \sigma_v^2)} \right]. \end{aligned}$$

Ideal stabilization fixes σ_v^2 at zero. Then the producer incentive is the expected price

$$P^S = \frac{A - B}{a + b}.$$

This is also the producer incentive and expected price when the output disturbance is additive.

For this linear model, if $\sigma_v^2 > 0$,

$$P^r < P^S < E_{t-1}(P_t).$$

So ideal stabilization reduces expected price but increases the producer incentive in this model. With responsive supply ($b > 0$), expected output increases. Both producers and consumers gain if (one-period lagged) supply is more elastic than demand, in contrast to the linear Massell model [Wright (1979, p. 1026)]. (In contrast to the Massell case illustrated in Figure 2, the instantaneous inverse supply function is nonlinear; horizontal

starting at zero, turning vertical at actual production.) The total social welfare change tends to be less negative than in the additive-disturbance case.

When demand is nonlinear in this model, the distributional results can be reversed. Using second-order approximations, one can show they depend on the ratio of the demand to the supply elasticity and on the demand curvature parameter C , which is important for the effect of quantity stabilization as noted above. This model can be generalized to the case of multiple producing regions with different i.i.d. disturbances feeding a single consumer market. Stabilization of production in one region can be interpreted as stabilization of excess demand in the others. If those other regions have stable output, they generally lose from ideal stabilization of a competing supply region [Wright (1979, p. 1029)].

Since the curvature of consumption demand is very difficult to measure empirically, the distributional effects of ideal stabilization are difficult to establish. Indeed the main general lesson from this model is that the distributional results are sensitive to the specification, even when risk aversion and problems of consumer heterogeneity are ignored. Signs may be reversed by a change from additive to multiplicative shocks, by a change in relative demand curvature, in the timing and extent of supply response, or in the source of the disturbance. The sign of the change in mean consumption and the extent of efficiency effects also depend on the interaction of supply responsiveness, demand curvature, and the nature of the disturbances.

At this point, it is useful to become a little more precise about the incidence of “producer gains” in the context of commodity production. In admitting lagged supply response, the reality of intertemporal allocation of productive resources by producers has already been recognized. And upward-sloped (lagged) supply implies the existence of factor rents. It is crucial to recognize that the expected stream of rents is then capitalized into the price of fixed and quasi-fixed factors if they have competitive markets.

4. Capitalization

The literature on market stabilization from its beginnings through the classic work of Gardner (1979) and Newbery and Stiglitz (1981) assesses the effects of stabilizing interventions using comparative statics. If the change under consideration is fully realized from one period to the next, as in the model of ideal stabilization discussed above, comparative statics, in the form of comparison of an equilibrium with and without ideal stabilization, accurately indicates the changes in prices and quantities in the first period in which production is stabilized. But the comparative statics effects on surpluses do not indicate how gains and losses are distributed.

If in period $t - 1$ it becomes known that ideal stabilization (deterministic production) will be permanently in effect from period t , there will be an immediate response in the prices of fixed factors like land and quasi-fixed factors such as machines and human capital. Figure 3 shows a case in which land is the only fixed factor, its market is competitive, and the interest rate is constant at r . If ideal stabilization is announced at

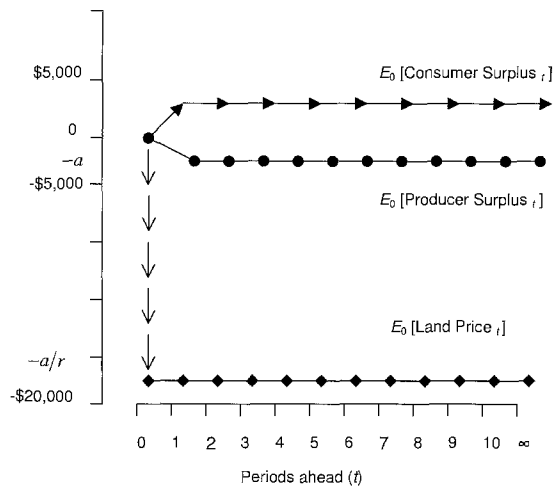


Figure 3. The welfare effects of ideal stabilization if announced the period before the stabilization operates.

period 0 and takes effect in period 1, the expected streams of consumer and producer surplus take permanent jumps to their new steady state levels in period 1.² Assuming demand is sufficiently convex, the jumps for consumer surplus and producer surplus are positive and negative as illustrated. But the figure does not imply that producers beyond period 1 are expected to be worse off. The incidence of the drop in the path of producer surplus occurs entirely in period 0, when the land price, the discounted present value of the expected path of land rents starting in period 1, falls by $1/r$ times the change in producer surplus to be realized first only in the next year. Producers who buy land after period 0 neither gain nor lose from ideal stabilization regardless of the effects on producer surplus. (Consumers might also find that at least some of the change in the flow of consumer surplus ends up as a jump in the costs of complementary durable consumption goods such as housing.)

The main lessons of this elementary illustration are simple but crucial: the incidence of agricultural policy change is dynamic and quite distinct, in general, from changes in current or steady-state surplus flows. But these insights are virtually ignored in current discussions of subsidized crop insurance and other means of assisting farmers via risk reduction. To assess the welfare implications of the rich dynamics in prices, quantities,

² If savings and the interest rate are endogenous, the path of land price and the interest rate will in general jump to new dynamic paths which, if stable and unique, converge on a new, steady-state level. In an overlapping generations model, Chamley and Wright (1987) show that only the initial jump is directly relevant for incidence on the initial landholders (the older generation). The incidence may be greater or less than in the Ricardian case considered here. In a modern open economy, induced effects of domestic agricultural policy on the cost of capital are unlikely to be very significant.

and surplus flows associated with changes in market stability, it is useful to become comfortable with the dynamics of capitalization introduced into the market stabilization literature by Wright and Williams (1984a) and explored in a policy context by Miranda and Helmberger (1988) and Wright and Williams (1988b).

5. Handling instability: from ideal stabilization to arbitrage

Most of the literature in this area that has moved beyond addressing disembodied “price stabilization” takes the source of instability, such as a stochastic shift in supply or demand, as given. It addresses activities that reduce the induced variation in some variable (for example, price) by increasing the variation in others. The simplest approach, chosen by Massell and others, and used extensively in several important papers by Newbery and Stiglitz incorporated in their classic book [Newbery and Stiglitz (1981, Chapters 17, 18, 21)], is to view stabilization as an arbitrage that moves supplies from a market in a low-price state to another in a high-price state. Newbery and Stiglitz identify the welfare effects on market participants, including the arbitrageur, of a small amount of “stabilizing” arbitrage. They distinguish these effects from those of a small amount of destabilization of a price stabilized by arbitrage. Though the transfer mechanism is sometimes described as “storage” or a “buffer stock”, such features fundamental to intertemporal exchange as the unidirectionality of time, discounting, and non-negativity of stocks, are generally ignored.

Indeed the obvious empirical analog of such a mechanism is not storage but trade in the stylized form of costless contemporaneous spatial arbitrage between markets, addressed in Samuelson (1957). As for ideal stabilization, the welfare effects are heavily parameter-dependent.

Newbery and Stiglitz (1981, Chapter 23; 1984) explicitly embrace the spatial interpretation of stabilization in their discussion of the possibility that trade can be Pareto-inferior. If individual price variability exactly offsets the destabilizing influence of output fluctuations on revenue, price fluctuations are a part of natural revenue insurance. Stabilization of price via trade is a Pareto-inferior policy if producers are risk-averse, given that the fundamental disturbances remain, and revenue insurance is unavailable.

For consumers, the stabilizing role of spatial arbitrage in the form of internal and international trade and assistance has been crucial over the past several centuries. Reductions in transport costs and trade barriers have greatly reduced the harm done by regional supply shortfalls. Worldwide supply variation cannot be removed by trade, but it can be mitigated by intertemporal arbitrage in the form of storage (in association with supply response), to which we now turn.

6. The nature of commodity storage

A broad definition of storage could encompass any activity that transforms a commodity available at a given point in time into a similar commodity available later. Exam-

ples abound in nature.³ Human storage activities include money management, inventory management at the firm level, water storage in reservoirs and cisterns, conservation of gases such as methane (natural gas) or helium below or above ground, management of forests, fisheries and mineral deposits, and preservation of information using various media. A common feature of all storage activity is that stocks are constrained to be non-negative. If current stocks are zero, it is impossible at the margin to “borrow from the future”.

Though conservation of inputs such as soil, water, and genetic resources is important in agriculture, the focus of this chapter is on storage of non-perishable agricultural commodities such as the major grains, responsible for most of the world’s food supply. An important stylized feature of these commodities (and of most minerals) is that the marginal cost of storage per period, including physical protection, insurance, and spoilage, increases only slowly if at all with the size of the total stock and may approach a finite upper bound; the assumption of constant unit costs is supported by Paul (1970).

In contrast, water storage in a reservoir may have highly nonlinear marginal cost, approximating zero up to full capacity, then increasing without bound. The implications for intraseasonal smoothing of price when water is a nonstochastic input have been elucidated by Pyatt (1978), in an excellent introduction to the economics of storage.

The fact that their supply is usually seasonal distinguishes major storable agricultural commodities and water from minerals. In modeling, choice of seasonal or higher frequency for time intervals is appropriate when the arrival of significant information within the harvest year engenders a dynamic intra-period response. Such information may be, for example, related to the evolution of the prospects for the next harvest or other relevant matters such as the harvest of competing crops grown in the other hemisphere. But important features of carryover storage associated with the non-negativity constraint can be studied at an annual frequency. Accordingly, agricultural commodity storage is often studied in models with annual time intervals.

Formal models of market-stabilizing storage also have focused on market aggregates. Transaction costs associated with adding or removing stocks are assumed negligible. These two features distinguish formal commodity storage models from the (S, s) model of firm inventory management [Scarf (1959)] in which ordering costs are dominant, and natural resource problems in which extraction costs are prominently featured. The literature on inventory management, which combines a firm-oriented perspective with a macroeconomic focus, is surveyed elsewhere [see for example Blinder and Maccini (1991)] and will not be discussed further here.

The arbitrage possible via storage is more restricted than that attainable via costless spatial arbitrage. The transfers are unidirectional; negative storage is not feasible. Furthermore even if storage itself is costless, discounting makes the transfer costly, and also makes the sequential ordering of welfare effects crucial to incidence. Finally, there is no obvious endpoint to the chain of potential intertemporal transfers.

³ The economics of foraging and food storage by animals is addressed by Salant et al. (1995).

The value of storage today depends on its expected value tomorrow, and so on to infinity. It seems one needs to know the answer for tomorrow before solving for the problem today. The first satisfactory solution to this conundrum did not appear until the 1950s in the pioneering work of Gustafson (1958). Important subsequent analytical models included Samuelson (1971), who addressed the optimality of competitive storage and showed that prices follow a nonlinear first-order Markov process, Scheinkman and Schechtman (1983), and Deaton and Laroque (1992).

6.1. A simple competitive model of storage

To facilitate further discussion, consider a competitive partial equilibrium model for a single storable consumption commodity. In general, we follow the notation of Scheinkman and Schechtman (1983). In recognition of a single exogenously determined annual harvest season, time is discrete. All agents have rational expectations. Production is subject to a market-wide exogenous multiplicative disturbance $\omega_t \in K \equiv [\underline{\omega}, \bar{\omega}]$, $0 = \underline{\omega} < \bar{\omega}$, such as a common realization of weather in period t . Let the history of disturbance from period 0 be $\omega^t = (\omega_0, \dots, \omega_t)$. Then $\omega_t \in K^{t+1} \subset R_+^{t+1}$, where K^{t+1} is the Cartesian product of $t + 1$ replicates of K , one for each period in the history of observed realizations, ω^t . A one-period lag exists between the representative competitive producer's choice of effort for "planting", $\lambda_t \in [0, \bar{\lambda}]$ and output, the "harvest" $h^t = \lambda_t \omega_{t+1}$. The cost of effort is $g: [0, \bar{\lambda}] \rightarrow \bar{R}_+$, with marginal cost $g': [0, \bar{\lambda}] \rightarrow \bar{R}_+$, where $\bar{R}_+$ is the extended positive real half-line, with

$$g(0) = 0, \quad g'(\bar{\lambda}) = \infty, \quad \text{and} \quad g''(\lambda) > 0 \quad \text{for all } \lambda \geq 0.$$

The harvest can be consumed and/or stored until the next period. The amount stored is $x \geq 0$. The storage cost is given by a differentiable function $\phi: R_+ \rightarrow R_+$, with $\phi(0) = 0$, $\phi''(x) > 0$, and $0 \leq \phi'(x) < k$ for $x \geq 0$, $k \in R$. At time t price $p_t: K^{t+1} \rightarrow \bar{R}_+$ is defined as a (Borel) measurable function of the history ω^t . The representative competitive producer is risk-neutral and takes the price sequence, the sequence of measurable functions $\Pi = \{p_t\}_{t=0}^\infty$, as given. To simplify notation, the number of competitive producers is normalized at unity.

Given ω^t , the producer chooses storage x_t , effort λ_t and sales c_t , all functions of ω^t . Available supply at period t is z_t , where

$$z_t(\omega^t) = x_{t-1}(\omega^{t-1}) + \lambda_{t-1}(\omega^{t-1})\omega_t.$$

Consumption at time t equals sales by the representative producer at t . The consumer's demand is

$$f: R_+ \rightarrow \bar{R}_{++} \text{ with } f'(c) \equiv \frac{df}{dc} < 0, \quad \text{and} \quad c \cdot f(c) < m < \infty, \quad \text{for all } c \geq 0.$$

Thus, following Scheinkman and Schechtman (1983), the model assumes an upper bound on the expenditure on consumption, but not on price as in for example Deaton and Laroque (1992).

Assume no market distortions, and that the representative consumer has infinite life-time and is risk neutral with no income elasticity of demand for the stored good, and constant exogenous finite endowment $m_t = m$. U is a concave "surplus" function defined by

$$U(c) = \int_{\underline{c}}^c f(u) du,$$

where the arbitrary constant $\underline{c} > 0$ ensures that U is finite.

There is a constant interest rate $r > 0$, and discount factor $\delta \equiv 1/(1+r)$. Given z_0 and Π , and denoting $x = \{x_t\}_{t=0}^\infty$, and $\lambda = \{\lambda_t\}_{t=0}^\infty$, the producer chooses (x, λ) to solve the problem

$$\sup E_0 \left\{ \sum_{t=0}^T \delta^t \left[p_t(\omega^t) c_t(\omega^t) - g(\lambda_t(\omega^t)) - \phi(x_t(\omega^t)) \right] \right\},$$

subject to

$$\begin{aligned} c_t(\omega^t) + x_t(\omega^t) &= \lambda_{t-1}(\omega^{t-1})\omega_t + x_{t-1}(\omega^{t-1}), \quad t \geq 1, \\ c_0(\omega^0) + x_0(\omega^0) &= z_0, \\ c_t(\omega^t) &\geq 0, \quad x_t(\omega^t) \geq 0, \quad \lambda_t(\omega^t) \geq 0, \quad t \geq 0. \end{aligned}$$

The producer's choices in period t must satisfy the set of complementary inequalities that comprise the arbitrage conditions

$$\begin{aligned} p_t(\omega^t) + \phi'(x_t(\omega^t)) &\geq \delta E_t[p_{t+1}(\omega^t)], \quad \text{with equality if } x_t(\omega^t) > 0, \\ g'(\lambda_t(\omega^t)) &\geq \delta E_t((p_{t+1}(\omega^{t+1})) \cdot \omega^{t+1}), \quad \text{with equality if } \lambda_t(\omega^t) > 0, \end{aligned}$$

where E_t denotes the expectation conditional on ω^t . The first of these conditions implies that the spread between next-period futures and the spot price can never exceed the cost of interest plus storage.

If there exist producer choices $(\hat{x}, \hat{\lambda})$ that solve the producer's problem such that, for each t , $f(\hat{z}_t(\omega^t) - \hat{x}_t(\omega^t)) = \hat{p}_t(\omega^t)$ almost surely, then $\hat{\Pi} = \{\hat{p}_t\}_{t=0}^\infty$ is a rational expectations equilibrium.

Scheinkman and Schechtman (1983) use Benveniste and Scheinkman (1979) to prove the envelope condition that $\hat{p}_t(\omega^t)$ is the partial derivative of the value function W with respect to z_t . The value function is optimized social welfare in this simple general

equilibrium competitive model, given initial availability z , and the history of disturbances ω^t :

$$W(z, t, \omega^t) = \sup E_t \left\{ \sum_{s=t}^{\infty} \delta^s \left[u(c_s(\omega^s)) - \phi(x_s(\omega^s)) - g(\lambda_s(\omega^s)) \right] \right\},$$

subject to

$$\begin{aligned} c_s(\omega^s) + x_s(\omega^s) &= x_{s-1}(\omega^{s-1}) + \lambda_{s-1}(\omega^{s-1}) \cdot \omega_s \equiv z_s(\omega^s), \\ z_t(\omega^t) &= z, \quad c_s(\omega^s) \geq 0, \quad x_s(\omega^s) \geq 0, \quad \lambda_s(\omega_s) \geq 0, \quad s \geq 0. \end{aligned}$$

The strict concavity of W means that price is decreasing in available supply z .⁴ If the disturbances are i.i.d. then z_t is the state variable. Below some threshold $z^* \geq 0$, storage is zero, and supply effort and expected price and consumption are all locally insensitive to z . Analytical propositions include [Scheinkman and Schechtman (1983, pp. 432–433)]

- (1) consumption increases with z ;
- (2) storage increases with z , for $z \geq z^*$;
- (3) supply of effort decreases with z , for $z \geq z^*$;
- (4) the distribution of z converges to a stationary distribution [Scheinkman and Schechtman (1983, Theorem 4, p. 436)].

All of these propositions confirmed and generalized results originally obtained in Gustafson (1958) or later numerical models [Gardner (1979), Wright and Williams (1982a)]. The marginal propensity to store is always less than unity. Furthermore, storage is a non-increasing function of price, decreasing as price increases until stocks reach zero at $p^* = p(z^*)$. It follows that expected price is decreasing in stocks for positive levels of stocks, a fact that is important for the numerical solution of the model, discussed below.

A further analytical result for a similar model without effort response [Deaton and Laroque (1992, Theorem 3, p. 8)] is that if consumer demand is convex, so is the price function $p(z)$. Beyond this, the analytical results tell us little about the nature of the relations among available supply, price, consumption, storage, and effort. But by the time these analytical results were published, the numerical solutions developed by Gustafson (1958) and further elaborated by Gardner (1979) had revealed a great deal about the relationships for the zero supply case. Behavior of the model with supply response for many specifications had been solved numerically by Wright and Williams (1982a), who also show the numerically derived invariant distributions for the endogenous variables.

⁴ In a similar model with no supply (effort) response and proportional storage cost, Deaton and Laroque (1992) prove the existence of the price function $p(z) = \max \beta E[p(h + z - f^{-1}(p(z))), f(z)]$ and its uniqueness in the class of non-negative continuous non-increasing functions.

6.2. Solving the storage model

The general storage model has till now been solved only by what is now called dynamic programming, using an approach pioneered by Gustafson (1958).⁵ The classic intuitive exposition of this method starts with the special case of a finite horizon, i.i.d. disturbances and no supply response. Imagine the world ends in period T . It is obvious if the commodity has only consumption value in period T that the optimal carryout stock is $x_T(\omega^T) = 0$. In period $T - 1$, the planner's problem is to maximize with respect to carryout storage $x_{T-1} \geq 0$:

$$V(z_{T-1}, x_{T-1}, T-1) = \int_0^{z_{T-1}-x_{T-1}} f(c) dc - \phi(x_{T-1}) \\ + \delta E_{T-1} \left[\int_0^{h_T(\omega^T)+x_{T-1}} f(c) dc \right],$$

where $h_t \equiv \lambda_{t-1}\omega_t$, $t \geq 0$.

This problem can be solved explicitly because future storage is zero. The solution satisfies

$$\frac{\partial V(z_{T-1}, x_{T-1}, T-1)}{\partial x_{T-1}} \\ = -f(z_{T-1}(\omega^{T-1}) - x_{T-1}) - \phi'(x_{T-1}) \\ + \delta E_{T-1}[f(h_T + x_{T-1})] \geq 0, \quad \text{with strict equality for } x_{T-1} > 0.$$

From this expression the optimal choice $\hat{x}_{T-1}$ can be expressed as a function of z_{T-1} . By Bellman's principle of optimality, the decision in period $T - 2$ assumes optimal choice of x in period $T - 1$ and T , $\hat{x}_{T-1}(z_{T-1})$ and 0, respectively. By backward induction,

$$V(z_{T-j}, x_{T-j}, T-j) = \int_0^{z_{T-j}-x_{T-j}} f(c) dc - \phi(x_{T-j}) \\ + \delta E_{T-j} \widehat{W}(h_{T-j+1} + x_{T-j}, T-j+1),$$

where $\widehat{W}(\cdot, \cdot)$ is the value function, the discounted expected present value of social welfare in future periods, as of period $T - j + 1$, given optimal contingent choices of

$$\hat{x}_t(z_t), \quad T-j < t \leq T.$$

⁵ The pioneering work in solving the storage model draws on earlier work on inventory models by Arrow et al. (1951) as developed by Dvoretzky et al. (1952). Gustafson (1958) solved what would later have been called a rational expectations model, essentially similar to that outlined above, with no effort response. He does not use the term "dynamic programming", and indeed shows no signs of being aware of Bellman (1957), the classic book with that title.

Thus, knowing $V(z_{T-j+1}, x_{T-j+1}, T-j+1)$, one can solve for $\hat{x}_{T-j}$. It is not necessary to “remember” any information about decisions in later periods as the induction moves back in time from T . In the limit as j approaches infinity, the functions $\widehat{W}(z_{T-j+1}, T-j+1)$ and $\hat{x}_{T-j}(z_{T-j})$ converge on the functions $W(z)$ and $x(\hat{z})$, respectively. The latter is the “storage rule” relating stocks to current available supplies. Thus, in the limit, the fact that we assumed a “final period” is made irrelevant by discounting, given a transversibility condition that ensures that discounted future producer returns cannot grow indefinitely.⁶ In the above model, this is ensured by the condition on consumer demand that limits consumer expenditures to less than m .

In practice, analytical solutions more than a few periods back from the terminal date T are unavailable, except in very special cases.⁷ Fortunately, numerical methods have been available since Gustafson (1958), and these have become cheaper and easier to implement as computers have advanced in speed and sophistication. Gardner (1979) shows how the value function can be derived using a vector of couplets consisting of discrete values of carryout storage and matching values of the value function for the next period. (Equivalently, the marginal values can be used, as Gustafson showed.) This method becomes cumbersome and memory-intensive as more state variables are added.

If rational competitive supply (or effort) response is included with a single-period lag (much as described above for ideal stabilization), no state variable is added. But the Gardner method encounters computational problems when there is continuous supply response related to non-monotonicity of values in availability.

An alternative method approximates the stationary relation between expected price and carryout stocks with an n th-order polynomial in x , $\psi(x)$. The basic idea is to choose a function $\psi_0(x)$ as a “first guess”, as shown in Figure 4. Then for each element of a predetermined vector of M , positive values of x solve the arbitrage equation for each of the N possible harvest outcomes h^i :

$$p(h^i + x^j - x^{*ij}) + \phi(x^{*ij}) - \delta\psi_0(x^{*ij}) = 0, \quad i \in [1, N], \quad j \in [1, M],$$

for x^{*ij} , the “next-period” value of x given h^i , x^j and $\psi_0(\cdot)$. If the solution $x^{*ij} \leq 0$, set $x^{*ij} = 0$. Then for each x^j , calculate the expected price $p^{*j} = \sum_{i=1}^M [p(h^i + x^j - x^{*ij})\text{prob}(h^i)]$ where $\text{prob}(h^i)$ is the probability of h^i .

Solving for the equilibrium price function as a function of the carryout is a simple problem in applied numerical projection methods. The approach adopted in Wright and Williams (1982a, 1984a) is to regress the values p^{*j} on an n th-order polynomial in x^{*ij} , where the elements of that vector increase in constant increments, to yield an update $\psi_1(x)$ of the initial estimate $\psi_0(x)$. The process is repeated till the first period,

⁶ See Gardner (1979) for a nice numerical exposition, and the Appendix in Deaton and Laroque (1992) for an existence proof using contraction mapping for their zero supply response model.

⁷ See Newbery and Stiglitz (1981, pp. 437–438) or Aiyagari et al. (1989) for analytically tractable cases, and Williams and Wright (1991, Ch. 3, Appendix) for analytic solutions to a model like that above for $T-1$ and $T-2$.

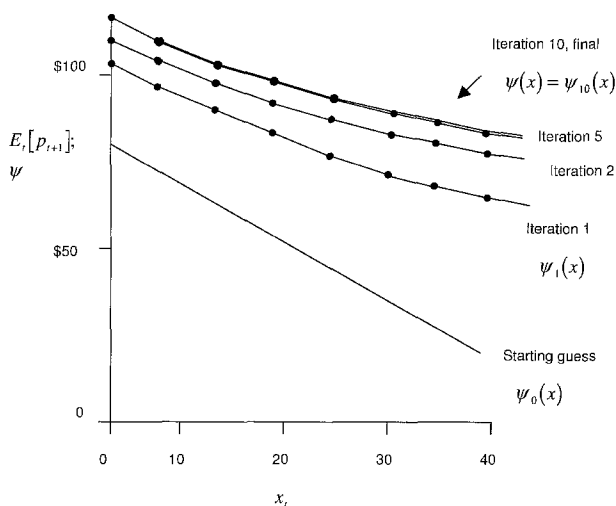


Figure 4. Iteration to find the polynomial approximation ψ .

k , in which the estimated polynomial $\psi_k(x)$ is, by a convergence criterion, sufficiently close to $\psi_{k-1}(x)$. Finally, set $\psi(x) = \psi_k(x)$.

Given the final function $\psi(\cdot)$, it is possible to solve for all the other endogenous variables, given the state z_t . For this application, the polynomial approximation illustrated performs well because the function ψ is smooth and monotonic when restricted to its support, as shown in Figure 4. (A demanding test of performance used by Wright and Williams is to check the deviation of average expected profits of storage from zero in large stochastic simulations of the equilibrium model.) More generally, numerical methods need not be applied to the problem as it is most easily conceived (determination of the kinked "storage model" in this case) if a smooth relationship exists that embodies the same information. Here that smooth relationship is the marginal value function as a function of stocks.

Results using this approach, extended to include responsive supply, were first published in Wright and Williams (1982a). The algorithm was first described in the Appendix of Wright and Williams (1984a), written contemporaneously with Wright and Williams (1982a). It is outlined in greater detail in Williams and Wright (1991, Chapter 3, Appendix). The algorithm is easily extended to several state variables [see for example the study of public and private storage in Wright and Williams (1982b), in which the private storage rule has multiple kinks in some cases], though at the cost of a substantial increase in the (otherwise modest) demand on computer time. A somewhat similar approach, termed "parameterized expectations", was introduced to the macroeconomic literature by Marcet (1990); the survey by Taylor and Uhlig (1990) indicates that the macroeconomic literature on this topic lagged behind the agricultural economics

literature in the 1980s. The recent paper by Christiano and Fisher (2000) indicates that much of the lost ground has been regained.

Although no significant problems with the accuracy of the polynomial regression method have been reported in the storage literature, when applied to an appropriate smooth relationship, the main methodological modifications to the implementation of this solution strategy over the past decade have concentrated on substitution of alternative means of approximation of the price function. Given the smoothness of the equilibrium price function (in contrast to the function, $x(z)$), a more generally numerically accurate and efficient method is to apply Chebyshev collocation, introduced into the economic literature by Judd (1992). This method uses as a basis the Chebyshev polynomials, defined over $[-1, 1]$ by $T_i(x) \equiv \cos(i \arccos x)$. Using the identity $\cos n\phi = T_n(\cos \phi)$, and the initial values, $T_0(x) = 1$, $T_1(x) = x$, one can recursively calculate [Boehm and Prautzsch (1993, p. 108)], $T_{i+1}(x) = 2xT_i(x) - T_{i-1}(x)$, $i = 1, \dots, \mu$. Adapted to the interval, $[0, x^{\max}]$, for stock values, the polynomial $\sum_{i=1}^M a_i T_i(x)$ is interpolated at the Chebyshev nodes

$$x^j = 0.5x^{\max}(1 + \cos((2j + 1/M + 1)\pi/2)), \quad j = 0, \dots, M.$$

As the number of nodes, M , increases, the above interpolant converges rapidly on the price function. [See Judd (1992, p. 421), for the appropriate theorem; its proof is in Rivlin (1990, p. 14)].

The first published application of this methodology in the commodity storage literature appears to be by Miranda and Glauber (1995), and it subsequently has been used by others [for example, Park (1996), Makki et al. (1996), McNew and Gardner (1999)]. If the price function is as smooth as typically observed for this type of problem, the gain over simple polynomial approximation should indeed be modest. If cases should arise in which curvature changes very rapidly, methods other than Chebyshev collocation may be superior. Extensive reviews of numerical methods of use for economists are found in Judd (1998) and Miranda and Fackler (1999, forthcoming 2002).

7. Storage behavior and its effects on consumption, price and production

7.1. Storage behavior in the simple model

The responsiveness of storage affects the behavior of other endogenous variables, making some less variable, others more so. An example of the infinite-horizon “storage rule” is shown in the lower panel of Figure 5.⁸ For simplicity, we assume i.i.d. production dis-

⁸ The rule is in general nonlinear beyond the kink, though this is difficult to see in the figure. The storage rule tends to exhibit a significantly increasing marginal propensity to store when there is no supply response. The qualitative results are generally robust to differences in numerical specification. In the example, consumer demand is linear with price elasticity of -0.2 , supply elasticity is 0.5 , marginal storage costs are constant at 2 percent of mean price, and the interest rate is 5 percent. The distribution of yield disturbance is a discrete approximation to the normal distribution with a coefficient of variation of 10 percent.

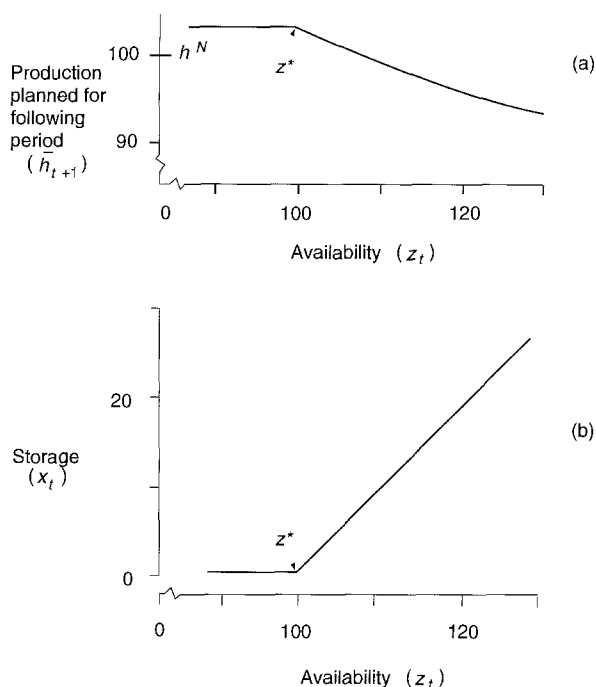


Figure 5. Joint rules for equilibrium planned production and storage.

turbances, except where noted below; availability is the sole state variable. Storage in this model is zero for $z < z^*$, then increases monotonically. The storage density has a mass point at zero, a mode at a low amount of stocks and a long upper tail. Consistent with intuition, the storage rule shifts to the right if output variance falls, interest costs or storage costs rise, or the length of horizon falls [Gustafson (1958)]. The storage rule implies that storage demand is positive and increasing in availability z for $z > z^*$, and this means that market demand has a kink at z^* and becomes more elastic beyond z^* , as shown in Figure 6. Storage reduces the dispersion of price, and truncates the density at the low-price end, leaving a long tail to the right. Given constant cost of capital, storage can eliminate very low prices but in general can only reduce, not eliminate, occurrence of famines.

Responsiveness of planned production tends to make the storage rule steeper and more nearly linear. Planned output decreases with availability for $z > z^*$, as shown in the upper panel of Figure 5. Its density has a mass-point at its maximum value and is skewed to the left, as shown in Figure 7. For $z < z^*$ and $x = 0$, planned production is highest but marginally unresponsive to current or future price. Importantly, "supply elasticity" to current price cannot be constant and positive in this model. The model with responsive production has higher expected availability $E_t(z_{t+1})$ when z_t is low,

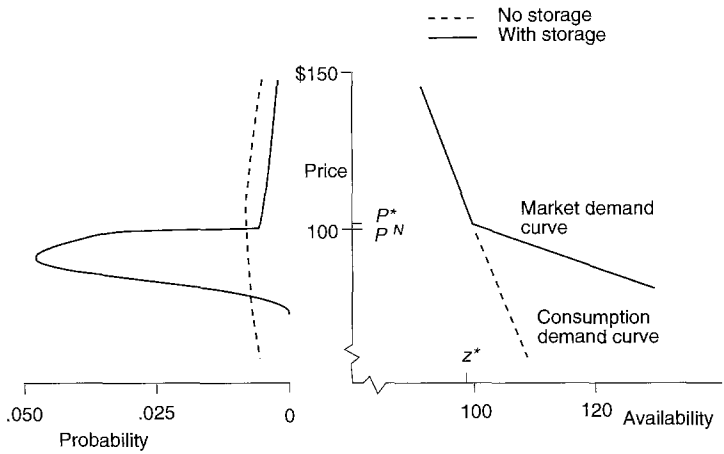


Figure 6. Probability distribution of availability and price.

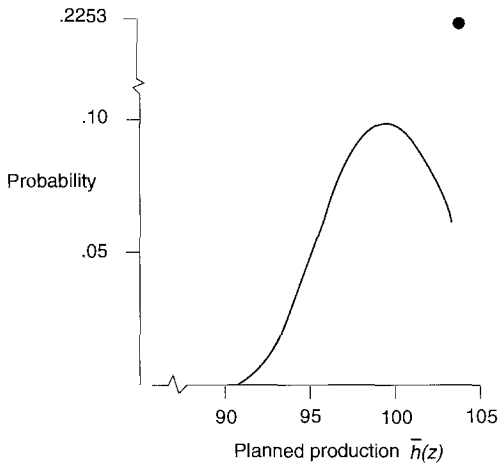


Figure 7. Probability distribution of planned production.

relative to the case with planned production fixed at its mean, and vice versa for high z_t . This lagged supply response, liberated in the i.i.d. case by the presence of storage, is highly stabilizing for consumption and price.

7.2. Market dynamics of a storable commodity

In a market with i.i.d. disturbances and no storage, realizations in one period have no implications for future realizations. Output incentives are constant, so supply response

is irrelevant for time series behavior. In such a model, the real effects of dynamic interventions such as ideal production stabilization, discussed above, can be analyzed by comparative statics. Given a one-period production response, distributions of outcomes of price, consumption, and production for period t , expected in period $t - 1$ after a regime change for period t has been announced, are the steady-state distributions in the new regime. But we have seen that even in this case, the incidence effects are dynamic.

In a model with storage, expectations are conditional on the state(s). Consider for example Figure 8 which shows the expectations of prices in future periods conditional on the state (the initial available supply z_0) in period 0. For given z_0 , these expectations can be estimated by generating thousands of simulations of the model, each for periods 1, 2, 3, ..., taking random draws from the harvest distribution for each future period in each simulation, and taking the mean of the prices realized for each period by each of those simulations. The mean in period 1 is an estimate of the expected value in period 1 price, conditional on available supply in period 0, that is, $E_0(p_1)$. Note that $E_0(p_1)$ is not the price expected in period 1, and indeed $E_0(p_1)$ may not equal the realized price in any state; consider the case of a discrete two-point harvest density.

The evolution of future expected prices is shown for two values of supply elasticity and of initial availability in Figure 8. When initial availability is high and there is no supply response, price is low and storage is high, dampening expectations of next period's price, which exceeds current price by the cost of storage including interest cost. This

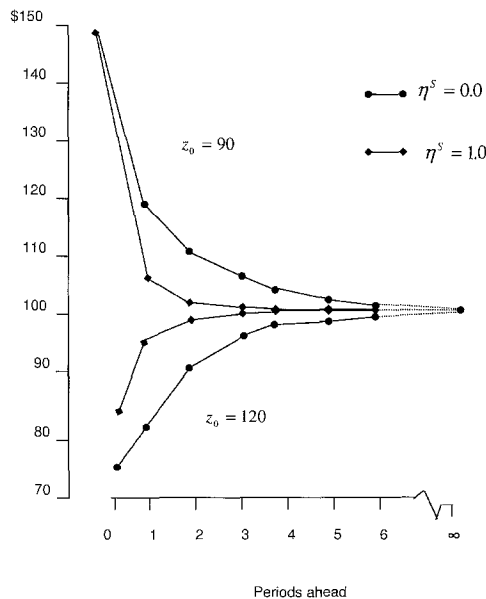


Figure 8. The effect of supply elasticity on the rate of convergence to the steady state.

overhang is expected to decline over time, allowing expected prices, conditional on z_0 , to rise to converge on their limit, the mean of the steady-state distribution. As expected prices rise (and expected stocks fall), expected consumption falls. Expected production rises, but not enough to counteract the expected decline in available supplies. Note that in general $E_0(p_1) \neq E_0(f(E_0(c_1)))$.

If one assumes futures markets to be efficient and risk-neutral, the expected prices in Figure 8 can be called futures prices for contracts with maturities 1, 2, 3, ... periods from period 0. In period 1, after (unanticipated) realization of the harvest h_1 , there is a jump in the path of futures prices starting in period 1 opposite in direction to the change in available supply ($z_1 - z_0$). The new path of expectations (not shown) is conditional on z_1 .

Figure 8 also shows the expected prices if available supplies z_0 are low and stocks are zero. The chain of expected prices declines toward the steady state as expected stocks are rebuilt towards their steady-state expectation. Paths of current futures prices for different maturities like those in Figure 8 can be observed in the array of actual futures prices for storable commodities reported in the financial press for any given trading day. They are not necessarily monotonic. If storage is positive at the steady-state mean price, then expected price the next period is sufficiently higher to satisfy the arbitrage condition, but the expected price conditional on z_0 for periods further in the future converges to the steady-state mean. [See Bresnahan and Spiller (1986), and Williams and Wright (1991, Figure 3.5, p. 136).]

The convergence of the futures price profiles to the same steady state values, independent of the current states, helps show why markets for long-term futures do not exist, despite the frequent lamentations of economists. The reason is that they are not needed. Futures prices are not reflections in a crystal ball. They embody relevant current information, and several periods out, the effect of current information on futures prices and on the spreads between them is greatly diminished. There are no markets for far-out futures because there is too little current information flow about them (not reflected in prices of existing futures contracts) to motivate trade [see Williams (1986, Chapter 6)].

The dynamic response of the land price associated with a change in current product price depends on the discount rate and (speaking loosely) the expected rate of convergence to the steady state. Discounting makes the near-term rent realizations more important than later realizations, but high interest rates also discourage storage and hasten convergence. As Figure 8 shows, supply response also speeds up convergence, thus increasing the importance of the steady state (comparative statics) effects, relative to the case with no supply response, while also changing those effects, in ways quantitatively similar to those noted for ideal stabilization above.

8. Storage and market stabilization

A major motive for studying storage is to analyze policy interventions that have long been controversial features of many commodity markets. These include controls on pri-

vate “hoarding” or “speculation”, buffer stocks, strategic reserves, rationing of low-price supplies, marketing boards, price floors, variable tariffs and other trade barriers, and production controls. In all of these interventions, efficiency effects tend to be dwarfed by distributional effects. Hence the underlying motivation, generally viewed by the public as stabilization and by economists as substitution for a missing risk market, is more often redistribution to those who most enthusiastically and effectively support such measures. To comprehend these distributional effects, it is necessary to recognize the dynamic nature of the problem and the importance of private responses to public actions.

A detailed analysis of all types of public interventions in commodity markets is well beyond the scope of this chapter. But many of the important considerations in “stabilization” schemes can be discussed in the context of a very simple public program, a “price floor” p^F that is implemented by an open public offer to buy any quantity at this price and to sell any available stocks at the same price, upon demand.

8.1. A simple floor price program

Consider, for example, the announcement and introduction of such a floor price in a market with positive harvest with an i.i.d. distribution (no supply response), and consumer demand of constant price elasticity in the inelastic range, with relative curvature parameter $C > 2$ and constant marginal storage cost.

If the initial available supply z_0 is low enough, there is no storage. As shown in the top panel of Figure 9, introduction of the floor price p^F may have no immediate effect on producer surplus, given storage remains at zero for available supply z . In the steady state, expected producer surplus is decreased for this set of parameters by the price stabilization induced by p^F , although the difference is too small to clearly show on the right-hand side of the top panel of Figure 9. This effect is anticipated from the analysis of ideal output stabilization for $C > 2$, discussed above. So initially there is no change in producer surplus, and in the steady state, expected producer surplus is lower. Yet the lower panel shows that stabilization favors those who own the fixed production assets (“land”) at period 0, at the expense of near-term consumers.

The earliest nonzero effects of the price floor scheme on commodity price must be positive, since purchases precede sales. Thus in the medium term it is expected that storage and price will be higher, and consumption lower, because of the effects of the price floor on market price. In the illustrated example, the influence of these medium-term responses on land price dominates that of the steady state (comparative statics) adjustment because of the “front-end loading” caused by discounting. As shown in the bottom panel of Figure 9 the land price jumps up upon announcement of the price floor, benefiting the current land owners even though current commodity price is unaffected. After the announcement, expected land price eventually becomes lower than its initial steady state mean, consistent with the result for producer surplus, but this has no direct distributional significance in a partial equilibrium setting.

If initial available supplies are sufficiently larger, there will be positive initial stocks. Imposition of a price floor then causes an immediate positive jump in the value of

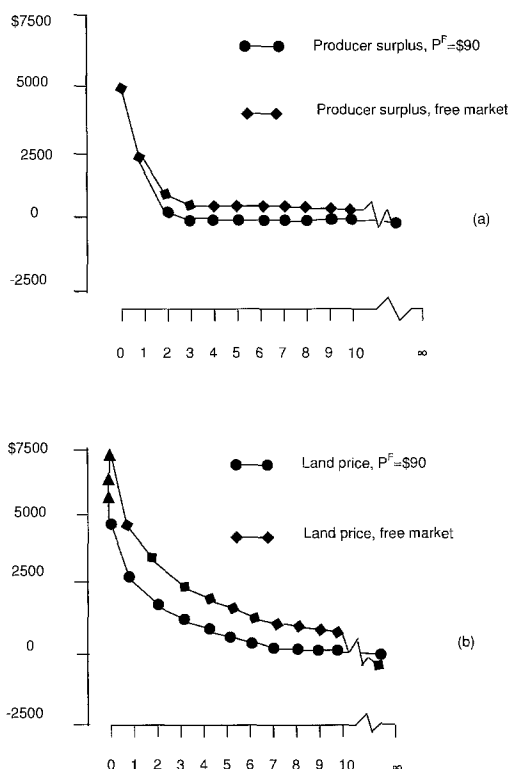


Figure 9. The effects of a price floor on producer surplus and its capitalization.

these stocks. Their owners unambiguously gain from the announcement of the price floor, whereas the price of land may jump up or down, depending upon the parameter values [see Miranda and Helmberger (1988); Wright and Williams (1988b)]. In general, the former conventional wisdom based on comparative statics (see the Kanbur quote above) underestimates the aggregate gains of landowners and stockholders.

Indeed analysis of this type of scheme can be used to illustrate several pitfalls of incidence and efficiency analysis of storage interventions in a dynamic model. As shown in Wright and Williams (1988b), comparative statics might not only give the wrong signs to the incidence effects on stockholders-landholders versus present and future consumers, it might also show the intervention to have negative deadweight loss, because it ignores the front-loaded cost of buffer stock accumulation. Analyses that ignore private storage may similarly conclude that a public buffer stock increases aggregate welfare; the “invention” of storage is incorrectly attributed to the government’s use of (pre-existing) storage technology.

8.2. Time-series behavior of “self-liquidating” floor price debt

Perhaps the most important and certainly the least understood aspect of a public price floor program and other buffer stock schemes is the time series behavior of their money balances. When price p^F is set at the mean (or the mean of a floor and ceiling price equals the free-market mean), the program is often assumed to be “self-liquidating”. This quality is frequently used to justify ignoring the evolution of the program funds in analyzing its implications, apparently based on the intuition that we expect funds from purchases and sales after several years of operation to be close to their initial value. But this intuition is wide of the mark, a point that seems to have been understood by Waugh at least as far back as 1967 [Waugh (1967, p. 31)].

To see this, consider the simple case in which demand is linear and planned production is constant, so the mean price is exogenous. Assume further that the harvest has a symmetric two-point distribution, there is no private storage, and p^F is set at mean price. Imagine a “buffer fund” scheme whereby the government pays $(p^F - p_t)$ for each unit sold at each time t . Negative payments are receipts by the government. The fund’s monetary balance, B_t , with initial value B_0 , follows a random walk. Given an infinite horizon, the balance passes any finite negative bound in finite time, and the probability that it is zero at any future date is the same as the probability that it is never zero before that date, and quickly becomes negligible [see Feller (1967, Lemma 1, p. 76)].

Similarly, a price floor scheme backed by a buffer stock generates a fund balance that behaves as a martingale with absorbing barrier at zero. The balance hits zero with probability one in finite time (that is, “infinitely often”). Though the theoretical inevitability of failure of similar public programs with finite resources was long ago noted by Townsend (1977), when they do fail there is generally a public consensus that the intervention price was wrongly set. There is scant recognition that failure is inevitable at any relevant intervention price; higher floor prices merely hasten its occurrence.

8.3. Private storage and speculative attack

Assume now that the floor price program has infinite financial resources, and consider the behavior of private stocks. The public floor price is set below the mean at $p^F = f(q^F)$ where $f(\cdot)$ is the consumption demand. A public storage rule for this type of model is shown in Figure 10 as the piecewise linear curve that follows the horizontal axis till z^{**} rises vertically, then turns to follow a straight line at a 45° angle.

Private storage, if allowed, tends to respond to the price floor by increasing stocks for a range of prices above p^F . In the example shown in Figure 10, the private storage rule, the dashed line, starts to the left of the free-market rule, and also to the left of q^F . Public acquisitions do not start at $z = q^F$, as they would in the absence of private storage, but at z^{**} . At levels of z below A^* , there is no storage. For levels between A^* and z^{**} , private stocks and consumption both increase in z as price decreases towards p^F .

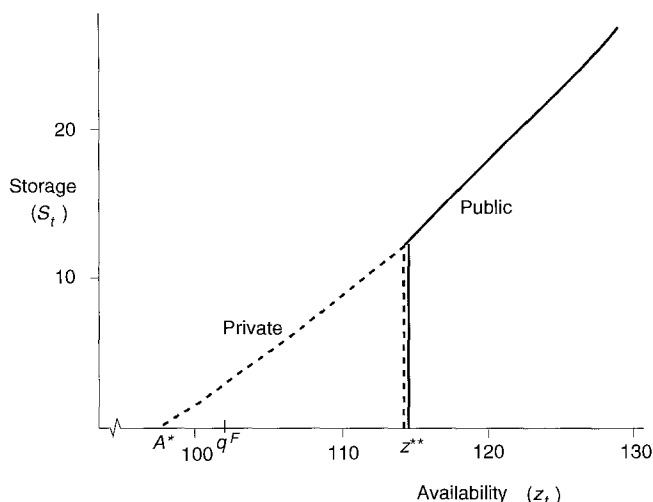


Figure 10. Public and private storage rules with a price floor.

At z equal to z^{**} , a marginal increase in z depresses future price below the level needed to sustain the private storage arbitrage. All private stocks are sold to (“dumped on”) the public floor price program in any period in which the harvest is large enough to increase available supply above z^{**} . Similarly, the next harvest that is low enough to reduce available supply below z^{**} coincides with a “run” or “speculative attack” on government stocks that reduces those stocks to zero.

The rationality of this type of speculative behavior was proved by Salant (1983). The social welfare implications of speculative attack in general are more controversial. It is often viewed as undesirable speculative disruption by public stabilization authorities, including defenders of national currencies and operators of emergency food reserves. But Williams and Wright show numerical results indicating that, given the public program, private speculation can stabilize consumption, in the sense of inducing a mean-preserving contraction of consumption in a model with fixed planned supply. Though it increases the frequency of price changes, it reduces the occurrence of large price swings.

If the public sector has a finite budget, private speculation may reappear when public stock accumulation has exhausted that budget, and it will tend to reduce the otherwise abrupt changes that occur around that stock level. In this case, the public policy is a price “peg” of the kind discussed in Wright and Williams (1991, Chapter 14).

Indeed if these numerical results can be generalized, limits on private speculation must be justified on second-best grounds; perhaps speculation is too stabilizing, given the public intervention, or prevents risky behavior (gambling on “leaning against the wind”) by public authorities that is for some reason desirable. This is an interesting and

promising area for further theoretical and numerical investigation. The storage model is a useful “test bed” for ideas that drive government policies regarding defense of exchange rates against speculative attack, and more generally fixed versus variable exchange rates.

A phenomenon related to speculative attack might be observed in poaching that leads to extinction of animals valued for their storable or durable products. Pursuing a model suggested by Martin Weitzman, Kremer and Morcom (2000) note that if extinction is anticipated, future price of the product (e.g., ivory from elephants) will rise, increasing current price and hence the incentive for competitive poaching. But there may also be a non-extinction equilibrium, in which future supplies are anticipated to be larger, reducing future price and hence current price and eliminating the incentive to poach. Government policy might ensure the second (survival) equilibrium by credibly committing to prevent extinction, as in the United States Endangered Species Act. Alternatively, it might be possible that public (or private) storage of confiscated contraband or harvested materials, with the threat of sale to the market if price rises above a threshold or the species becomes endangered, could eliminate the extinction equilibrium.

8.4. Buffer stock schemes: theory and practice

The floor price scheme described above is pedagogically useful for its simplicity. The commodity programs that have been tried over the past seventy years have often combined the floor price with a higher “ceiling” or “release” price. These are not so simple. Numerical models of this type of arrangement show important interactions between band width, private storage within the band, the expected rate of accumulation of losses, and the maximum level of stocks [see Williams and Wright (1991, Chapter 14)]. For many, a strong intuition is that such a program keeps price around the middle of the “price band” most of the time, if the band is judiciously chosen. But numerical examples show the price density has mass points at both ends of the band, and little mass between the mid-point of the band and the top. Most of the time, the market may appear to be “challenging” either the floor or the release price.⁹

In practice, postwar experience has affirmed that the “finite time” within which we expect such programs to fail is disconcertingly short, often less than a decade. Recent failures in programs for tin and wool [Bardsley (1994), Gilbert (1996), Haszler (1998)], among others, have shown that the largest and most catastrophic price effect of these interventions is the severe price collapse that accompanies their inevitable failure.

⁹ In an interesting empirical paper, Zant (1997) finds that in the Indian rubber market, operation of a buffer stock did not significantly reduce relative real price variation, compared to periods before and after the scheme. The market was subject to trade interventions throughout.

9. Storage with market power

Discussions of the effects of market power on storage behavior cover a range of quite distinct cases that are easily confused. If output demand is price elastic, a monopoly over risky production may extend to storage if demand is not too convex (that is, if marginal revenue is steeper than demand), as Newbery (1984) showed. Otherwise competitive storage will dominate monopolistic storage in this model unless there are entry barriers to storage as well as production.

When storage and production are monopolized, the nature of storage behavior depends upon the flexibility of decisions over pricing and production. [See Williams and Wright (1991, Chapter 11, Section 11), for a review.] For example, storage can help reduce the cost of a constraint on price adjustment (as in Keynesian models), or on production planning. The storage model most familiar to operations researchers is the (S, s) model. In this model, ordering cost of a firm is linear with a fixed cost component, and demand is random. Scarf (1959) proved the optimality of a discrete ordering policy in which stocks are raised to S whenever they fall to s . Caplin (1985) extended the previously firm-oriented focus of this model to take an aggregate perspective on the behavior of stocks.

But this literature has not taken the market-wide perspective of commodity storage models. The firm in the (S, s) model for some reason does not adjust price as demand fluctuates. It is implicitly assumed that the firm cannot sell excess inventory at an equilibrium “market price”. The lack of such a market price implies market power, transaction costs, or other market imperfections not explicitly specified.

If storage alone is monopolized, the storage service is reduced in supply relative to competition. As Adam Smith recognized, charges of excessive hoarding by monopolists are misdirected. But the precise behavior of the profit-maximizing monopolist depends upon the ability of the monopolist to commit to announced policy, in the presence of competitive producers and speculators who respond to the monopolist’s actions. This “time consistency” problem is like that faced by government in its storage interventions.

10. Optimizing (second-best) government interventions

When a government, instead of choosing the usual rather simple behavioral rule, attempts an optimizing intervention in a commodity market, justified by either a market distortion or an attempt to exploit market power vis-à-vis a trade partner, the optimization via dynamic programming breaks down. [See Wright and Williams (1982b) for an example of operating a strategic petroleum reserve in the presence of private storage.] Public storage interventions announced for next period, based on current available supply, may not be credible; other market participants might anticipate that the government will have an incentive to re-optimize next period, rather than follow its pre-announced strategy. Government then finds itself in a strategic game in which pre-commitment is

valuable but difficult. This can make flexibility, normally very valuable in handling risk, actually disadvantageous.

Commitment problems are, paradoxically, at the heart of the most cogent argument for public intervention in the market for consumer commodities with stochastic supply or price. In an extreme shortage, government may be unable to withstand pressure to put a ceiling on price (for example, by rationing the good). Given this inability is common knowledge, private speculators will adjust their price expectations and store less of any given available supply. The inadequacy of private storage then justifies the public intervention on efficiency grounds.

The lack of a capacity to store can be advantageous as a source of commitment in a two-period game between an oil importer and an oil exporter [Eaton and Eckstein (1984)]. Another context in which storage capacity may be disadvantageous is in a context of self-motivated, stabilizing risk-sharing such as the “sovereign borrowing” studied by Eaton and Gersovitz (1981) and, in a renegotiation-proof context, by Kletzer and Wright (2000), and the related literature on risk-sharing in village economies [Ligon (1998)]. In these models, storage can increase the value of autarchy, weakening the force of punishments that reduce a defector’s utility to the autarchy level, thus diminishing the potential for consumption-smoothing achieved by a sequence of unilateral equilibrium transfers [Ligon et al. (2000)].

Storage itself may be destabilizing in other special if not bizarre cases, such as the highly stylized model of Hart and Kreps (1986) in which demand alternates between radically different forms from period to period. Leach (1997) shows that storage can arise as a method of increasing the firm’s strategic strength in the context of wage bargaining, and strikes evolve as a means of limiting that strength, in a model with no exogenous uncertainty. A related point is that, by decreasing the cost of strikes, storage may increase the frequency of labor market instability [Paarsch (1990)].

McLaren (1996) makes the interesting claim that the International Coffee Agreement, in which consumer countries have participated, is an example of a Pareto-improving commitment mechanism. He argues that it reassures suppliers, who have a long production lag between planting and first harvest, against *ex post* exploitation by monopsonistic consumers.

11. Spatial and trade models

Commodity models are made richer, and more complex, when storage and trade are both explicitly included as costly activities in a stochastic context with rational behavior. The unidirectionality (non-negativity) of storage combines with the unidirectionality of transport costs (returning an import doubles, rather than eliminates, transport costs) to make for interesting behavioral relations. [See Knapp (1982), Miranda and Glauber (1995), Williams and Wright (1991, Chapter 9).] Among the interesting results are the following:

- If disturbances in each country are not negatively correlated, storage tends to be more stabilizing than trade, but the interaction of the two is highly complementary.

- Two countries actively trading a commodity between them should not both be storing it unless transport takes significant time.
- The f.o.b.-c.i.f. bounds are not good guides to the range of competitive prices in a small country that can store the commodity [Anderson (1985)].

Intertemporal considerations also make traditional spatial models in the tradition of Von Thunen much more interesting. A major problem in constructing such a model is in general the lack of sufficient spatially disaggregated data. Taking advantage of data made available through the extraordinary powers of a Royal Commission, Brennan et al. (1997) modeled the major region of the Western Australian wheat market, using data including storage technologies, capacities, and costs for 104 delivery locations, capacities and costs of two different rail systems, and costs of road hauling. They modeled efficient transportation of a wheat harvest to the export terminal over the harvest (direct delivery) and off-peak (store then deliver) periods, for different combinations of peak and off-peak export prices. As price pressure for immediate delivery increased, storage decreased overall but increased in locations “inconvenient” to the port in terms of intensity of use of scarce transport resources. Rail trips became shorter and concentrated on locations with high-throughput loading facilities, to save scarce locomotive time.

When the spread between the post-harvest price and the harvest price is plotted against aggregate stocks after harvest, a typical “supply of storage” curve with “convenience yield” [Kaldor (1939)] at low levels of stocks is obtained in this model. As first documented by Working [for example, Working (1934)], low but positive stocks are held at negative spreads, and high stocks are held at prices reflecting positive storage returns. This showed, as conjectured in Wright and Williams (2000), that convenience yield could occur as an aggregation phenomenon in which stocks are held at full carry according to local prices but appear to be held at a loss according to spreads in a related market separated by transport costs that vary with delivery pressure.

The idea that marketing costs can explain the “convenience yield” phenomenon is embodied in the extension of the Scheinkman and Schechtman (1983) model by Bobenrieth and Wright (1998). In this model, marketing costs are modeled as a concave increasing function of available supplies and a convex decreasing function of carryout stocks. Thus the marketing cost function is not convex. This formulation is actually consistent with some intuitive discussions of the notion of “convenience yield” (as distinct from efforts to formalize that notion) in the literature. In contrast to the notion that at low levels stocks offer a positive dividend-like “convenience yield”, as in modern empirical models of commodity price behavior [for example, Fama and French (1987), Pindyck (1993, 1994)], stocks on hand have a shadow price below the market price, yet the typical “supply of storage” behavior is exhibited by the model. This model shows promise of helping explain the related phenomenon of “liquidity preference”, in which the transaction cost function has been assumed to be convex in consumption and money [e.g., Brock (1974, p. 769), Bougheas (1994)].

12. Testing the storage model

The lack of a closed-form solution for the storage model long hindered testing of the storage model. Recently, however, substantial progress has been made on two fronts. First, in an important and innovative line of research, Deaton and Laroque (1992) have tested simple versions of the model with annual commodity price data. They estimated the equation implied by the model with i.i.d. disturbances, storage decay rate δ , and discount factor β ,

$$E_t \left(\frac{p_{t+1}}{p_t} \right) = \min \frac{(p_t, p^*)}{[\beta(1 - \delta)]},$$

using the Generalized Method of Moments with lagged prices as instruments.

The results show mean values of $1/[\beta(1 - \delta)]$ in excess of unity, for twelve of thirteen commodity price series, where r is the interest rate, and p^* below the maximum sample observation (so that the frequency of stockouts is positive though in some cases very low). There is also heteroscedasticity as implied by the storage model, though the stockout frequency was too low to test the prediction of theory that the variance of the disturbance is constant conditional on $p_t > p^*$, and there is little evidence of residual autocorrelation. There is substantial evidence in favor of the storage model and against the random walk hypothesis.¹⁰

However, the coefficient $1/[\beta(1 - \delta)]$ is not significantly different from unity for each commodity, and the i.i.d. model does not appear to reproduce the degree of autocorrelation seen in the data at high prices. Chambers and Bailey (1996), using a similar approach on monthly data, found some informal support for a model with “periodic disturbances”, that is, different disturbance distributions and associated threshold prices for different groups of months in the year. In further work, Deaton and Laroque (1996) assumed linear demand; their pseudo maximum-likelihood estimation results imply that their parameterization of the storage model does not track prices when they are high, and that adding autocorrelation in harvest does not adequately solve this problem.

In a very interesting paper, Miranda and Rui (1996) reassessed the model specification of Deaton and Laroque and Chambers and Bailey. They point out that the restriction of storage cost to a “constant decay” specification implied a “supply of storage” function which has a slope that is roughly the *negative* of the *ad hoc* empirical “supply of storage” curve pioneered by Working [see Working (1934)]: storage becomes more expensive at high prices in the Deaton and Laroque model, discouraging storage.

Instead, Miranda and Rui use a semilog storage cost (“supply of storage”) function, $c(x) = a + \beta \ln(x)$, that has the qualitative characteristics of the numerous empirical estimates for various storable commodities dating back to the studies of Holbrook Working. Like Deaton and Laroque (1996), they assume linear consumer demand and a fixed

¹⁰ Ardeni and Wright (1992) also reject the martingale hypothesis for the aggregate barter terms of trade between primary commodities and manufacturers using the state-space approach of Harvey (1989). However, the long price swings that are a major feature of these data are not explained by the storage model.

interest rate of 5 percent. Using maximum likelihood methods and the Chebyshev orthogonal collocation method with Gaussian quadrature [Miranda and Rui (1996), Judd (1992, 1998)], they estimate the model for the same commodities studied by Deaton and Laroque. They find that their storage model explains the autocorrelation of commodity price data very well, in sharp contrast to earlier results. What remains is to make the empirical connection between their storage cost specification and the progress on its microfoundations that has recently been made in terms of spatial aggregation [Wright and Williams (2000), Brennan et al. (1997)] or in terms of marketing costs more generally [Bobenrieth and Wright (1998)], as discussed above.

The spatial model of storage of Wright and Williams (2000) has itself been indirectly tested by Benirschka and Binkley (1995) on United States corn data. They find that the loan rate, a proxy for distance from market, in which it is decreasing, is significantly negatively related to the amount of grain storage capacity, in line with a theory that carryover stocks will be held where they have the least opportunity cost and are least “convenient” to the market. They also show that the rate of drawdown of stocks within the year is slower for states like Iowa relative to states like Illinois, Indiana, and Ohio, that are closer to the market. Further, locations with the highest prices at harvest tend to exhibit lower rates of price increase during the remainder of the crop year. Clearly, further tests of the storage model should follow the example of this work in paying closer attention to the disaggregation of price and quantity data. This is no easy task. For example, data limitations render the results of Frechette and Fackler (1999) inconclusive.

A less formal but no less important test of the storage model is its usefulness in interpreting market behavior. A particularly instructive application of the model to make sense of volatile commodity prices is Verleger (1994).

13. Tests using the storage model

The storage model can be used to generate sample data series for use in evaluating econometric tests of market behavior [Williams and Wright (1991, Chapter 7)]. Monte Carlo evaluations of published tests of forecasting ability raise serious questions about statistical inference using standard methodologies. For example, common tests of forecasting ability [e.g., Stein (1981)] that rely on R^2 as an index of predictive value are shown to be misleading, especially when the response to predicted changes is very effective. Similarly, the interpretation of R^2 in tests of the ability of the spot-futures spread to forecast movements in the spot [Fama and French (1987), Peck (1989)] is clarified by explicit reference to the commodity model [Williams and Wright (1991, pp. 180–181)]. Furthermore, common tests of relative bias in futures markets, and tests of excessive price variability can be quite unreliable when applied to markets for storable commodities. In addition, Monte Carlo tests of adaptive and “rational” expectations estimates to agricultural supply response reveal serious downward bias when the source of variability is yield variation.

This section would be longer if the potential of the model for quality control on tests of market behavior had been adequately exploited. The results so far merely scratch the surface, but they raise serious questions generally neglected in the relevant literature.

14. Challenges for the future

Storage behavior in response to market risk is only one element of commodity market dynamics. The possibility of persistent productivity shifts is another issue that bears on the adequacy of storage as a protection against shortfalls in output. Progress is being made on the effects of El Niño and La Niña on medium-term agricultural output. The evidence on more persistent disturbances is entirely inadequate. Studies of long time series of commodity prices are difficult to interpret, partly because a century or so is not really “long” enough, and the world is not static enough for inference about the longer-frequency movements that appear to be important features of the data. One way to begin investigating this question is to examine the long-run behavior of the underlying production disturbance. However, sample data on yields and weather rarely cover much more than a century. The best long-run evidence regarding annual growing conditions may be indirect, in such forms as tree rings and ice cores. One attempt that points to the possibility of persistent changes in the long-run local growth environment is the study of California tree-ring histories presented in Yoo and Wright (2000).

Macroeconomic effects on storage may well be very important. Using the many commodity price series available, we should be able to make more progress on the dynamic effects of cyclical changes in the cost of capital, exchange rates, and aggregate demand.

For some developing economies, the macroeconomic benefits of price stability deserve another look in the light of advances in macroeconomic theory. On the supply side, a challenge is to address the poor performance of current econometric approaches in Monte Carlo studies. It should be possible to make better inferences about aggregate supply responses in commodity markets by incorporating insights garnered from storage models.

A continuing challenge is to distinguish persistent structural changes including technical change in production and utilization and the effects of global warming from short-term fluctuations and positive or negative price bubbles. Adaptive learning, pioneered in an agricultural context by Rausser (1978) and Rausser and Hochman (1979), will be an important topic on the research agenda. Given the amount of historical data we have, it would be a mistake to expect great precision from inferences in this area, but it would be a greater mistake to neglect it.

In the context of very high frequency (daily) price data, the work of Bobenrieth (1996), applying the approach of Hamilton (1989), shows how statistical inferences about short-run, spot-price regime changes can reconcile questions implicit in earlier studies [e.g., Yang and Brorsen (1992)] about the consistency of economic and statistical theory and evidence with respect to the distribution of average daily price changes in some storable agricultural commodities.

Another recent research initiative [Bobenrieth et al. (forthcoming 2001)] derives the behavior of price in a model like that of Scheinkman and Schechtman (1983), but assuming that probability of zero output is positive, and that price (but not market revenue) approaches infinity as consumption goes to zero. (Think of the case of consumption demand with constant elasticity of unity.) In this model, if storage is strictly positive, it remains strictly positive. The path of expected price conditional on current information approaches infinity monotonically, but price falls with probability one in finite time, as in common conceptions of a commodity price bubble. Yet the price has a unique invariant distribution (“long-run price distribution”) with infinite mean.

These results are easiest to understand by noting that price is a mapping from consumption, which in this model has an invariant distribution with finite positive mean. When consumption is low, it is expected to rise, but equilibrium stocks ensure that consumption remains positive when harvest is zero, and that expected price always exceeds the spot price by the current cost of storage. Interestingly, the sample mean of future prices, conditional on current information, underpredicts the path of “full carry” price expectations with arbitrarily high probability at sufficiently long horizon, in a manner similar to the behavior of “mean reversion” models in finance. Successive price realizations are always positively correlated, as in models with “convenience yield”. The econometric implications of this type of model are currently under investigation.

15. Conclusion

Large fluctuations in output and prices are prominent features of markets for agricultural commodities. Analyses of the implications of such fluctuations are highly sensitive to assumptions about consumption demand, risk aversion, and the nature of “stabilization”. Too often, storage is neglected, or the effects of storage interventions on welfare are overstated by ignoring private storage or other means of stabilizing consumption.

In a market with storage, interventions induce dynamic responses that tend to dominate any comparative static effects. Because stocks must be bought before they can be sold, initiation of storage interventions tends to favor producers more strongly than indicated in current analyses of price stabilization.

Developed within agricultural economics beginning with Gustafson (1958), the storage model is an essential tool for learning about the dynamics of commodity market behavior under rational expectations, and the potential and limitations of market manipulation and government interventions. It is also a useful “test bed” for Monte Carlo studies evaluating econometric results regarding the performance of futures markets and agricultural supply response. Finally it has potential, till recently unexploited, for elucidating bubble-like price behavior, and “mean reversion” in commodity prices.

A current challenge is to extend the storage model to include learning about changes in the agricultural environment, such as possible global weather changes on the one

hand, or biological innovations on the other. Uncertainty about the occurrence of such changes and their implications may be a factor in apparent bubble-like commodity price behavior, a subject that certainly merits further research.

Many commodity policies involving storage had their genesis in the Great Depression of the 1930s. It is not surprising that they have seemed less appropriate in the more robust economic environment that has existed since then, especially since Keynes' (1942, p. 309) apprehension that market-stabilizing intervention might degenerate into supply restriction schemes has been validated. But should a Depression-like global market collapse recur, it is not clear that economists are equipped with theories and policy prescriptions for early detection of a commodity market crisis or for crisis intervention much superior to those of the 1930s. Given recent instability in global markets, this topic merits attention from commodity economists, macroeconomists, and historians.

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FOOD PROCESSING AND DISTRIBUTION: AN INDUSTRIAL ORGANIZATION APPROACH

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Abstract

This chapter focuses upon competitive relationships in agricultural markets. These markets often exhibit high and increasing levels of buyer and/or seller concentration. Both food manufacturing and retailing are characterized by aggressive attempts by firms to achieve product differentiation. Vertical coordination within the sector through integration or various forms of vertical control is also increasingly important. In addition agriculture is relatively unique among industries in that governments often permit and encourage producers to form selling cartels. Exports and imports of agricultural commodities also often involve intervention by marketing boards and state trading agencies. We review and evaluate recent research on each of these topic areas.

JEL classification: Q13

1. Introduction

Marketing, including processing, distribution, and retailing, accounts for the majority of retail food and beverage costs for most commodities. Behavior in the marketing sector, thus, has an important effect on the welfare of both consumers and farmers, and, accordingly, the sector has been studied extensively by agricultural economists. This chapter focuses specifically upon competitive relationships in the agricultural marketing sector or, alternatively stated, the industrial organization (IO) of the sector. The various stages of the marketing sector often exhibit high levels of buyer and/or seller concentration. Both food manufacturing and retailing are also characterized by aggressive attempts by firms to achieve product differentiation. Vertical coordination between the production and processing sectors through integration or various forms of vertical control has also become increasingly important. In addition, agriculture is relatively unique among industries in that governments often permit and even encourage farm producers to form selling coalitions or cartels. Moreover, exports and imports of many commodities are often characterized by the intervention of marketing boards and state trading agencies. Each of these characteristics supports analysis via the theory and methods of industrial organization and each is discussed in this chapter.

1.1. Historical perspective

Bressler (1964) credits Cassels (1933) with introducing industrial organization research in agriculture. Cassels provides a lucid classification of market structures and presents a framework for investigating market behavior which comports closely with what later became known as the structure–conduct–performance (SCP) paradigm.

The first analytical treatise on industrial organization in agriculture was by Nicholls (1941), who presented a sophisticated analysis rich in agricultural applications of Cournot and Bertrand models of oligopoly/oligopsony, bilateral monopoly, product differentiation, and price discrimination. At about this same time, Hoffman (1940) published an influential monograph that examined big business in agriculture in the U.S. Although lacking the analytical sophistication of Nicholls' analysis, Hoffman's contribution documented the growth of firms and increasing concentration in each of the major agricultural sectors and framed the policy issue in terms of balancing the efficiency virtues of large-scale operations against the problems of monopolistic control. Hoffman proposed an activist government policy of antitrust when "clear and attainable economies of large-scale operation" were not apparent, and regulation or public ownership when such efficiencies were present.

Hoffman's and Nicholls' work did not attract much interest in an IO approach to agricultural market analysis. Rather, a significant focus during this time was the concept of workable or effective competition [Clark (1940)]. This theory was predicated on the notion that the market structure and conduct characteristics which defined perfect competition did not provide a satisfactory basis for evaluating actual market behavior. Thus, workable competition represented a recognition that most markets could not, and

perhaps should not, meet the stringent requirements of perfect competition and sought instead to identify desirable economic outcomes that were practically attainable [Sosnick (1958)]. Sosnick (1968) defined 25 structure, conduct, and performance outcomes that he viewed as incompatible with effective competition.

The work on effective competition proceeded contemporaneously and in intellectual harmony with the development of the SCP framework. The SCP paradigm was grounded in a loose economic theory which posited that structural characteristics of an industry (degree of buyer/seller concentration, extent of product differentiation, and conditions of entry) determine largely the conduct of firms in the industry (price and output policies, product development and promotion policies, and behavior towards rivals), which, in turn, determines the market performance (price-cost margin, production efficiency, relative costs for advertising and promotion, product character, and progressivity).¹ This approach became the dominant paradigm for conducting IO analyses in agriculture for the ensuing 25 years.

The SCP paradigm's applicability to the agricultural industries was set forth in an influential article by Clodius and Mueller (1961). The first SCP studies in agriculture analyzed rates of reported profit for food manufacturing companies as functions of four-firm concentration ratios (CR4), firm market share, and measures of advertising intensity, generally finding each of the key variables to be positively correlated with profit [Schrader and Collins (1960), Collins and Preston (1968), and Imel et al. (1972)]. More recent work in the SCP framework has emphasized price as a dependent variable in response to the well-known Demsetz (1973) critique of the studies using profit measures.²

A particularly influential set of industry studies with a strong SCP influence was produced under the auspices of the U.S. National Commission on Food Marketing. Formed in 1965 at the direction of the President to conduct a comprehensive investigation of food market conditions in the U.S., this Commission issued 10 technical reports which evaluated each major agricultural sector. The summary report of the National Commission (1966) argued that concentration had reached undesirable high levels in various segments of the food system, especially in grocery manufacturing, and that spending for advertising and sales promotion had attained excessive levels. The Commission rejected the notion that growth in concentration was necessitated by economies of size in operation, asserting that "firms tend to grow, especially by merger and acquisition

¹ A more formal theoretical justification for the SCP framework emerged somewhat later through static oligopoly models, e.g., Cowling and Waterson (1976), which showed how the price-cost margin in a homogeneous products oligopoly can be expressed as a nonlinear function of the industry's Herfindahl index, elasticity of demand, and weighted behavioral (conjectural variations) parameter. See also Clarke and Davies (1982) and Cotterill (1993) for further conceptual background on the SCP approach and discussion of criticisms leveled against it.

² Demsetz's essential argument was that the often-observed positive correlation between profit rate and concentration could be caused by an efficiency effect rather than by market power. Firms with an efficiency advantage would gain market share and earn larger-than-average reported profits, thus producing the correlation observed in the profit studies.

well beyond the size needed to attain full operating efficiency” (p. 106). The Commission also sounded an early warning about the emerging buying power of food retailers and recommended an activist government policy in overseeing and regulating the food system.

2. The horizontal structure of food marketing

Marketing activities account for the majority share of costs for most foods and beverages and, moreover, the share of costs due to marketing is rising over time. Consider the U.S. where the farm share of the U.S. Department of Agriculture’s “market basket” of food products remained stable at about 40 percent from 1960–80 but has declined rapidly since then, to 30 percent in 1990 and 22.2 percent in 1998.

Several comprehensive studies of structure and performance in U.S. food marketing – Marion et al. (1979), Connor et al. (1985), and Marion (1986) – are now somewhat dated. Marion et al. focused on structure and performance of grocery retailing, while Connor et al. discussed concentration, diversification, advertising, and pricing in food manufacturing. The emphasis in each study was on firms’ roles as sellers, not buyers, and the analysis in each case led to conclusions which were critical of important aspects of the industries’ performance outcomes, most notably pricing and profits.

Connor et al. reported that food manufacturing firms spend 3.5 times more on advertising per unit of sales than other manufacturing firms. The highest rates of advertising intensity usually come from those industries with high concentration ratios. Connor et al. also concluded that entry barriers are in general high in food manufacturing due primarily to the cumulative effects of high advertising and promotion expenditures by food manufacturers. Their analysis focused primarily on data from the 1977 Census of Manufacturing. Concentration in food manufacturing in the U.S. and elsewhere has risen since that time due to rapid growth of the largest manufacturers, fueled by mergers and consolidations. Rogers (1997) estimates that the top 100 U.S. food manufacturers accounted for 80 percent of sales in 1995, doubling their cumulative share from an estimated 40 percent in 1954. Rogers reports increasing concentration in most of 53 food and tobacco industries classified by four-digit standard industrial classification (SIC) codes; average CR4 in 1992 was 53.3 percent compared to 43.9 percent in 1967. In Canadian food manufacturing, CR4 $\geq$ 70 percent in 1992 were found in cereal grain flour (79), prepared flour mixes and cereals foods (99), sugar and chocolate confectionery (80.7), tea and coffee (100), dry pasta products (100), potato chips, etc. (87.6), soft drinks (100), distillery products (76), and wine (70) [Industry Canada (1997)].³

³ CR4 in various other highly concentrated Canadian food industries such as sugars, chewing gum, and brewery products were not reported due to confidentiality considerations.

Viaene and Gellynck (1995) provide an overview of market structure, conduct, and performance in the European food sector, and Oustapassidis et al. (1995) report preliminary results of a study on concentration in the food industries in the European Union (EU). Average four-firm concentration among EU countries was highest in Greece at 76 percent, followed by the United Kingdom (U.K.) (CR5 = 57 percent). The most highly concentrated industries tend to be the same in Europe as in the U.S. or Canada.

Strak and Morgan (1995) provide a sector-by-sector analysis of the food and drink industry in the U.K. They regard the evidence on the structure, conduct, and performance of the sector as "consistent with an industry where imperfect competition is likely. The industry displays high degrees of concentration ... and relatively high profit rates ..." (p. 73). Vollmers (1988) documents high and rising concentration in Australian agribusiness. Huault, Priolon and Reviron (1997) assess the state of food manufacturing and retailing in France. In contrast to reports for most other countries, these authors find relatively low concentration in most food sectors and no discernible trend towards increasing concentration. Lavergne, Réquillart, and Simioni (2001) focus specifically on food manufacturing in France. They report widely varying concentration levels, with CR4 > 90 percent for mineral water, beer, and soups.

Sutton (1991) developed and analyzed a rich set of data on concentration and firm-level market shares in six countries (France, Germany, Italy, Japan, U.K., and the U.S.) for 20 food and beverage industries. In general, the various studies indicate that the most highly concentrated industries tend to be the same in Europe as in the U.S. or Canada.

These concentration ratios apply only to food manufacturers in their role as sellers, although the power of food handlers as buyers from farmers has also long been an issue in agriculture. The relevant geographic and product markets for the purchase of raw agricultural commodities will usually be narrower, and, thus, concentration will normally be higher, than in the relevant markets for the associated finished products for two reasons [Rogers and Sexton (1994)]: first, farm products are often bulky and/or perishable, causing shipping costs to be high, restricting the products' geographic mobility, and limiting farmers' access to only those buyers located close to the production site.⁴ Second, processors' needs for agricultural products are highly specialized. Other inputs cannot normally be substituted for a given farm product, nor can a given farm product substitute readily for agricultural product inputs in alternative production processes. For example, various meats such as pork, beef, and poultry may substitute for one another in consumers' budgets, but they do not substitute at all as inputs into a particular processing plant.

Farmers are often specialized in the supply of particular commodities through extensive investments in sunk assets which represent exit barriers for these farmers and cause farm product supply to be inelastic. High buyer concentration in the relevant farm product markets and inelastic farm supply represent structural conditions conducive to the

⁴ In the U.S., maximum hauling distances are about 50 miles for broilers [Rogers (1998)], 150 miles for processing tomatoes [Durham et al. (1996)], and 650 miles for beef [Hayenga et al. (1996)].

exercise of monopsony power. Buyer market power, however, is given little attention in the general IO literature, and has been a far less frequent focus of analysis in agriculture than has been processors' power as sellers.

Food retailing has also been subjected to considerable analysis from an IO perspective. Food retailing in the U.S. is increasingly dominated by large chains of grocery supermarkets, and supercenters.⁵ Retail markets are inherently local in nature, making national or regional measures of concentration meaningless. The average CR4 in grocery retailing for U.S. metropolitan areas has increased due to consolidations and mergers among grocery chains, reaching 68 percent in 1987, the most recent data available [Franklin and Cotterill (1993)]. Food retailing is also highly concentrated in France and the U.K., with the four leading chains accounting for 67 percent of sales in the U.K. and 55 percent in France [Allain and Chambolle (1999)].

3. Vertical market relationships

The vertical organization of food marketing channels varies widely by type of industry and by country. In the U.S., for example, most produce commodities are marketed directly from vertically integrated grower-shippers to retail food chains, with very little intervention by market intermediaries. Conversely, in most Asian countries these same markets exhibit little integration and instead involve several intermediaries, including wholesalers and terminal markets. Most processed food industries generally feature a distinct food manufacturing sector which is independent of either producers or retailers. However, there are several examples of industries where integration of the production and processing sector is important. A small percentage of U.S. livestock production takes place through integrated firms that own both production and slaughterhouses, more than 25 percent of refined sugar (both cane and beet) is produced through integrated operators, and upwards of 70 percent of market eggs are produced by integrated grower-marketers. There is also little vertical integration between the food processing and retailing sectors. Although large grocery chains in the U.S. and Europe usually offer their own brands of various dry and canned goods, these "private labels" are generally produced on contract by independent food processors.

Great variety also exists in the form of business arrangements among farmers and processors. Farmer-processor relationships comprise a continuum with pure spot markets at one extreme, and farmer-processor vertical integration at the other extreme. In between are various forms of contractual relationships between growers and processors. Use of spot markets is in decline for two primary reasons. First, as the number of firms buying in a given geographic area declines, the efficiency of price discovery in auction-type markets diminishes and concerns over buyer market power escalate. Second, arm's-length transacting is a poor way to coordinate activity and transmit market

⁵ Similarly, the market share of French "hypermarkets" and supermarkets has risen from 12.6 percent in 1970 to 61.3 percent in 1997 [Allain and Chambolle (1999)].

information between buyers and sellers, and this type of coordination has become increasingly important in meeting consumers' demands for variety and high quality in food [Barkema et al. (1991) and Hennessy (1996)].⁶

Mighell and Jones (1963) developed a classification scheme for contracts that remains in use today. Market-specification contracts indicate the basis for computing price in accord with market conditions, but few management functions are specified. Production-management contracts give the contractor partial control of farm production methods. For example, contracts may specify the field location, seed variety, and harvest date. Under resource-providing contracts, the contractor provides major inputs into the production process as, for example, in U.S. broiler production where processors provide chicks, feed, and medicine to producers. Frank and Henderson (1992) and Henderson (1994) report estimated shares of farm-processor output marketed through vertical integration and the aforementioned forms of contract production for major U.S. food manufacturing industries.⁷

3.1. Vertical integration

The analytical study of vertical integration is generally traced to Coase's (1937) article on the economic rationale of the firm. Coase recognized that both the market, through the price mechanism, and the firm, through managerial guidance, performed coordinating functions. Williamson in a series of articles [see Williamson (1989) for a summary] amplified upon Coase's transactions cost approach to understanding vertical integration. In addition to transactions economies, Perry (1989) cites technological economies (e.g., the advantages of having various phases of a production process in close physical proximity) and market imperfections as reasons for vertical integration. An important market imperfection is market power itself. Monopoly firms may have incentive to integrate with downstream firms to correct distortions caused by pricing the monopolized input in excess of its marginal cost, exercise third-degree price discrimination, and eliminate the inefficiencies caused by market power at successive vertical stages. Similar incentives for upstream vertical integration are created by the existence of monopsony power.

Although the IO literature has focused primarily on the incentives to vertically integrate for firms that possess market power, an important consideration in agriculture is

⁶ Hennessy (1996) shows formally how the open market can undervalue an investment to promote food quality. Firms that have made the investment will produce a higher percentage of high-quality product than will firms that have not invested. Imperfect testing for quality does not eliminate the adverse selection problem because some low-quality product will be graded as high quality and vice versa. Competitive prices for the tested product will reflect these errors in testing, and the open market prices for high- and low-quality product will be a blend of the market's valuation of high- and low-quality product, with the specific weights in the blending determined by the accuracy of the testing process. The problem can be eliminated by integrating the production and processing stages.

⁷ To get a sense of the evolution of vertical control in U.S. agriculture, compare these estimates to those reported for 1960 and 1970 by Mighell and Hoofnagle (1972).

that farmers who face monopoly power in input purchases or monopsony power in output sales have incentive to integrate vertically to countervail the market power. In this case, the firms facing market power may, by integrating vertically, not only eliminate the market power's inefficiency or deadweight loss, but also the larger distributional loss created by monopoly/monopsony power.

Because the scale of operation in farming is ordinarily much smaller than in the markets upstream or downstream from the farm, it is generally infeasible for farmers to integrate unilaterally. A solution is for farmers to coordinate horizontally and form a marketing cooperative to integrate downstream or a purchasing cooperative to integrate upstream. Recognition of the essential economic similarities between cooperation and vertical integration dates at least to Nourse (1922). Sexton (1986) developed a formal model to study farmers' incentives for downstream integration through a marketing cooperative.

3.2. Vertical control and contracting

Models of vertical control are members of the class of principal-agent models. The principal hires the agent to perform some task. The principal is modeled as a Stackelberg leader who offers a take-it-or-leave-it contract which the agent must either accept or reject. In most applications the agent acquires an informational advantage at some point in the game as to his/her type, actions, or other states of the world. Applications in agriculture may involve the farmer as the principal seeking, for example, a marketing firm as agent to sell his/her production. The agent may have specialized knowledge as to his/her own ability, market conditions, etc. Alternatively, a processor may be modeled as the principal who seeks farmers to grow products to his/her specifications. Farmers may have specialized knowledge as to their types, production costs, etc. The processors' job in these cases is to specify contracts with growers that elicit the processor's desired quality level subject to incentive compatibility with growers and also their financial viability, known as the "individual rationality" or "participation constraint". Imperfect monitoring may involve inability to observe directly either farmers' horticultural practices or the characteristics of the harvested product.

The various models can be partitioned according to the nature of the information asymmetry. Models with moral hazard involve the agent taking actions that are unobserved by the principal, and in models with adverse selection the agent has hidden knowledge prior to contracting with the principal. In most models with moral hazard the unobserved action is referred to as the agent's "effort". In the context of a marketing firm, effort could refer to speed of transit to market for sake of freshness, proper refrigeration to retard spoilage, advertising and promotion activities, diligence in processing, etc. The moral hazard problem arises because the principal cannot observe the agent's level of effort. However, a variable related to effort such as profits, the level of output, or the grower price may be observable. The problem is then to design a contract based on the observed variable to elicit the optimal expenditure of the unobserved variable – effort.

Suppose the principal cannot observe effort but can observe the revenue received for the product $R(E)$, $R'(E) > 0$. Given that production has already taken place, the principal's profit function is simply:

$$\pi(E) = R(E) - W(R(E)), \quad (1)$$

and the problem is to choose a payment schedule, $W(R(E))$, for the agent as a function of revenues received so as to maximize profit.

The formulation of this problem is completed by specifying a utility function for the agent, $U(W, E)$, which is increasing in W and decreasing in E , and a reservation level, U_R , of utility that specifies the agent's opportunity cost. Any contract that the principal offers must satisfy the individual rationality or participation constraint:

$$\max\{E\}U(W(R(E)), E) \geq U_R. \quad (2)$$

Second, the principal wishes the agent to voluntarily expend the level of effort, E^* , that maximizes $\pi(E)$. This condition is known as the incentive compatibility constraint:

$$E^* = \operatorname{argmax}\{E\}U(W(R(E)), E). \quad (3)$$

The payment scheme, W^* , that maximizes (1) subject to (2) and (3) is known as a forcing contract because it forces the agent to choose the level of E that maximizes the principal's profits.

An important complication is added to the problem when R is observable only with noise. This feature is especially realistic in agriculture where markets are often rather volatile. To depict this problem, let ε represent a random variable that affects revenue so that $R(E, \varepsilon)$ is the revenue function. A low observed revenue can now be due either to poor market conditions or shirking by the agent. Specification of this problem is the same fundamentally as the nonstochastic problem depicted in (1), (2), and (3) except that expected values over possible realizations of ε must be taken for π and U . Key references are Grossman and Hart (1983) and Rogerson (1985).

Risk and risk aversion may play an important role in principal-agent models with uncertainty. It will often be realistic to assume that farmers (as agents) are risk averse and a processor (as principal) is risk neutral because its stockholders hold diversified portfolios. The processor has incentive in these cases to specify contracts to shift risk away from farmers because they have to be compensated, *ceteris paribus*, to bear risk. A price schedule that is constant across realizations of random variables may accomplish this objective but will not give farmers appropriate incentives in the presence of moral hazard.⁸

⁸ Contracts which set a fixed output price do not eliminate income risk to the agent and may actually exacerbate the risk. This point is made formally by Perry (1982). Farmers will generally be exposed to risk in both their downstream markets and upstream markets. Often these risk exposures will be offsetting, as, for example, when higher input prices reduce farm supply and, thus, raise the price for the farm output. Fixing the farmer's selling price will then increase his/her exposure to income risk.

Repeated play and agent reputation may be ways of mitigating moral hazard problems, but some lessons from game theory are instructive here. In a finite horizon setting, the subgame perfect equilibrium will unravel to reveal an agent producing low quality or low effort at every opportunity if that is the optimal response for any single iteration of the game. For reputation to have its effect, the model must be specified with incomplete information as in Kreps and Wilson (1982) and Milgrom and Roberts (1982a). For example, if the principal entertains even a slight probability that the agent is predisposed to produce high quality or effort, the agent has incentive to actually produce high quality or effort to perpetuate that perception at least until the latter plays of the game.

In models of adverse selection the principal's job is to sort out agents of alternative characteristics. These situations are modeled as games of incomplete information, where Nature selects an agent's type, and the choice is unobserved by the principal. The principal then offers one or more contracts to the agent who may accept one or reject them all. Adverse selection models often involve signaling, with the agent taking actions to signal (conceal) his/her type to (from) the principal, or screening, where the principal offers a menu of contracts designed to elicit agents' types. If signaling is successful, then the various types of agents are revealed, and each can be offered a contract according to his/her characteristics.⁹ Accordingly, the equilibrium where agents' types are revealed is known as a separating equilibrium. Such equilibria are generally efficient. If signaling is not successful, then the equilibrium involves pooling across types. Such equilibria are generally not efficient as demonstrated aptly by Akerlof's (1970) famous model of the market for "lemons".

A number of conditions may attenuate adverse selection problems by facilitating the transmission of credible signals. Contracts may specify dimensions of product quality, products may be tested, and sellers may offer warranties. Adverse selection also provides a rationale for government intervention in the form of grades, licenses, and certification. Hennessy (1996) and Chalfant et al. (1999) demonstrate, however, that when grading or testing is done with systematic error, as will often be true in practice, adverse selection problems may not be attenuated. In particular, when grading involves a single quality dimension, e.g., size, grading errors will always cause the highest-quality products to be undervalued and the lowest-quality products to be overvalued.

There is considerable scope for application of models of adverse selection to agricultural markets. Consumers' emphasis on product characteristics places a premium on the sector's collective ability to provide the desired product attributes. If the marketing sector at its various stages is unable to recognize and reward quality, the message of adverse selection models such as Hennessy (1996) and Chalfant et al. (1999) is that

⁹ An example is the price at which the agent is willing to perform [Klein and Leffler (1981)]. Depending on the model specification, the high-quality firm may use either a high price or a low price as its signal. Advertising provides another mechanism to signal quality because the likelihood of repeat sales is greater for high-quality sellers than low-quality counterparts. Thus, advertising is relatively more valuable for high-quality sellers.

high quality will be driven out. The various quality provisions mandated by marketing orders and marketing boards may be justified as a response to adverse selection. If not for adverse selection, quality standards that proscribe products with certain characteristics merely limit consumers' choices. With asymmetric information, however, failure to impose quality standards also limits consumer choice by driving out high quality.

The so-called "industrialization of agriculture" in large part refers to the evolution in the vertical market arrangements governing the flow of product from farms to consumers. Driven jointly by the market's demand for quality and by technical innovations in food processing and marketing, these changes are designed to improve coordination and flow of information among participants [Barkema et al. (1991)]. An important example is the U.S. broiler industry studied by Knoeber (1989), Knoeber and Thurman (1994, 1995), and Goodhue, Rausser and Simon (1998). About 90 percent of broiler chickens in the U.S. are now produced under contract. The processing firm provides chicks, feed, and veterinary service to the producer, who provides labor and capital in the form of chicken houses. Knoeber and Thurman note that the large, sunk investments needed to raise chickens and the difficulty in transporting the farm product binds producers in most cases to a single processor. Thus, a significant risk of opportunism exists, and spot markets will be an ineffective means of transacting. They argue that willingness to commit to the capital investment in chicken houses sends a credible signal that would not be present under vertical integration and, thus, induces the self-selection of high quality producers, thereby overcoming the adverse selection problem.

Payments to broiler producers are determined by their performance (efficiency of converting caloric inputs into live weight) relative to other producers also raising broilers for the processor – a tournament arrangement. Goodhue, Rausser and Simon (1998) find empirical support for the proposition that processors also use the tournament structure as a screening device whereby high-quality growers receive larger flocks and receive flocks more consistently than low-quality growers. Knoeber argues that the relative payment scheme is an efficient way of transferring systematic production risk from the producers to the processor for whom risk is unlikely to be an important consideration. He further argues that similar arrangements have not been used in related industries because the relative scales of operation differ across these industries. For example, the number of producers per plant – 67 for broilers, 14 for turkeys, and 21 for eggs – was insufficient in the latter industries to implement a tournament structure.

Although only 15 percent of U.S. hogs were produced on contract, surveys reported by Kliebenstein and Lawrence (1995) and Hayenga et al. (1996) indicated efficiency gains to coordinated production and processing. Contracts typically specify feed formula, production facilities, and veterinary care but are not fixed price. The most cited rationale for production contracts among processors was improved quality of the farm product, while for producers market assurance and reduced price risk were cited most frequently. Johnson and Foster (1994) compared six alternative contracts in use in the U.S. and concluded that risk aversion was a necessary characteristic for producers to

prefer contracting to independent production. Contract production is also important in the Canadian hog industry. Here the primary impetus has come from feed mills who have been precluded from expanding in the dairy and poultry industries due to production quotas and, thus, have utilized downstream contracts with the hog industry to lock in stable markets. The mills supply hogs, feed, and technical services to the operation, while the producer provides facilities and labor. Contracts involve a base price plus efficiency incentive but lack the tournament feature of broiler contracts [Gillespie et al. (1997)].

Use of contracting and producer-packer integration has also been increasing in the U.S. beef industry. Government surveys suggest that from 17–23 percent of cattle supplied over 1988–94 were from such “captive supply” arrangements. Azzam (1996) has argued that vertical coordination could be an attempt by packers to offset efficiency losses due to output restrictions caused by packer monopsony power.¹⁰ A key concern in the beef industry has been the effect of captive supplies on slaughter cattle prices. The most extensive study of the use of captive supplies and the associated price effects is by Ward et al. (1996) and Ward, Koontz and Schroeder (1998), conducted as part of the U.S. Department of Agriculture (USDA) Grain Inspection, Packers and Stockyards Administration (GIPSA) study on concentration in meat packing. An important statistical determinant of the use of captive supplies was plant capacity utilization, suggesting that processors use captive supply arrangements to ensure efficient plant utilization. Price variability, however, was not an important factor. Prices for cattle purchased under forward contracts were significantly lower than cash prices, but, in general, the authors found captive supplies to have little effect on fed cattle transactions prices. However, Elam (1992) and Schroeder et al. (1993) did find an inverse relationship between the spot market price and the incidence of exclusive contracts in a region.

Additional scope for application of principal-agent models in the food chain is at the processor-retailer level, where vertical coordination issues assume increased importance over time. It sometimes may be useful to model the behavior of a large retail food chain seeking manufacturers of private-label products as a principal and the manufacturer as an agent.¹¹ However, the more common context in the IO literature considers a manufacturer as the principal and retailing firms as the agents. The objective of the manufacturer in these models is to select contractual instruments to maximize his/her profit subject to conditions similar to (2) and (3) holding for the retailer agents.¹² McCorriston and Sheldon (1997) discuss the applicability of vertical control models to food manufacturer–retailer interactions and summarize the legal status of vertical restraints

¹⁰ See Sections 5 and 6 of this chapter for discussion of packer market power in beef procurement.

¹¹ See Mills (1995), Raju, Sethuraman and Sanjay (1995), and Narasimhan and Wilcox (1998) for recent conceptual analyses of retailers’ incentives to utilize private label products.

¹² The principal vs. agent designation in processor-retailer interactions may vary depending upon country. Cotterill (1997) observes that retailers tend to dominate in the U.K., while manufacturers play a leadership role in the U.S.

in the food system under both U.S. and U.K. law. However, apart from McLaughlin and Rao's (1990) empirical study of food manufacturer-retailer interaction in new product introduction, little actual application has occurred to date.

4. Institutions and organizations in agricultural markets

4.1. Farmer cooperatives and coalitions

Explicit cooperation among sellers is a violation of most antitrust statutes, but countries often have an exemption allowing farmers to form coalitions to market their production. In the U.S. such an exemption is provided by the Capper-Volstead Act of 1922. Cooperatives collectively account for about 30 percent of farm product sales in the U.S. The share marketed by cooperatives is often higher in Western European countries, with an especially strong cooperative presence in Denmark, France, the Netherlands, and Sweden [Bergman (1995) and Hendrikse (1998)].

Two rather different possibilities have been investigated as to cooperatives' effect on market behavior. The first is that cooperatives may exert a procompetitive "yardstick" effect [Nourse (1922)]. The idea is that cooperatives have no incentive to exercise market power over their own members. Thus payments received by members of a marketing cooperative may be used as a yardstick or barometer for farmers who patronize rival, for-profit handlers to gauge and improve their treatment at the hands of these firms. Sexton (1990) derived a procompetitive yardstick effect for cooperatives as an equilibrium outcome in a formal model of spatial oligopsony. The key for a yardstick effect to emerge in this model is that the cooperative be willing or required to serve new members. A cooperative with a closed membership may actually inspire less competitive conduct from rival firms than would an otherwise identical for-profit processor.

A second way in which farmer coalitions may inspire procompetitive market outcomes is through collective bargaining with for-profit processors. There have been few attempts to develop formal models of processor-farmer collective bargaining, and there is almost no empirical evidence on the effects of cooperative bargaining.¹³ Presumably, a key source of leverage for farmers in collective bargaining is that they might integrate vertically into the processing and marketing of their production if they are unable to obtain a satisfactory agreement through bargaining. Sexton and Sexton (1987) pursued this reasoning in a two-stage noncooperative game model between a coalition of farmers and a monopoly seller of a farm input. Adapting that model to the food processing sector, in stage 1 the farmers decide whether to form a cooperative and enter processing, and in stage 2 production and trade occur. If no cooperative forms

¹³ Helmberger and Hoos (1965) utilized a bilateral monopoly model to study cooperative bargaining. However, seldom if ever do U.S. bargaining associations control the entire supply, nor do they bargain with buyers who are pure monopsonists.

in stage 1, the farmers will face monopsony pricing in stage 2. Cooperative entry in stage 1 is deterred if the processing firm is able to commit to a stage 2 “limit” price that is high enough to eliminate the farmers’ economic incentive to form the cooperative.¹⁴ Potential entry by a cooperative has a procompetitive effect on market behavior in this model if incumbent handlers are able to commit to paying farmers a favorable price. However, the model predicts that cooperative entry will occur if the incumbent is unable to commit credibly to the limit price. Inability to commit credibly forms the essence of Klein, Crawford and Alchian’s (1978) post-contractual opportunism problem, which Staatz (1984) has argued is a primary motivation for cooperative marketing.

A second possibility is that cooperatives themselves may become instruments for the exercise of monopoly or oligopoly power through the cartel selling authority the law generally grants them.¹⁵ In general, marketing cooperatives are ill suited to the practice of market power for two reasons: First, most marketing cooperatives’ output levels are determined implicitly by the levels of production chosen by their farmer members. Thus, even if farmers collectively have market power through their cooperative, the market power will not be exercised if each farmer makes production decisions independently and competitively, and the cooperative accepts and markets all of the production, as is typically true.¹⁶ Second, membership in cooperatives in market economies is voluntary, and seldom does any single cooperative control the complete market supply of a product. Without significant control of the market, attempts by a cooperative to restrict output and raise price will be undermined by free ridership. Other sellers will benefit from restriction of supply by the cooperative without bearing the cost. They will then earn superior returns relative to the cooperative, be able to bid away its membership, and undermine the attempted exercise of market power.¹⁷

¹⁴ Innes and Sexton (1993) developed a more generic model wherein no customer coalition exists, but one may emerge through a costly coalition formation process. Adapting this model to a food processing context, the analysis shows that, if a monopsony processing firm can practice price discrimination, it can deter a cooperative coalition from ever forming by adopting a set of prices that “divide and conquer” the farmers. Such an incumbent strategy vitiates the procompetitive effects cooperation among farmers would otherwise have.

¹⁵ Jesse et al. (1982) discuss cooperative conduct within the context of U.S. antitrust laws, including the Capper-Volstead Act. Garoyan (1987) examines cooperation in the European Community within the context of EC antitrust regulations.

¹⁶ Notably some recent theoretical models have been constructed on the premise that a cooperative will regulate the amount of member production and sales. Both Tennbakk (1995) and Bergman (1995) developed Cournot duopoly models involving competition between a cooperative and a for-profit seller. The cooperative’s goal in Tennbakk’s model is to maximize its members’ joint welfare as producers of the farm product and as sellers of the processed product. The cooperative thus sells more than would an otherwise identical for-profit processor whose objective is maximizing seller profit only. As such, a better market performance is achieved when one of the duopolists is a cooperative than when both are for-profit sellers.

¹⁷ This problem is closely analogous to the well-known problems faced by traditional price leaders. The price leader must regulate its own output to maintain the price it sets, while other sellers, usually modeled as a competitive fringe, sell freely at that price.

One key to discerning whether and when cooperative market power is an issue is to ascertain situations when these conditions do not hold. U.S. cooperatives have the legal right to restrict membership and limit members' deliveries, although comparatively few exercise these rights. Conversely most European cooperatives must maintain open membership to qualified producers and may not limit deliveries.

Even without the power to regulate total sales, a cooperative may control the flow of its product across alternative market outlets and engage in price discrimination. This is the key form of anticompetitive behavior that has been alleged against U.S. marketing cooperatives, especially in the dairy industry. Masson and Eisenstat (1980) estimated that U.S. dairy cooperatives inflated the price of fluid milk to U.S. consumers and caused an annual social loss of \$71 million for 1967–1975, due to a combination of deadweight losses and other efficiencies, before the behavior was halted by antitrust action. A subsequent study by Madhavan, Masson and Lesser (1994) focused on the monopoly power of a single cooperative, the Associated Milk Producers, Inc., and concluded that it was able to raise margins by \$0.026 per gallon prior to the 1975 consent decree.¹⁸ With free entry into production of the farm commodity, successful price discrimination by cooperatives actually leads over the long run to production in excess of the competitive output level because the price paid to farmers with price discrimination (a blend of prices for fluid and manufacturing milk) will exceed the market equilibrium price in the absence of such discrimination.

There are a few other examples of U.S. antitrust actions against agricultural cooperatives. The Federal Trade Commission (FTC) in 1977 charged Sunkist Growers with monopolizing the California–Arizona citrus industry. This case was settled by a consent decree in 1981. Mueller, Helmberger and Paterson (1987) presented a critical analysis of the FTC case, which apparently unfolded without giving much, if any, consideration to the two points noted above. An FTC case (eventually dismissed) against the Central California Lettuce Producers Cooperative alleging monopolizing behavior was analyzed by Sexton and Sexton (1993).

A few studies have attempted to measure the general impact of cooperatives on market performance. Wills (1985) used an SCP framework to analyze prices in the U.S. for cooperative brands relative to prices for leading noncooperative brands. In all cases the prices for cooperative brands were lower than prices for comparable noncooperative brands with similar advertising and market shares. However, as Wills himself noted, criticisms of cooperative market power have not been leveled against cooperative branded products. Haller (1993) studied the impact on prices of cooperatives' participation in a single market – cottage cheese – for 47 U.S. metropolitan areas. Haller also found that co-op brands are likely to be priced lower than non co-op brands, *ceteris paribus*, and

¹⁸ Baumer, Masson and Masson (1986) argued that the monopoly power needed in U.S. milk markets to exercise price discrimination over and above that mandated through U.S. marketing orders (see Section 4.2) was caused by a wave of mergers among milk marketing cooperatives during the 1960s. The mergers were not challenged in the belief that they were protected under the Capper–Volstead Act.

also that a yardstick-of-competition effect apparently exists in the market because the presence of one or more cooperatives in the market was associated on average with a 4.1 percent decline in brand prices in the market.

Petraglia and Rogers (1991) examined the effect of cooperative participation on relative price-cost margins in 136 U.S. food and tobacco industries. The results showed a negative and significant relationship between cooperatives' share and the price-cost margin. Interpretation of this result is somewhat clouded because the price-cost margin may include both monopsony and monopoly power components. If cooperatives cause more competitive pricing in the procurement of raw agricultural products, relative margins would fall due to diminution of monopsony power.

4.2. Marketing orders

The U.S. Agricultural Marketing Agreement Act of 1937 and parallel state-level legislation allow farm industries to act collectively for purposes of financing research and advertising, setting grades and standards, and regulating industry sales. Marketing orders are implemented by initiative from the industry involved. Federal orders must have the concurrence of the Secretary of Agriculture and a two-thirds affirmative vote (based either on the number of voters or on the volume of product marketed) from the farmers who will be subjected to its provisions. Depending upon the provisions of the order, agreement of handlers who control at least 50 percent of the product's volume may also be required. If an order is implemented, its provisions become legally binding upon all industry participants.

Marketing orders enable an agricultural industry to act as a cartel. Although a centralized authority may be innocuous or even socially beneficial for coordinating expenditures on advertising and research, its use to regulate the amount and distribution of product sold may have significant market power implications. Jacquemin and Slade (1989) list four prerequisites to achieving market power through a cartel: (1) an agreement must be reached, (2) cheating must be detectable, (3) cheating, once detected, must be punished, and (4) outside entry must be deterred. Marketing orders solve the first and the third of these problems, and have some influence on the second. Their mandatory nature facilitates reaching a *de facto* agreement, i.e., if an order is enacted, even dissenting participants must abide by its provisions, and defectors are subject to legal penalties. Heuristic evidence indicates that cheating on agreements is a problem in U.S. marketing orders, but at least the orders can provide resources for monitoring compliance.¹⁹ Orders, however, generally do not prevent entry into an industry; nor can they regulate producers' behavior outside their geographic boundaries.

¹⁹ The most extensive evidence of cheating involves the federal orders for Arizona and California oranges and lemons. The USDA's decision to terminate those orders in 1994 was primarily in response to several lawsuits that had been filed over alleged cheating on the orders' provisions.

Only a few studies involve formal analysis of how agricultural cartels do make or should make decisions on volume allocations. Elementary analysis is merely to apply static monopoly models and assign volume controls or choose allocations of product among multiple markets so as to maximize short-run profits. Use of the monopoly model to study behavior by marketing orders is questionable. First, those with a generally favorable attitude towards U.S. orders argue that orders are used to stabilize as well as increase returns to U.S. farmers [USDA (1981), and French (1982)]. Thus, a risk-reduction role is imputed to the orders. Second, because of the importance of outside entry to an order's long-run effectiveness, it might be argued that orders will employ some form of dynamic limit pricing to deter or at least diminish outside entry.

Berck and Perloff (1985) developed a dynamic analysis that took account of effects of marketing order policies on entry. The rate of entry was modeled as a simple function of entrants' expected profits. Each member of the order was assumed to maximize discounted profits subject to the entrants' decision rule. The main result is that members of the order will vote at each point in time to maximize instantaneous profits, i.e., no attempts at entry deterrence will be made. The reason is that the order cannot commit over time to a strategy that reduces profits. Since the order cannot influence entry, it is best off maximizing current period profits. The time path of prices is downward under this trajectory because entry occurs. Thus, each period's static profit maximizing price is lower than the previous period's price until a steady state is reached in which the marginal entrant earns zero profits. Cave and Salant (1995) employed median voter decision theory to show that heterogeneity among the marketing order's membership, both in terms of capacity and per-unit costs, causes the marketing order members to vote for quotas that do not maximize static profits and tend to discriminate against the largest producers.²⁰ Their model takes no account of the effect of the cartel's decisions on entry.

Alston et al. (1995) studied optimal output strategy for the California almond marketing order over a 50-year horizon, given potential entry into almond production from within California and from Spain, the main producer outside of California. A distinction between these two types of entry is important because California entrants would fall under the auspices of the order and their production could thus be regulated, whereas Spanish producers are not subject to the order's authority and can free ride on any volume control efforts by California. Alston et al. used dynamic programming to derive a 50-year, open-loop trajectory for the industry's sales and allocations between domestic and export markets, i.e., the industry was assumed to commit at the outset to its strategy and there is no revision. Although this assumption is unrealistic, the results from the analysis are illuminating from a normative context because they demonstrate the

²⁰ This result has a political economy appeal. Because U.S. orders derive their authority from the government, an order that exercises only modest power and supports smaller farmers is apt to garner more political favor than an order that selects the monopoly solution at each opportunity.

industry's incentive to engage in entry deterrence if it can overcome the commitment problem noted by Berck and Perloff. The optimal strategy called for the industry to refrain from exercising much cartel power in early periods of the horizon and instead to dump product in export markets where Spanish sales were concentrated, thereby discouraging future Spanish production.²¹

The short-run impacts of marketing orders may be relatively easy to discern when the primary purpose of the order is to price discriminate among multiple market outlets. Ippolito and Masson (1978) analyzed the welfare cost of U.S. milk marketing orders for 1973 by exploiting the actual price differential between milk sold for fluid consumption versus manufacturing uses. They estimated the cost differential to be about \$0.15 per hundred lbs., but actual fluid versus manufacturing price differences were as high as \$1.26. Transfers to producers in 1973 dollars were estimated at \$210 million, with deadweight losses estimated at \$60 million.²² Somewhat higher loss estimates were obtained by Kwoka (1977), who estimated an econometric model of the U.S. dairy market and then used the model to predict market outcomes in the absence of regulation. Kwoka concluded that fluid milk prices were raised from 7 to 15 percent above competitive levels with deadweight losses in the range of \$55 to \$180 million annually for 1960–70.

Powers (1992) utilized the price differential between fresh oranges and processing oranges and methods of the new empirical industrial organization (NEIO – see Section 5) to measure the extent to which the California–Arizona navel orange order was successful in exercising monopoly power in allocating oranges between fresh and processed use. He first obtained estimates of the demands in the fresh and processed markets and then expressed fresh versus processed market price differential as the solution to a profit maximization problem. Monopoly power was measured in terms of a parameter, θ , that ranged from 0 (perfect competition) to 1 (pure monopoly). Results for 1965–89 data indicated modest but statistically significant monopoly power, with point estimates of θ ranging from 0.18 to 0.44. Market power was found to decrease after 1983 when the USDA implemented rules that limited the number of weeks that allocation restrictions were in effect.

Occasionally, suspension of an order's provisions provides a natural experiment as to the regulation's effect on market behavior. Thompson and Lyon (1989) used reduced

²¹ Of course, implementation of such a strategy may well run a foul of international trade agreements.

²² Analysis of market power abuses by U.S. cooperatives is often difficult to disentangle from the effects of marketing orders. Strong U.S. cooperatives have often been rather effective in controlling decision making under marketing orders. Examples are citrus marketing, which has been dominated by the Sunkist cooperative [Rausser (1971) and Shepard (1986)], and Florida celery, where sales are regulated by a marketing order and all sellers belong to a single cooperative [Taylor and Kilmer (1988)]. Rausser (1971) argued that failure of attempts at market control through cooperatives in the California–Arizona orange industry in the early 1900s due to free ridership led to formation of the federal marketing order in 1933. U.S. milk marketing is regulated by marketing orders, but cooperatives also dominate various regional markets. Masson and Eisenstat (1980) argued that the cooperatives were able to achieve price discrimination over and above what was mandated through the marketing orders.

form models of the farm-retail price spread and estimated that the suspension in 1985 of the California–Arizona orange prorate caused a reduction in the price spread of about \$0.01 per lb. This work was subsequently criticized by Powers (1991), whose own estimates suggested that the price spread *increased* by about \$0.01 per lb. during the periods of suspension. An increase in the proportion of sales allocated to fresh uses should decrease both retail and farm prices, making the effect on the price spread ambiguous and perhaps explaining why both Powers and Thompson and Lyon obtained small and opposite predicted effects.²³

Another approach to studying the effects of marketing orders, exemplified in work by Kwoka (1977) on U.S. milk, Rausser (1971) and Shepard (1986) on California–Arizona oranges, Kinney et al. (1987) on California–Arizona lemons, and French and Nuckton (1991) on California raisins, is to estimate a complete econometric model of the industry at issue. Although Rausser represented marketing order decision making in terms of a multi-attribute utility function, the more common practice has been to utilize a “reduced form” specification of volume control and/or market allocation decisions made under the marketing order rather than model these decisions as solutions to formal optimization problems. French and Nuckton, for example, specified the volume of raisin tonnage marketable under the order as a function of current deliveries plus inventories, previous year’s price of raisins, and domestic movement. Following estimation of the model, simulations are then run wherein the effects of the marketing order are “removed”.

This approach has the potential to discern the long-run impacts of volume control. However, it is subject to the well-known Lucas critique [Lucas (1976)] that important policy changes influence the structure of the underlying economic model, invalidating policy simulations that impose a given structure. These industry models are generally estimated with data gathered over a period when the order was in existence and, thus, the estimated parameters reflect that structure. Abolition of an order would change the structure of the industry. For example, a key argument by proponents of volume regulation is that the controls stabilize returns in the industry, which encourages greater production, *ceteris paribus* [Shepard (1986) and French and Nuckton (1991)]. Implicitly this argument assumes producers in the industry are risk averse. However, in the absence of a risk reduction mechanism, we would expect to see the industry populated by producers, such as diversified agribusiness firms, who are either not concerned with

²³ A rather opposite perspective on the effects of citrus volume regulations is provided by Richards et al. (1996). These authors argue that the primary purpose of the order is to enable growers to countervail market power by food retailers and that suspension of the order enabled retailers to exercise monopsony power over growers and monopoly power over consumers, i.e., suspension of the order was argued to shift monopoly power from growers to retailers. According to this argument, suspension of the order would widen the farm-retail price spread. The authors utilized a NEIO model to produce estimates that support this hypothesis. A major factor complicating the analysis of suspension of volume controls for lemons and oranges is the well-known phenomenon that retail prices for produce commodities are less variable than farm prices and moreover respond more to increases in the farm price than they do to farm price decreases. The existence of this pricing phenomenon in the lemon market was confirmed by Pick, Karrenbrock and Carman (1990).

risk or are readily able to diversify so as to avoid its effects. Thus, supply response estimates that embody the existence of the order cannot be relied upon to simulate behavior in its absence.

4.3. Marketing boards and state trading enterprises²⁴

Another form of government intervention in the market is through the creation of a state-trading enterprise (STE), alternatively referred to as a marketing board or single-desk seller. The functions of these entities vary. Many STEs have sole authority to control the amount and destination of exports for their home country. Such STEs are especially prevalent in the grain and dairy industries where 16 STEs exporting wheat and 10 exporting dairy products have been reported to the World Trade Organization [Ackerman et al. (1997)]. STEs are also common in key industries in developing countries [Arhin et al. (1985)], where they may have responsibility for fixing prices to farmers and domestic consumers as well as export selling. Examples are country marketing boards for cocoa, groundnuts, and grains in tropical Africa. Finally, some countries also give STEs sole buying authority for imports. Rice purchases, for example, are controlled by STEs in Indonesia, Japan, and Korea.²⁵ There is a concern that STEs circumvent the Uruguay Round commitments on export subsidies, market access, and domestic support, and that STEs, “through their monopoly powers and government support, may have the ability to distort worldwide trade in their respective commodities” [U.S. General Accounting Office (USGAO) (1996, p. 4)].

A basic disagreement concerns what types of activities constitute state trading. Quasi public or public boards or corporations such as the Canadian and Australian wheat boards (CWB and AWB) represent clear and obvious examples of state trading. In contrast, wheat trade in the U.S. is in the hands of private traders, but the U.S. government historically has intervened in the market through price and income stabilization policies and policies to target exports, most recently through the Export Enhancement Program. Skully (1992) argues that U.S. behavior in wheat exports is consistent with a model of an STE. We limit our consideration to situations when actual marketing decisions are controlled by the state trader.

Three aspects are important in modeling the behavior of STEs in a given market. The first is to specify correctly the objective function(s) of the STEs participating in

²⁴ Our discussion focuses on situations where industry policy is enacted by autonomous or semiautonomous enterprises or boards. We do not focus on instances where supply controls are imposed upon an industry as part of a government price and income support policy. Good examples of such policies are the U.S. tobacco and peanut programs [see Rucker et al. (1995) and Rucker and Thurman (1990), respectively]. These policies, when combined with import controls, as is common, have the effect of creating market power for the domestic industry and monopoly rents to the holders of the quota. However, the existence and structure of such programs are fundamentally products of the political process and are beyond the scope of this chapter.

²⁵ STEs may translate their single-buyer authority into a monopoly power over the domestic market by purchasing grain at world prices and then reselling it at higher prices in tightly controlled domestic markets, thus earning rents for the treasury.

the market. STEs are complicated institutions that have various levels of government intervention. They may pursue multiple and varied objectives, given the pressure that they face from different interest groups. Hoos (1979), Kostecki (1982), and AHV (1985) provide an overview of the role and mandate of STEs in various countries and industries. In many of the developed country examples, the stated goal of the STE is to act in the interests of the home country producers, although there is disagreement as to what this goal may mean in practice. In the case of the CWB, McCalla (1966) assumed that its goal is maximization of sales. Conversely, Alaouze, Watson and Sturgess (AWS) (1978) assumed that the CWB maximizes revenues. Grennes and Johnson (1979), in turn, criticized AWS for ignoring the costs of marketing. More recently, Thursby and Thursby (1990) assumed that the CWB pursues maximization of producer returns, and Carter, Loyns and Berwald (1998) analyzed the behavior of the CWB using a model of bureaucratic decision making wherein the CWB's objective is to maximize its revenues in the handling market.

The problem of identifying an appropriate objective function is even more severe for the developing country applications. Producer welfare may take a back seat to the goal of generating revenue for the treasury or, when the STE controls a staple commodity such as a food grain or oilseed, to the goal of providing cheap food to domestic consumers. Implementation of these goals would cause the STE to act as a monopsonist in making purchases from farmers and to exploit whatever monopoly power it had in export markets, but prices to domestic consumers may be set below cost. Franco (1981) discusses how oppressive taxation of the cocoa industry in Ghana by the Cocoa Marketing Board contributed to the demise of a major industry. Beghin and Karp (1991) propose modeling STE behavior in these settings as the outcome of a bargaining game among farmers and consumers, who each seek to maximize utility, and the STE which seeks to maximize tax revenue.

Finally, farmers in developing countries often have limited financial reserves, poor access to credit markets, and few opportunities to diversify production, thus making income risk a dominant concern. STEs in these settings may add a price stabilization function to their menu of objectives. Cardenas (1994) examines the interplay of revenue generation and income stabilization goals for various state traders in coffee.

The second important aspect of modeling trade in the presence of STEs and marketing boards is to recognize STEs' participation in the market by incorporating their behavior into the model. Early research investigating imperfect competition in trade focused mainly on the wheat industry and did not take into account the presence of market intermediaries. Instead, the countries were considered as agents with market power. The various models proposed for the world wheat market were based on casual empiricism and, for the most part, not tested: U.S.–Canada duopoly [McCalla (1966)], U.S.–Canada–Australia triopoly [AWS (1978)], EC–Japan duopoly [Carter and Schmitz (1979)].

Kolstad and Burris (1986) developed a spatial equilibrium model in which countries acted as Cournot competitors in the international wheat market and used nonnested tests to examine the alternative hypotheses of conduct in the international wheat market put forward by other authors. For the crop year 1972–1973, their results supported Mc-

Calla's view that the world wheat market is best depicted as a U.S.–Canada duopoly as opposed to a U.S.–Canada–Australia triopoly or an EC–Japan duopsony. These characterizations of the market are controversial. For example, the U.S. exports wheat through private traders but the government intervenes in the market with income support programs and targeted export subsidies, so it is unclear whether the U.S. should be considered as a market agent. Neither the AWB nor the CWB control production, and thus their difficulty in exercising market power is similar to that of a marketing cooperative that has open membership and open production. For both McCalla and AWS, market power was associated with the willingness and ability of the STE to hold stocks. However, either the CWB's or AWB's ability to hold stocks to increase prices is limited both by storage capacity and the need to clear stocks annually to make room for the next year's harvest.

The third aspect in modeling trade involving STEs and marketing boards is considering their strategic interactions with other STEs/marketing boards and private firms. Thursby (1988) and Thursby and Thursby (1990) studied the strategic interactions between STEs, which were assumed to maximize producer returns, and private firms, which were assumed to maximize profits. Thursby (1988) analyzed how the presence of state trading and the competitiveness of private trade affects optimal governmental policy. She used a model where a marketing board and private exporters act as Cournot rivals, given government policies, in a world market for a competitively produced good. Thursby and Thursby (1990) did not constrain competition to be Cournot but, rather, used conjectural variation parameters to allow for a range of behavior.

Krishna and Thursby (1992) studied optimal tax/subsidy policies in a model with duopoly STEs.²⁶ The STEs were assumed alternatively to pursue a profit maximization objective, wherein monopsony power over domestic producers would be exploited, or a producer surplus plus export revenue maximization objective. Results demonstrate the sensitivity of policy prescriptions to the behavioral goal of the STE and, thus, emphasize a key difficulty in analyzing markets with one or more state traders when the underlying objective function is not transparent.

Various studies have focused directly upon measurement of the market power exerted by particular STEs. Buschena and Perloff (1991) used a dominant firm and competitive fringe model of the world coconut oil export market to examine the competitiveness of the Philippines' coconut exports before and after the creation in 1973 of the Philippines Coconut Authority (PCA). The estimated Lerner (1934) indexes were 0.41 at the mean of the pre-PCA period (1959–73) and 0.89 at the mean of the post-PCA period (1974–87), indicating that PCA exercised substantial market power.²⁷ Love and

²⁶ Their work extends a fundamental contribution by Just, Schmitz and Zilberman (1979), who first demonstrated that export taxes or subsidies were necessary to maximize welfare (the sum of producer and consumer surplus) in the home country when trade is distorted by either a monopoly/monopsony middleman or a state trader who maximizes producer welfare.

²⁷ The Lerner index [Lerner (1934)] measures the proportional deviation of price p from marginal cost c , i.e., $L = (p - c)/p$.

Murniningtyas (1992) considered the simultaneous exertion of market power in both domestic and foreign markets of the Japanese Food Agency, a major wheat importer, and found that it exercised a high degree of monopsony power in the world market (in fact, more than the theoretical pure monopsony solution) but no monopoly power in the domestic market. Kraft, Furtan and Tyrchniewicz (1996) did not measure market power *per se* but concluded that Canadian wheat producers realized on average \$13.35/ton more from 1980–94 with the CWB than what would have been realized by multiple sellers.

STEs and marketing boards might also exercise market power through price discrimination. The pricing to market (PTM) approach [e.g., Goldberg and Knetter (1997)] is a common tool to test for price discrimination in trade. The basic PTM model [Knetter (1989)] specifies a single product with n destination markets. The conceptual framework involves simply expressing the markup of price over marginal costs in each destination market as a function of the residual demand elasticity in the market. Application involves a cross section of destinations observed at multiple points in time. Knetter used a fixed-effects model, where price at time t to destination i was expressed as a function of time γ_t and destination λ_i indicator variables (one destination variable must be omitted) and exchange rate, E :

$$\ln(p_{i,t}) = \gamma_t + \lambda_i + \beta_i \ln E_{i,t} + \varepsilon_{i,t}.$$

In a competitive market, both destination and exchange rate effects are zero. Variations in the λ_i relative to the base country may signal market power through exploiting different residual demand elasticities among the destinations, or might be due to differences in quality of product shipped to the destinations. However, nonzero estimates of the β_i reveal price discrimination even with product differentiation.

Using this approach, Pick and Park (1991) found that among U.S. exports of wheat, corn, cotton, soybean, and soybean meal and oil, the strongest evidence against a competitive market structure was in the wheat market.²⁸ Yumkella, Unnevehr and Garcia (1994) found evidence of market power in certain market segments for high-quality rice. They also found price discrimination across destinations in the U.S. and between Thai long grain exports and U.S. parboil exports. Patterson, Reza and Abbott (1996) also found some evidence of discriminatory pricing across markets and in support of the PTM hypothesis for U.S. chicken, fresh or chilled beef, and frozen beef exports.

A problem in the PTM literature is that price discrimination is sometimes investigated empirically without first considering its feasibility. Most food industry PTM studies have focused on U.S. exports where no centralized trading authority exists. Price

²⁸ Results from an SCP model estimated by Patterson and Abbott (1994) provide support for the Pick and Park conclusion. The export price markup over farm value for wheat was positively related to both U.S. market share and the concentration measure (Herfindahl index divided by import elasticity of demand) for a pooled data set of 98 countries and the marketing years 1979–89, suggesting that U.S. exporters are able to discriminate relatively more in concentrated markets and in markets dominated by U.S. exports.

discrimination among foreign markets is difficult to rationalize when there are multiple selling agents, unless there is collusion among them. Results attributed to price discrimination might alternatively be evidence of product heterogeneity and/or data aggregation problems. However, price discrimination may emerge through government involvement – for example, in the form of export subsidies. In Kallio's (1997) model of export competition between the EU and U.S., government moves first and acts as a Stackelberg leader in choosing export subsidies, taking into account exporting firms' subsequent reactions.

Kazmierczak, Zapata and Diop's (1997) study of Mauritanian octopus exports is an example of applying the PTM model in an industry where a powerful state trader exists. Results supported the PTM hypothesis and indicated that the state trader utilized price discrimination to stabilize price in the importing countries. The PTM studies reveal information only about the power of state traders as sellers. To date, we have almost no statistical analysis of monopsony power exercised by state traders.

5. Static models of food markets under imperfect competition

Most formal models of food marketing assume that all marketing functions are performed by an integrated marketing or processing sector that buys raw product from farmers, converts it into a finished product by performing various functions, and then sells the finished product to consumers. Static models of marketing firm behavior in agriculture can be partitioned according to the assumptions made regarding the role played by the farm product in producing the finished consumer product. One class of models, based upon the tradition of Gardner (1975), treats the farm product as an ordinary input in a variable proportions production process to produce a homogeneous finished product. Substitution possibilities between the farm product and other inputs, often represented by a composite "marketing" input, are important in these models. A second class of static structural models is based upon classic work by Bressler and King (1970) and George and King (1971). These models assume that no substitution exists between the farm product and final products produced from it, although there may be substitution among the processing inputs.

5.1. Homogeneous product models with variable proportions

The Gardner framework was extended to an imperfectly competitive industry by Holloway (1991), who considers only departures from competition by marketers as sellers. Let Q denote output of the finished product, R the volume of farm product input, and X the quantity of marketing input. Inverse retail demand is

$$p = D(Q, N), \quad (4)$$

where p is retail price and N denotes unspecified demand shifters.

We follow a notational convention whereby firm-level quantities are denoted by the equivalent lowercase of the uppercase letter denoting market quantities. Production costs in the Gardner/Holloway framework are derived from a neoclassical production function, which, given the notational convention, can be written as $q_i = f(r_i, x_i)$, where $i = 1, \dots, n$ denotes firms in the processing sector. When the subscript to denote firms is inessential, we will dispense with it and consider a representative firm. The function $f(\cdot)$ is assumed to be homogeneous of degree 1, and, therefore, processors have constant marginal costs:

$$C = c(w, v)q, \quad (5)$$

where w and v denote, respectively, the prices of the farm product and the processing input, and marginal costs are $c(\cdot)$.

A key feature of any model of imperfect competition is the manner in which rival firms respond or react to one another. In contrast, in perfect competition firms recognize no active rivalries, and in monopoly or monopsony no direct rivalries exist. Most authors of static structural market models of imperfect competition in agriculture, including Holloway, have used the paradigm of conjectural variations. Firms choose quantities of sales in Holloway's model, so the conjecture concerns how industry output will respond to a change in the given firm's output. The firm is assumed to envision a relationship of the form $Q = K_i(q_i)$. The conjecture written in elasticity form is then

$$\theta_i = \frac{\partial Q}{\partial q_i} \frac{q_i}{Q}. \quad (6)$$

A processing firm's variable profit can be written as

$$\pi_i = D(Q, N)q_i - c_i q_i. \quad (7)$$

Using the conjectural variation expression in (6), the first-order condition to maximize (7) can be written as

$$p \left(1 - \frac{\theta_i}{\eta} \right) = c_i, \quad (8)$$

or in Lerner index form (note 27) as

$$\frac{p - c_i}{p} = L = \frac{\theta_i}{\eta}, \quad (8')$$

where η is the absolute value of the price elasticity of retail demand. Under rather stringent assumptions discussed in detail by Appelbaum (1982), the condition in (8) can be

aggregated to obtain an industry equilibrium condition where $\theta_1 = \theta_2 = \dots = \theta_n = \theta$.²⁹ Equation (8') indicates that the anticompetitive effects of seller oligopoly power are determined by processor conduct, as measured by θ_i , in conjunction with η . Elastic demand moderates the harmful effects on market performance of oligopoly power, whereas inelastic demand exacerbates the impact.

The great virtue of θ is that it is bounded in the unit interval, $\theta \in [0, 1]$, and, hence, represents an index of market power. Perfectly competitive behavior is denoted by $\theta = 0$ (i.e., the firm anticipates that market price and, hence, output will not change in response to its change in output), and $\theta = 1$ denotes monopoly or perfect collusion (i.e., the firm believes that industry output will change by a percentage equal to its own percentage change in output). Various models of oligopoly behavior, including Cournot, are represented by values of θ between these polar cases, with higher values of θ denoting more significant departures from competitive behavior.³⁰

Given the necessary assumptions for aggregation to the market and an assumption on market conduct (specified in the form of a value for θ or a rule for determining θ), Equations (4), (5) and (6) describe a complete model of the finished product market which can be solved to yield equilibrium values for Q and p . Given appropriate choices of functional forms for (4) and (5), this model may be used empirically to estimate θ and, thus, test for various types of market behavior.

The model as specified is short run in nature and offers no explanation for the exogenous number, n , of processing firms. Holloway (1991) employed a simple convention to convert the model to a long-run solution. He allowed for nonzero fixed or set-up costs, F , and then imposed a zero profit entry condition, thereby making n endogenous to the system:

$$pq_i - c(\cdot)q_i - F = 0. \quad (9)$$

Holloway derived input demand functions for R and X by applying Shephard's lemma to (5) and then simplified the model by assuming that X was in perfectly elastic supply to the industry and R was in perfectly inelastic supply. The first condition merely requires that the farm industry be a sufficiently small user of X so that changes in its usage do not affect input price, v , which can then be treated as exogenous even with aggregation to the industry level.

Exogenous farm supply is often appropriate, given the biological lags between planting decisions and subsequent harvest, which range from months for annual crops and

²⁹ The requirement essentially is that all firms have identical marginal costs, $c_1 = c_2 = \dots = c_n = c$, but fixed costs, if any, may differ. The alternative procedure utilized to aggregate the firm-level condition to the market is to weight the individual supply relationships by market shares and then add them up to obtain an industry supply relationship of the form $p(1 - \theta/\eta) = \sum_i s_i c_i$, where $s_i = q_i/Q$, and $\theta = \sum_i s_i \theta_i$ [Porter (1983)].

³⁰ The Cournot case is clarified by first writing $Q = q_i + Q_{\sim i}$, where $Q_{\sim i}$ denotes output of all firms except firm i . Then $\partial Q/\partial q_i = 1 + \partial Q_{\sim i}/\partial q_i$. Cournot competition is represented by $\partial Q_{\sim i}/\partial q_i = 0$, so $\theta = q_i/Q = s_i = 1/n$ with homogeneous processing firms.

some livestock to several years for perennial crops. A problem, though, is created in modeling competition in the farm product market when there is inelastic supply; it is not possible to model firms' behavior in this market analogously to what was done in the output market because supply is exogenous and a derivative $\partial R/\partial r_i$ is not defined. Holloway avoided the problem by assuming perfect competition in the farm product market.

Holloway did not estimate values for θ . Instead he derived the comparative static implications of the model under the assumption of perfect competition and then tested these restrictions econometrically under the null hypothesis of perfect competition, $H_0: \theta = 0$. Holloway did not reject the null hypothesis for any of the eight aggregate commodity categories he analyzed and concluded that "any departures from competition have been relatively insignificant" [Holloway (1991, p. 986)].³¹

Several other studies have utilized this same basic model structure to derive point estimates of θ as their basis for testing competitiveness of the market. These applications follow closely the work of Appelbaum (1982), who specified the demand function (4) in double log form and the marginal cost function (5) in generalized Leontief (GL) form.³² The first application of this model to agriculture was by Ramon Lopez (1984), who examined oligopoly power in Canadian food processing. An ambitious recent application is by Bhuyan and Rigoberto Lopez (1997), who tested for oligopoly power in each of 40 U.S. food industries classified by four-digit SIC code.

Because both demand and supply relationships are being estimated, it is necessary to estimate the system using simultaneous equation methods. An issue arises as to whether the market power parameter θ is identified. Identification is achieved easily in direct applications of Appelbaum's model because the cost function is restricted to satisfy homogeneity of degree 1 in the input prices. This restriction guarantees that any appearance of Q in the marginal cost function must be in a form interactive with the input prices, v . Generally analysts go even further and assume a constant returns technology, so output is not an argument at all in the marginal cost function. Accordingly, all coefficients in the supply relationship (5) not associated with input prices are indicators of market power.

Alternatively, θ can be identified from rotations (as opposed to shifts) of the market demand curve [Bresnahan (1982) and Lau (1982)]. In analyses of oligopsony power, rotations of the farm product supply curve are needed. The first application of this idea was Just and Chern's (1980) analysis of oligopsony power in the California tomato processing industry. They argued that substitution of a fixed capital input (the mechanical harvester) in place of a variable input (farm labor) made farm supply less elastic,

³¹ Holloway's product categories (beef and veal, pork, poultry, eggs, dairy, processed fruits and vegetables, fresh fruit, and fresh vegetables) are in general much too broad (see Section 7) in terms of market definition to constitute serious tests for market power.

³² Among the class of so-called "locally flexible functions", the GL is generally preferred in these applications because it permits a more convenient specification of marginal costs than does, say, the translog.

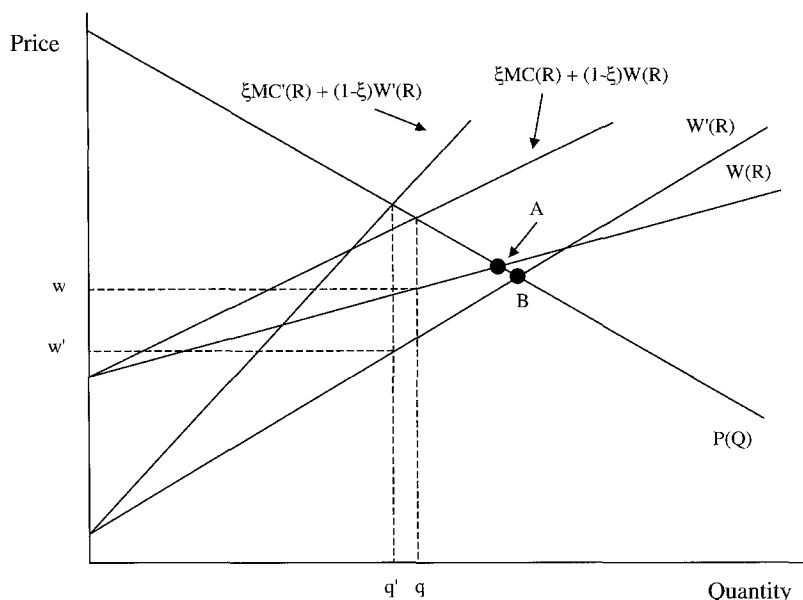


Figure 1. Ambiguous quantity effect of a supply shift under oligopsony.

offering a natural experiment wherein a competitive market's response could be distinguished from the response of a market with oligopsony power. Whereas the competitive model predicts unambiguously that the supply shift will lead to greater production of the farm product as in the movement from equilibrium point A to equilibrium point B in Figure 1, the effect is ambiguous in the oligopsony model because the impact of the supply shift is offset by the change in slope which favors increased oligopsony distortion and, thus, lower farm production. Figure 1 illustrates an oligopsony equilibrium where the supply shift reduces output from q to q' .³³ Additional applications in agricultural product markets of the rotation method include Buschena and Perloff (1991) on coconut trade, Love and Murniningtyas (1992) on wheat trade, Azzam and Park (1993), Muth (1996) and Muth and Wohlgenant (1999) on U.S. beef, and Deodhar and Sheldon (1997) on soybean trade.

The choice of identification principle should depend upon the specific application and the types of data available. The demand (supply) rotation method requires the presence of one or more exogenous variables that interact with price to determine demand (supply). It also requires implicitly the ability to estimate demand or supply precisely, but many applications that use a flexible cost function to achieve identification do not estimate consumer demand or farm supply at all, relying instead on extraneous estimates

³³ Chen and Lent (1992) and Hamilton and Sunding (1997) provide general comparative static analyses of the effect of farm supply shifts under imperfect competition.

to get the necessary elasticities.³⁴ Reliance on the rotation method may give the analyst more freedom to creatively specify the cost relationship. This consideration is important in the Muth (1996) and Muth and Wohlgenant (1999) applications because each study hypothesizes that economies of scale in beef packing may have caused false inferences of market power by other analysts. Given identification by the rotation method, they were able to adopt parsimonious specifications of the processing cost relationship that allow for economies of scale (but do not necessarily satisfy homogeneity in input prices), as opposed to the assumption of constant returns to scale employed in most applications of Appelbaum's model.

The analyst also faces the choice of whether to estimate θ as a constant parameter or to specify it as a function of exogenous variables in the system. As documented in Section 2, many agricultural markets face increasing concentration with concerns that higher concentration will result in less competitive behavior. Given that the typical application will analyze two or more decades of industry-level time series data, an obvious approach is to specify θ as a function of market structure variables that are hypothesized to have an impact on processor conduct.

This basic market model has also been used to conduct tests for market power based on nonparametric methods [e.g., Hanoch and Rothschild (1972), Varian (1984)]. Ashenfelter and Sullivan (1987) extended the nonparametric methodology to incorporate the possibility of monopoly power. Love and Shumway (1994) extended the approach to the analysis of monopsony power in agriculture.

Consider an industry where only monopoly power is at issue and the firm-level profit equation is (7). If the industry is a monopoly or perfect cartel, then for any observed output, Q , any deviation, ΔQ , in output must reduce profit based upon the following condition:

$$p\Delta Q + Q[P(Q + \Delta Q) - P(Q)] \leq c\Delta Q, \quad (10)$$

where the left-hand side of (10) represents a discrete form of marginal revenue and the right-hand side is a discrete form of marginal cost.³⁵ Conversely, if the industry were competitive the condition for profit maximization is

$$\Delta Q P(Q + \Delta Q) - c\Delta Q \leq 0, \quad \text{or} \quad P(Q + \Delta Q) \leq c. \quad (10')$$

Equations (10) and (10') can be extended to a general oligopoly specification by introducing the parameter $\theta \in [0, 1]$ and writing the profit maximization condition as

$$p\Delta Q + \theta Q[P(Q + \Delta Q) - P(Q)] \leq c\Delta Q. \quad (10'')$$

³⁴ Love and Murniningtyas (1992) note that extraneous estimates of demand and/or supply elasticities typically come from studies that have assumed at least implicitly that the indicated market is competitive, meaning that the estimates likely suffer from a misspecification bias if the market is not competitive.

³⁵ For simplicity of exposition, we retain the assumption of a constant returns technology, although the analysis does not depend upon this assumption.

Firm-level analogues to the industry conditions in (10), (10'), and (10'') may also be set forth.

The key to application of the nonparametric methodology is to find industry settings where comparative statics shocks (shifters of c in this abridged model structure) produce a sufficient set of observations on p and Q , e.g., $\mathbf{p} = (p_1, \dots, p_T)$, $\mathbf{Q} = (Q_1, \dots, Q_T)$, to evaluate the optimality of each (p, Q) pair relative to all alternative pairs in the $\mathbf{p}, \mathbf{Q}$ set. For Ashenfelter and Sullivan, frequent changes in the cigarette excise tax rate represented an ideal experiment by which to evaluate industry behavior under the alternative behavioral models.³⁶

The output from this analysis, rather than point estimates of parameters like θ , is the percentage of trials for which the predictions of a given behavioral model are consistent with the observed data. The nonparametric approach is, thus, able to indicate the consistency of data with alternative economic models but does not provide an estimate of actual market conduct. For example, Ashenfelter and Sullivan found that the monopoly model's predictions were consistent with behavior in the cigarette industry in only a minority of instances, and Raper and Love (1998) concluded that U.S. cigarette manufacturers were able to exercise monopsony power in procuring tobacco from domestic growers but had little monopsony power in the international tobacco market.

5.2. Homogeneous product models with fixed proportions

Consider now the class of models that assumes a fixed proportions relationship between the agricultural product and the finished product(s). A production function incorporating this feature can be written as:

$$q = \min \left\{ \frac{r}{\alpha}, h(x) \right\},$$

where α is a Leontief conversion factor between raw and finished product, which without further loss of generality can be set to 1 ($q = r$), and x is a vector of inputs used in processing. The function $h(\cdot)$ may exhibit variable proportions.

The associated cost function for the representative processor is then separable in farm product costs, wq , and all other processing costs, $M(v, r)$. If we assume in addition that processing is characterized by a constant returns technology, then $M(v, r) = m(v)r$, and

$$C(w, v, r) = wr + m(v)r. \quad (11)$$

To specify a complete model using this framework, write market demand for the final product as in (4), and express farm supply of the farm commodity in inverse form as

$$w = W(R, Y), \quad (12)$$

³⁶ The idea of using industry response to changes in the excise tax rate to analyze competition in the cigarette industry was proposed originally by Sumner (1981).

where Y denotes farm supply shift variables. Profits for a representative processor can be written as

$$\pi = P(Q)q - (W(R) + m)r, \quad (13)$$

where notation for exogenous variables N , Y , and v is henceforth suppressed.

The first-order necessary condition for maximizing (13) is

$$\frac{\partial \pi}{\partial q} = p + P'(Q) \frac{\partial Q}{\partial q} q - (w + m) - W'(R) \frac{\partial R}{\partial r} r = 0. \quad (14)$$

The processor's conjectural variations are $\lambda^f = \partial R / \partial r$ and $\lambda^r = \partial Q / \partial q$.

Equation (14) can be written in elasticity form as

$$p \left(1 - \frac{\theta}{\eta} \right) = w \left(1 + \frac{\xi}{\varepsilon} \right) + m, \quad (15)$$

where $\varepsilon = (\partial R / \partial w) \cdot (w / R)$ is the market price elasticity of supply of the farm product and $\xi = \lambda^f (r_i / R)$ and $\theta = \lambda^r (q_i / Q)$ are the conjectural variations in elasticity form for the farm product and the final product respectively.

Because firms produce a homogeneous product and have identical technologies, optimizing behavior compels that *ex post* all firms' conjectures are identical. Equation (15) thus represents an industry equilibrium condition which, in conjunction with the retail demand and farm supply functions specified in (4) and (12), yields market equilibrium values for p , w , and $Q = R$ for any given set of market conduct parameters.

Following Melnick and Shalit (1985), (14) can be written alternatively as

$$\theta MR(Q) + (1 - \theta)P(Q) = \xi MC(R) + (1 - \xi)W(R) + m, \quad (14')$$

where $MR(Q) = \partial[P(Q)Q] / \partial Q$ is the industry marginal revenue function and $MC(R) = \partial[W(R)R] / \partial R$ is the industry marginal cost function for the farm product. In other words, the output market behavior parameter, θ , can be interpreted as a weight expressing the importance of the demand function relative to the marginal revenue function in determining finished product output, and ξ is similarly a weight that represents the importance of the farm product supply curve relative to the industry marginal cost curve in determining purchases of the farm product.³⁷ Figure 2 illustrates price and output determination in an oligopoly-oligopsony market, with point A representing the equilibrium condition stated in (14').

The empirical analogue for this model includes functional specifications for the retail demand function (4), the farm product supply function (12), the marginal processing

³⁷ This interpretation becomes clear when one considers the polar cases of perfect competition ($\theta = 0$, $\xi = 0$), monopoly ($\theta = 1$, $\xi = 0$), and monopsony ($\theta = 0$, $\xi = 1$).

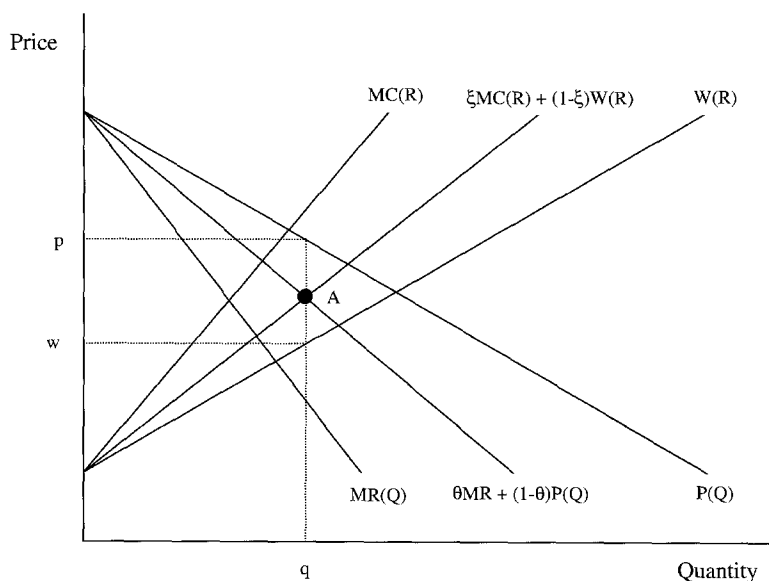


Figure 2. Equilibrium purchasing (w) and selling (p) prices in a market characterized by the presence of oligopsonist-oligopolist firms.

cost function, $m(v)$, and its associated processing input demand functions. This model was first estimated by Schroeter (1988) to examine oligopoly and oligopsony power in the U.S. beef industry.

An alternative estimation procedure developed by Azzam (1992) involves expressing the first-order condition in (14) as a regression equation by solving it for the farm-retail price spread as follows:

$$p - w = m - P'(Q)\lambda^r q + W'(R)\lambda^f. \quad (14'')$$

This formulation does not attempt to decompose the firm's influence on price into a market demand or supply curve slope parameter and a conjectural variation. Rather, estimation proceeds by specifying the price spread as a function of the exogenous factors that determine m , processor demand, and farm product supply. Under perfect competition, the margin is determined solely by m , so the demand and supply shift variables have no effect. Thus, the joint significance of the demand (supply) shift variables represents a rejection of price taking behavior in the output (farm product) market. Azzam's approach is similar to the nonparametric methodology in the sense that it provides a test of price taking behavior, but, in the event price taking is rejected, it does not provide an estimate of the extent to which behavior departs from competition.

As noted, a problem in investigating oligopsony power in many agricultural industries is that supply at any point in time is fixed by planting decisions made months or

years previously. This situation applies to essentially all nonstorable commodities. The standard approach shown in (14) and (15) of deriving the curve marginal to the supply curve and specifying the oligopsony parameter ξ cannot be used in these settings. The approach taken by Sexton and Zhang (1996) in an analysis of pricing for iceberg lettuce was to first identify the per-unit surplus available to the industry, taking into account retail demand, farm harvest costs, and marketing sector costs, and then estimate empirically the share of the surplus accruing to growers as a function of relevant structural variables.

Let R denote the fixed available harvest. Then $P(R) - m$ denotes the marketing sector's ability to pay for alternative harvest volumes. Given that farmers must recover at a minimum their per unit harvest costs, h ,

$$S(R, m, h) = P(R) - m - h$$

is the function which defines the per unit surplus to be shared among farmers and marketer/retailers. As owners of the factor in fixed supply (i.e., the available harvest), growers would receive 100 percent of the surplus with perfect competition among buyers. However, Sexton and Zhang estimated that on average growers of California iceberg lettuce received only 6.5 percent of the available surplus.

Extension of the basic model to multiple outputs is straightforward theoretically but potentially vexing in application, unless significant simplifying assumptions are made. If the output markets are related as is likely the case, then estimates of cross elasticities of demand and "cross-conjectural elasticities" are also required, where $\theta_{i,j} = \partial Q_i / \partial q_j (q_j / Q_i)$ would denote a representative firm's perception of the percentage impact on market output of product i induced by a one percent increase in its sales of output j . Introduction of multiple products into a flexible cost function causes the number of parameters to be estimated to increase at a geometric rate unless strong separability restrictions are imposed as in Schroeter and Azzam (1990) and Wann and Sexton (1992).

The Schroeter (1988) and Schroeter and Azzam (1990) models do not allow θ to be estimated separately from ξ , although in general they will not be equal. Wann and Sexton (1992) and Huang and Sexton (1996) show how to resolve this problem empirically if either multiple processed products are produced or if the product is sold into separable geographic markets, and at least one of the finished product markets can unequivocally be assumed to be perfectly competitive. Behavior in this "benchmark" market is then used to test oligopsony power, and oligopoly power in each of the other finished product markets is evaluated by comparing it to the benchmark.³⁸

³⁸ For example, in fruit, vegetable, and nut industries, the raw product is often sold in both processing and fresh markets. The fresh market often may be assumed to be competitive because the technology of selling to the fresh market generally involves modest economies of size and easy entry and exit relative to the technology for producing the processed product. Similarly, when a given product is sold into both domestic and export markets, trade restrictions and/or spatial market conditions may make market power an issue in the domestic market, even though the export market is clearly competitive.

This model consists of (i) processors' multiproduct cost function and associated demand functions for processing inputs, (ii) marketing margin equations which characterize processor behavior in the procurement of the farm product and sale of processed products, (iii) farm supply of the raw product, and (iv) retail demand for processed products. Consider the simple version of Huang and Sexton where only a single finished product is produced and is then sold either into a competitive export market or a domestic market which may be characterized by imperfect competition. A representative processor's profit function can be expressed as

$$\pi = P^D(Q^D)q^D + p^E q^E - [W(R) + m]r, \quad (16)$$

where $P^D(Q^D)$ denotes the inverse domestic demand curve, Q^D denotes aggregate quantity supplied to the domestic market, q^D is a representative processor's domestic market sales, p^E is the parametric export price for the product, q^E is the export sales volume for the representative processor, and $q^D + q^E = r$. Substituting this fixed-proportions relationship into (16) enables the optimization problem to be expressed in terms of the volumes of farm product $r^E = q^E$ and $r^D = q^D$ allocated to export and domestic sales, respectively. The first-order conditions for maximization of (16) can be expressed in elasticity form as

$$w = \frac{p^E - m}{1 + \xi/\varepsilon}, \quad (17)$$

$$p^D = \frac{w[1 + \xi/\varepsilon]}{1 - \theta/\eta} + \frac{m}{1 - \theta/\eta}. \quad (18)$$

Substituting (17) into (18) obtains

$$p^D = \frac{p^E}{1 - \theta/\eta}. \quad (18')$$

The first-order conditions can also be expressed in Lerner index form:

$$\frac{(p^E - m) - w}{w} = \frac{\xi}{\varepsilon}, \quad (17'')$$

$$\frac{p^D - p^E}{p^D} = \frac{\theta}{\eta}. \quad (18'')$$

Export sales in this model play the role of the competitive benchmark product. Markups of domestic prices above export prices are used to measure departures from competition for domestic product sales. Similarly, mark-downs of the farm product price below the export price, after adjusting for processing costs, measure processors' oligopsony power in farm product procurement. Wann and Sexton (1992) provide an example where the market for fresh product sales is the benchmark.

Azzam and Pagoulatos (1990) offer an alternative but conceptually similar resolution to the problem of distinguishing market power in the farm product versus processed product markets. They adopted a variable proportions processing technology and utilized a production function (primal) approach to analyze the problem.³⁹ Processors choose inputs, including the farm product, to maximize profits. Consider a model with only two inputs, r and x , where x is a composite marketing input. The production function is $q = f(x, r)$. Inverse demand and inverse farm product supply are as in (4) and (12). The representative firm's problem is to maximize profits,

$$\pi = p(Q)f(x, r) - w(R)r - vx, \quad (19)$$

in terms of the choices of x and r . The first-order conditions to the problem can be arranged to obtain:

$$p = \frac{v}{MP_x} \left(\frac{\eta}{\eta - \theta} \right), \quad (20)$$

$$\frac{w}{v} \left(1 + \frac{\xi}{\varepsilon} \right) = \frac{MP_r}{MP_x}, \quad (21)$$

where MP_x and MP_r are the marginal products for inputs x and r respectively.

Equation (20) shows that the markup of output price over the ratio of the processing input's price to its marginal product is determined by the degree of oligopoly power in conjunction with the demand elasticity. Equation (21) is the familiar cost minimization condition of an isocost–isoquant tangency adjusted for processor oligopsony power in the farm product market. Thus, the markup of output price over the price of the processing input identifies the degree of oligopoly power, and the mark-down in w relative to v after adjusting for the relative difference in their marginal products identifies the degree of oligopsony power.⁴⁰

5.3. Models with differentiated products

Products may be differentiated due to real or perceived differences in the products' physical characteristics, or differentiation may be due to the physical location of sellers or buyers in space. Thus, while branded food product markets provide obvious examples of product differentiation in agriculture, so too do spatially dispersed retail grocery

³⁹ Gollop and Roberts' (1979) study of market power in the U.S. coffee-roasting industry is an important early application of a production function approach to measuring conjectural variations. Gollop and Roberts, however, were concerned only with oligopoly power.

⁴⁰ This approach does not extend readily to multiple outputs because the multiple product production technology is represented by a set rather than a differentiable function. In contrast, a multiproduct cost function from the dual approach is a straightforward extension of the single product case.

stores and processing firms. When product differentiation is important, we can seek to estimate demand or supply functions facing individual firms or groups of firms.

Consider an industry with n firms. An individual firm's demand function can then be written as

$$q_i = D_i(p_1, \dots, p_n, N), \quad i = 1, \dots, n, \quad (22)$$

where $p_1, \dots, p_n$ denote prices charged by each firm and N denotes exogenous demand shifters, assumed to be common across the n firms.

One approach to analyzing the demand system set forth in (22) is the residual demand methodology developed by Baker and Bresnahan (BB) (1985, 1988). The residual demand is the demand facing a firm expressed as a function of the price charged by the firm after taking into account rival firms' behavior at each price level. The residual demand can indicate whether demand facing a firm or group of firms, having incorporated rivals' behavior, is sufficiently inelastic to enable the firm or group of firms to exercise market power. To derive an analytic expression for residual demand of, say, firm 1, use the first-order conditions for profit maximization for firms $2, \dots, n$ to express their supply behavior as follows:

$$\frac{p_i - c_i(q_i, v_i)}{p_i} = - \left(\eta_{ii} + \sum_{j=2}^n \eta_{ij} \phi_{ji} \right), \quad i = 2, \dots, n, \quad (23)$$

where η_{ii} is the partial own-price elasticity of demand facing firm i , and $\eta_{i,j} = (\partial q_i / \partial p_j)(p_j / q_i)$ are the cross price elasticities. The $\phi_{ji} = (\partial p_j / \partial p_i)(p_i / p_j)$ are conjectural elasticities expressed in price terms. They will normally range in the unit interval with $\phi_{ji} = 0$ representing Bertrand behavior and $\phi_{ji} = 1$ representing perfect collusion. The next step is to use (22) and (23) to "solve" for the equilibrium behavior of firms $2, \dots, n$, thus obtaining expressions of the form

$$p_i = p_i^*(p_1, N, V; \phi), \quad i = 2, \dots, n,$$

where V denotes the union of the v_i and ϕ is the union of the ϕ_{ji} .

Finally, the residual demand, $R_1(\cdot)$, for firm 1 is obtained by substituting the p_i^* into D_1 from (22). The resulting expression,

$$q_1 = R_1(p_1, N, V; \phi), \quad (24)$$

contains as arguments firm 1's price, the vector N of demand shifters, and the vector V of exogenous determinants of the rival firms' supply behavior. The elasticity, η_1^R , of the residual demand function can be decomposed as follows:

$$\eta_1^R = \eta_{11} + \sum_{i=2}^n \eta_{1i} \phi_{i1}, \quad (25)$$

where η_{11} is the partial own-price elasticity for firm 1, the $\eta_{1i} = (\partial q_1 / \partial p_i)(p_i / q_1)$ are cross price elasticities, and the $\phi_{i1} = (\partial p_i / \partial p_1)(p_1 / p_i)$ are conjectural elasticities.

Equation (24) is estimated jointly with firm 1's supply relationship. Identification of residual demand will normally require that the firm(s) under investigation have some unique cost shift parameters, e.g., v_1 must contain one or more variables that are not part of V in (24). The residual demand approach can indicate whether a firm has the potential to exercise market power, and it is particularly useful in evaluating merger proposals and the impact of other structural changes such as entry or exit. BB (1985) applied the approach to investigate the competitive impacts of hypothetical mergers between various U.S. brewers.

Scheffman and Spiller (1987) applied the residual demand methodology to a setting with costly transportation and geographic markets. Durham and Sexton (1992) adapted the approach to the analysis of residual supplies and the study of buyer market power. Residual supply is the supply facing the purchaser of an input after taking into account the input demand relationships of all competing buyers. This concept applies broadly in farm product markets because transportation is often costly and, thus, buyers are differentiated spatially.

With detailed micro data now available for many food and beverage products from grocery store scanner data, a more ambitious approach to analyzing (22) is to estimate a system of demand equations for a particular product category. This approach was first set forth by Hausman, Leonard and Zona (HLZ) (1994), who studied the demand for different brands of beer. Other recent applications include Cotterill (1994) to soft drinks and Cotterill and Haller (1997) to ready-to-eat breakfast cereals. The approach relies on the multistage budgeting framework utilized commonly in demand analysis. HLZ studied demand in three stages. The top stage is the total demand for beer, the middle stage involves demand for beer by product category (premium, light, imported, and popular). The bottom stage consists of demand for individual premium beers such as Budweiser and Miller set forth in an almost ideal demand system, where demand, measured in revenue share form, is expressed as a function of own price, and prices of competing brands, and the expenditure share for the product category, the latter representation being an outcome of the assumed multistage budget process.

Prices are endogenous within this framework, and the various authors have relied upon the panel nature of their data sets to use prices in other city markets as instruments for the price in a given city. Estimation results indicate the unilateral market power accruing to various brands based on the estimated own price elasticity (e.g., HLZ find brand elasticities in the -4.0 to -6.0 range), and the potential for enhanced market power from mergers based on the cross price elasticities and an assumption on competition (e.g., HLZ assume Bertrand behavior and estimate that, in the absence of any efficiency gains, a merger between Coors and Labatts would increase the price of Coors

by 4.4 percent and Labatts by 3.3 percent due to the loss of competitive pressure between the two brands).⁴¹

A demand systems approach can also be used to separate the residual demand elasticity into its component parts as indicated in (25). In this case the demand system is estimated jointly with a set of pricing equations or reaction functions. The own and cross-price elasticities, η_{ii} and η_{ij} , are obtained from the demand system, and the price conjectural elasticities, θ_{ji} , are obtained from the reaction function equations. This approach enables the extent of market power to be decomposed into a demand elasticity effect, η_{ii} , and a coordinated pricing effect – the sum of the $\theta_{ij}\eta_{ji}$ terms. Most applications of this approach have been to food products and include Liang (1989), Cotterill (1994), Vickner and Davies (1999), Cotterill and Putsis (1999), and Cotterill, Putsis and Dhar (2000).

Neither the BB nor the HLZ approaches to analyzing (22) invoke any assumptions about competition among the firms in conducting the estimation. The same can be said for the conjectural variations models discussed in the previous sections. This virtue of flexibility in being able to depict competition along a continuum between perfect competition and monopoly/monopsony is also a drawback in the sense that point estimates of θ and/or ξ may not be readily represented as equilibrium outcomes to a specific oligopoly/oligopsony game.

Gasmi and Vuong (1991) and Gasmi, Laffont and Vuong (1992) propose alternatively to estimate specific oligopoly models such as Cournot–Nash, Bertrand–Nash, Stackelberg leadership, and collusion, and then use nonnested hypothesis tests to discriminate among the various alternatives. They illustrate this approach for the soft drink rivals Coca-Cola Co. and Pepsico Inc. Because they model the simultaneous choice of price and advertising expenditure, the basic model consists of a demand equation similar to (22) and two first-order conditions for each firm. As Gasmi, Laffont and Vuong note, this system of equations is the same as would be constructed using a conjectural variations approach. However, the conjectural variations parameters and the structural parameters are not identified, given the simple demand and cost functions that these authors utilize. They show that imposing specific assumptions about the form of competition can impose sufficient *a priori* restrictions on the conjectural variations to enable the system to be identified. Using restrictions implied by theory to achieve identification enables the analyst to work with simpler models than would be necessary if identification were to be achieved via the cost function or via rotations in the demand or supply functions. A further advantage is that the nonnested hypothesis tests are not predisposed to favor any particular form of competition in contrast to most conjectural variations and SCP

⁴¹ As Deneckere and Davidson (1985) demonstrated, the profit-enhancing potential of mergers in price-setting games is a consequence of the merged firms internalizing the beneficial effect on competing brands when a given brand raises its price. For example, a price increase by Coors will increase demand for Labatts to a degree that is based on the cross elasticity of demand between Labatts and Coors. This effect is an externality to an independent Coors, but is internalized if Coors and Labatts merge, with the consequence that the optimal post-merger price for Coors is higher than the optimal pre-merger price, *ceteris paribus*.

studies, where the null hypothesis is one of competition which then must be rejected by the data.⁴²

The preceding methods are useful when either a full demand system is not required or when the number of close substitutes is small, making a systems approach manageable. With many substitute goods, a common situation with differentiated products, a system approach may be unmanageable because of the large number of parameters to be estimated. One solution to this problem is to model products as bundles of characteristics. Consumer preferences are then defined over the characteristics' space, and it is the dimension of this space which is relevant for estimation, not the square of the number of products in the system.

The most general of these models is the random coefficient discrete choice model. Here, different consumers have different preferences for the various characteristics of the goods. A demand equation that can be estimated econometrically can be derived from a utility function of the form

$$u_{ij} = x_j \beta_i - \alpha p_j + \xi_j + \varepsilon_{ij}.$$

The utility of individual i in consuming product j is a function of a vector x_j of observed product characteristics, p_j the price of j , ξ_j the unobserved product characteristics, and ε_{ij} , the consumer-specific error term. It is assumed that all characteristics are observable to the consumer but not to the econometrician. Therefore, ξ_j accounts for unobservable characteristics such as reputation. Because of the random taste parameter β_i on product characteristics, reasonable substitution patterns emerge. Following an increase in the price of product j , consumers will substitute towards the group of goods that resemble j the most.

Berry (1994) and Berry, Levinsohn and Pakes (1995) explain this model and various special cases in further detail. Nevo (1998) used a modified version of the model to study the ready-to-eat breakfast cereal industry.

5.4. A summary of empirical analyses

We do not attempt to provide an exhaustive survey of empirical analyses of market power in food processing and distribution. Rather, we focus on some key industries or sectors that have been the objects of several studies.

Beef packing. U.S. beef has been the object of particularly frequent attention due to the dramatic rise in seller and buyer concentration. The U.S. Congress in 1992 commissioned the USDA Grain Inspection, Packers and Stockyards Administration to in-

⁴² Carter and MacLaren (1997) have applied this model to test six alternative models of competition between the U.S. and Australia for imports of beef into Japan. They concluded that the model which best fit the data was a Stackelberg model with price leadership by Australia.

investigate the effects of concentration in the industry. This study alone resulted in seven technical reports which are summarized in USDA (1996a).⁴³

The rise in concentration in beef packing was fueled at least partially by technological change. During the 1960s the boxed-beef technology was introduced, wherein carcasses were processed into individual cuts, packed, and shipped from the same plant where slaughter took place. This capital-intensive technology resulted in expanded economies of size in the industry. In addition, declining consumption of red meats led to excess capacity, triggering a wave of mergers and acquisitions during the 1970s and 1980s [Purcell (1990)]. In 1977, the four leading packers were estimated to hold 30 percent of total slaughter capacity. By 1992, the CR4 was estimated at 82 percent.

SCP studies of the beef packing sector include Menkhous, St. Clair and Ahmaddaud (1981), Quail et al. (1986), and Marion and Geithman (1995). These studies found a negative relationship between CR4 and the price paid to ranchers and a positive correlation between feedlot size and price, suggesting possible countervailing power. Ward (1981, 1982, 1988, and 1992) pioneered the use of transactions price data to examine the determinants of fed cattle prices. In both Ward (1981) and Ward (1992) feedlot prices are positively correlated with the number of buyers bidding for the purchase. The Texas A&M Agricultural Market Research Center (1996) found only a weak effect on fed cattle price for a regional Herfindahl index variable.

Using a conjectural variations model and a sample period from 1951–83, Schroeter (1988) rejected price-taking behavior but found that distortions from competitive pricing were modest in magnitude – on the order of 3 percent in output sales and 1 percent in input purchases. Several extensions of this work followed soon thereafter. Azzam and Pagoulatos (1990) studied meat packing as an aggregate industry. Through their production function formulation (Section 5.2), they were able to obtain point estimates of both oligopoly power ($\theta = 0.223$) and oligopsony power ($\xi = 0.178$). However, because the estimated farm product supply was less elastic than was the retail demand, the input market distortion was relatively more important than the distortion in the output market. Schroeter and Azzam (1990) developed a multiproduct model of the meat packing industry, treating pork and beef as separate products, but not allowing oligopoly and oligopsony conjectures to differ. This study also rejected price taking behavior, although the estimated $\theta = \xi$ parameters were small in magnitude. Azzam (1992) rejected price taking behavior by U.S. beef packers in farm product purchases but not in processed product sales.

More recent tests of beef packer market power include Muth (1996), who analyzes oligopoly power, and Kambhampaty et al. (1996) and Muth and Wohlgenant (1999), who analyze oligopsony power. Muth and Muth and Wohlgenant fail to find any evidence of market power in contrast to the majority of prior studies. They attribute the

⁴³ Among the technical reports is a detailed survey of research on the competitiveness of the U.S. meat packing industry by Azzam and Anderson (1996). Azzam (1998) is a somewhat more concise survey of the same material.

different results to the prior authors' assumption of a fixed proportions and constant returns processing technology. Kambhampaty et al. had access to plant-level data as part of the USDA GIPSA investigation. They treated the conjectural elasticity/farm product supply elasticity ratio (ξ/ε) as a single parameter (see Equation (14)). This parameter was positive and significant in the estimation, but other estimated parameters did not comport with economic theory.

Fruits and vegetables. Empirical results in Just and Chern (1980) supported their oligopsony model's prediction. The industry was later analyzed by Durham and Sexton (1992), who estimated residual supply elasticities for six production and processing regions in California. The estimated elasticities were large, ranging from 8.6 to essentially infinity, which caused the authors to conclude that oligopsony potential in the industry was limited. Structural changes in the industry since the time of the Just and Chern analysis may account for the different conclusions about competitiveness.⁴⁴

Melnick and Shalit (1985) worked with an expression analogous to (14') to analyze oligopoly and oligopsony power of marketers of fresh tomatoes in Israel. Estimation of oligopsony power was facilitated by the existence of a government-set price floor thereby obviating the need to estimate grower supply. The degree of oligopsony power was estimated simply by regressing farm price on consumer price, the floor price, and a handler marginal cost parameter. The parameters on the two price variables were constrained to sum to one, and, therefore, the magnitude of the coefficient on the price floor variable (0.64), based on (14'), is an estimate of ξ . The estimate of oligopoly power, inferred indirectly from other parameter estimates, was $\theta = 0.18$.

Applications of Appelbaum models (Section 5.1) include Wann and Sexton (1992) on U.S. pear processing, Huang and Sexton (1996) on Taiwanese tomato processing, Taylor and Kilmer (1988) on Florida celery, and the studies of U.S. marketing orders discussed in Section 4. Estimates from Wann and Sexton's multiple product framework suggested limited oligopoly power in pear processing ($\theta = 0.08$), but greater power in the sale of fruit cocktail ($\theta = 0.48$). Hypotheses of perfect competition and pure monopsony in pear procurement were both rejected. Huang and Sexton found modest oligopoly power for Taiwanese processors in domestic sales of ketchup and tomato juice and near perfect monopsony ($\xi = 0.98$) in farm product procurement.⁴⁵ Florida celery is marketed through a single cooperative supported by a federal marketing order. Taylor and Kilmer investigated whether this organization was able to exercise market power. Estimation results found modest ($\theta \in [0.03, 0.15]$) and insignificant levels of oligopoly power.⁴⁶

⁴⁴ A dominant processor during the time of the Just and Chern study had since seen its share erode, a grower bargaining association had arisen to prominence, and longer hauls may have stimulated greater interregional competition.

⁴⁵ This extreme result was supported by casual evidence that processors colluded in setting prices to growers.

⁴⁶ This result is consistent with the observation that Florida is a relatively minor player in celery sales in the U.S. In most metropolitan areas and in most months, most sales are from California, where marketing is not coordinated [Sexton et al. (1991)].

Dairy. Suzuki et al. (1993, 1994a) examined dairy policy questions for Japan and the U.S. respectively. In both instances, the authors exploited observed price differentials between fluid and manufacturing milk to derive nonparametric estimates of the Japanese milk board's [Suzuki et al. (1993)] and the U.S. dairy cooperatives' [Suzuki et al. (1994a)] market power.⁴⁷ The manufacturing milk price plays a benchmark role analogous to the Wann and Sexton (1992) framework in these studies. The imputed θ values ranged from 0.04 to 0.23 in Japan and 0.06 to 0.08 in the U.S. Liu, Sun and Kaiser (1995) estimated mean values of θ equal to 0.10 and 0.18 for U.S. dairy processors in manufacturing and fluid milk respectively.

Grocery retailing. Rising concentration and consolidation of sales among large supermarket chains and supercenters in the U.S. have made retailer market power in the food industry a topical issue. Food retailing is not amenable to the application of NEIO methods because it involves the production and sale of a vast number of different products – an average of 30,000 different items for U.S. supermarkets.⁴⁸ SCP methods are, however, useful because prices can be observed readily and aggregated into indices. Data are also often available on the explanatory variables that might be utilized within the loose theoretical structure of the SCP paradigm to account for demand- and cost-side determinants of price. Studies such as Hall, Schmitz and Cothorn (1979), Lamm (1981), Newmark (1990), Marion, Heimforth and Bailey (1993), and Binkley and Connor (1998) have examined average retail price relationships using cities as the unit of observation.

Cotterill (1986), Kaufman and Handy (1989), and Cotterill and Harper (1995) focused upon the behavior of individual stores, giving them the opportunity for increased precision and relevance in construction and use of explanatory variables relative to earlier studies. Cotterill (1986) studied food retailer monopoly power in Vermont, a sparsely populated state which provided an almost ideal setting to delineate relevant geographic markets for identifying concentration.⁴⁹ Concentration variables (CR4, CR1, or the Herfindahl index) were positively associated with price and statistically significant. A parallel study of Arkansas supermarkets by Cotterill and Harper (1995) reached similar conclusions as to the impacts of retailer concentration on food prices.⁵⁰

However, not all studies of grocery retailing have found a positive association between concentration and price. Kaufman and Handy (1989) studied 616 supermarkets

⁴⁷ Studies that have focused specifically upon market power in the dairy industry exercised through U.S. marketing orders are discussed in Section 4.

⁴⁸ Hyde and Perloff's (1998) study of market power in the Australian meat sector is an attempt to apply NEIO methods to measure grocer market power. They avoid issues of the multiproduct technology by using simple linear marginal cost specifications for each meat product studied, implicitly assuming that the unspecified cost function is strongly separable.

⁴⁹ This geographic isolation has, ironically, been the primary basis to criticize the study on the grounds that the very high levels of concentration observed are atypical.

⁵⁰ Studies conducted at the city level which have found a positive structure-price relationship include Hall, Schmitz and Cothorn (1979), Lamm (1981), and Marion, Heimforth and Bailey (1993).

chosen from 28 cities selected at random. Both firm market share and a four-firm Herfindahl index were negatively but insignificantly correlated with price. Newmark (1990) also obtained a negative and insignificant coefficient on CR4 in a study of the price of a market basket of goods for 27 cities. Cotterill's (1993) part 5 contains a debate on the issue of market power in grocery retailing, including a critique of the Kaufman–Handy study and response by the authors.⁵¹

6. Dynamic models of the food sector

The game theory revolution in industrial organization was inspired by the recognition that some features of competition in concentrated industries cannot be captured adequately in static models. A given firm's actions in an oligopolistic/oligopsonistic setting most likely have a significant effect on its rivals. These actions may trigger a responsive action by the rival firms, which the given firm, in turn, should anticipate in making its own decision. History also matters in these interactions, and the effects of history can only be captured in a dynamic model. For example, in games of incomplete information, the past is important because firms can try to learn about key factors pertaining to their rivals. This, of course, is understood by the rivals, who can try to manipulate the information that is received. The conjectural variation concept employed by the static models cannot capture the richness of strategic interactions among imperfectly competitive firms. Similarly, matters of firm growth, entry, and exit involve inherently dynamic features that cannot be subsumed adequately within a static model. We mention only briefly conceptual developments in this vast literature and then consider applications to the food and beverage processing and distribution sector.⁵²

6.1. *Dynamic models of collusive price setting*

Even noncooperative behavior, such as represented by the Cournot model, can result in supracompetitive profits in a concentrated industry. However, much of the policy concern with concentrated markets is based on the belief that concentration facilitates collusive behavior among firms which may cause price to be set above levels implied by noncooperative behavior. In a static environment, firms always have an incentive to defect from any collusive agreement. However, in a dynamic setting the costs of anticipated retaliation by rivals may dominate the short-run gains from cheating on an agreement and thereby make the agreement stable [Stigler (1964)]. Green and Porter (1984) enriched the analysis through the introduction of demand uncertainty so that

⁵¹ Binkley and Connor (1998) suggest one explanation for the conflicting results in terms of the product coverage in the price variable. They found a positive and significant concentration-price correlation for dry groceries and a negative and insignificant correlation for fresh and chilled food items.

⁵² Key general references are Fudenberg and Tirole (1986), Schmalensee and Willig (1989), and Tirole (1988).

an unexpected price decrease may be the outcome either of exogenous demand shifts or cheating on a cartel agreement. Although firms cannot identify the cause of the price change, they respond to the market signal with an episode of noncooperative pricing to punish the possible cheating and thereby preserve the stability of the cooperative agreement. These models are known as “trigger” price models for obvious reasons.

Koontz, Garcia and Hudson (KGH) (1993), Stiegert, Azzam and Brorsen (1993), and Weliwita and Azzam (1996) applied the trigger pricing model to study beef packer market power in the U.S. KGH studied the prices packers paid for fed cattle in four regional markets. During noncooperative periods, Bertrand pricing ($\partial p_i / \partial p_j = 0$) was assumed, with cooperative behavior represented by $\partial p_i / \partial p_j > 0$. Probabilities of observing cooperative behavior ranged from as low as 0.06 to as high as 0.60.⁵³ Gains to processors from cooperation were generally small, however, ranging from \$2–19 per head.⁵⁴

A second approach to examining dynamic pricing in beef packing was set forth by Azzam and Park (1993), who also used a switching regression procedure that allowed conduct to change over time. However, unlike the KGH framework, where conduct shifts discontinuously due to periods of cooperative and noncooperative behavior, conduct changes gradually according to a polynomial transition path. Results indicated that no oligopsony power was exercised from 1960–77, and then a transition period ensued, culminating in significant but still very modest market power (e.g., $\theta = 0.016$) after 1982. A problem with this approach is that no dynamic theory of oligopsony underpins the model similar to that provided by the Green and Porter (1984) theory to the KGH model. At best, each period’s estimate of θ can be interpreted as the result of some unspecified model of single period play. However, in this context the traditional approach of generating time-varying θ parameters by making θ a function of exogenous structural variables might be preferred as a means to generate some insight as to the market forces causing changes in conduct.

Whereas the preceding contributions have sought theoretical justification from the multistage noncooperative game literature, Karp and Perloff (1989, 1993, 1996) have worked with a class of pricing models that are grounded in classic dynamic programming. They argue that application of static oligopoly models is inappropriate in instances where key dynamic phenomena such as adjustment costs in training or in cap-

⁵³ The implied values of the conjectural variation parameter were in the range of 0.5, considerably less than the pure cartel solution of 1.0. However, such a result is consistent with the Green and Porter (1984) trigger pricing equilibrium because moderate cartel power is easier to maintain due to diminished incentives for individual firms to cheat on the agreement. Thus, the tradeoff is diminished short-run market power against increased probability of cartel stability.

⁵⁴ In a follow-up study, Koontz and Garcia (1997) tested for whether the periods of cooperation found in KGH (1993) were independent across regional markets. Tests of independence among the periods of regional cooperation test the credibility of the KGH results because it is difficult to rationalize that regional independence could occur as part of any concerted strategy of cooperation among packers. In most cases, Koontz and Garcia rejected the hypothesis of independent pricing behavior.

ital accumulation are important or where firms learn over time. A representative firm's discounted stream of profits is

$$\sum_{t=1}^{\infty} \beta^{t-1} \left[(p_t - c)q_t - \left(\gamma + \frac{\delta}{2} \mu_t \right) \mu_t \right] \kappa, \quad (26)$$

where $\mu_t = q_t - q_{t-1}$ is the adjustment in output, β is a discount factor, γ and δ are parameters of a quadratic adjustment cost function, and κ is the length of a time period. The firm maximizes (26) through choice of a sequence of adjustments, μ_t . Karp and Perloff considered both open and closed loop equilibria. Under an open loop strategy, the firm commits to a trajectory for its strategic variable at the outset of the horizon. Under a closed loop strategy, the firm updates its actions as a function of its current information, its previous output, and rivals' previous output.

Application of the model involves estimation of demand curves facing the sellers and adjustment equations where current output is expressed as a function of lagged own output and rivals' output and other exogenous variables from which values of θ are inferred. Applications to rice exports [Karp and Perloff (1989)] and coffee exports [Karp and Perloff (1993)] treated key exporting countries as players.⁵⁵ Little market power was found in either instance.

6.2. Models of entry and exit

Entry and exit can be handled in only a mechanical way in static models. Given identical firms and a mode of conduct such as Cournot, a basic approach is to introduce a fixed set-up or entry cost $F \geq 0$. Entry is then assumed to take place until profits, π , are driven to the point where $\pi \leq F$ for the marginal entrant. The ensuing solution for the number of firms, n , price, and output represents a long-run equilibrium as in Holloway (1991).

A second static concept of how entry might work is provided by contestability theory as summarized by Baumol, Panzar and Willig (1982). Here $F = 0$, and entrants are assumed to have access to the same technology as incumbents, but in addition "hit and run" entry can take place, where an entrant can observe a profit-making opportunity, enter and exploit it, and exit if necessary before the incumbent firm(s) can react by adjusting price.⁵⁶ In contestable markets, incumbent firms' profits are driven to zero, and in all markets where $n \geq 2$, price equals marginal cost. The requirements for contestability to hold are stringent indeed, and probably no real-world industry is characterized by complete absence of sunk costs. Nonetheless, the powerful implications of

⁵⁵ The countries-as-players assumption is justified because in each instance a central authority controls exports.

⁵⁶ In the approach of the preceding paragraph, hit and run entry does not occur. Rather, the marginal entrant forecasts the ensuing post-entry equilibrium under the prevailing mode of conduct and decides, given its profits in that equilibrium, whether to sink F and enter.

contestability illustrate the perils of analyzing behavior in concentrated markets without considering explicitly the role of potential entry in influencing incumbent firms' behavior.

Sutton's (1991) classification of sunk costs as endogenous or exogenous helps to clarify their role in deterring entry and, hence, determining market structure. Exogenous sunk costs are the costs of setting up a business (e.g., Holloway's F in Section 5.1). For a given level of industry demand and mode of competition among firms, F determines the structure of the industry. However, as demand grows for a given level of F , concentration will diminish. Endogenous sunk costs are things like advertising and R&D expenditure. In industries where endogenous sunk costs are important, Sutton argues that the "normal" inverse relationship between market size and concentration will not hold because firms will spend more on these endogenous sunk costs the larger is the market.

The static limit pricing model provides an example of a strategic entry barrier in contrast to a structural entry barrier such as a sunk cost. An entrant is assumed to believe that the incumbent will not change its output in response to entry. The incumbent is assumed to deter entry by expanding output and reducing price to the point where the entrant's average cost curve exceeds its residual demand for all output levels. However, modeling with dynamic, multistage noncooperative games and fully rational players has obtained a clearer understanding of when and how strategic entry barriers might be important to industry structure and behavior. Application of the concept of subgame perfection [e.g., Dixit (1982)] showed that rational entrants cannot be deterred by threats of retaliatory behavior by incumbents unless these threats are credible, which in general they are not because behavior such as price wars is at least as costly for an incumbent as for an entrant. This observation led to several papers [Dixit (1981), Milgrom and Roberts (1982b), Salop and Scheffman (1983), Klemperer (1987), and Aghion and Bolton (1987)] that showed how an incumbent, exploiting its natural first-mover advantage, could undertake strategic actions during a pre-entry period that would alter an entrant's rational perception of post entry play and, thus, influence the entry decision. Gilbert (1989) provides a good summary of this literature.

A key focus for analysts of the food manufacturing industries has been the role played by advertising and new product development in creating barriers to entry. Connor et al. (1985) argued that advertising in food manufacturing plays the role of an endogenous sunk cost in Sutton's (1991) terminology and thereby contributes to high and increasing concentration and processor market power. They offered case studies of the brewing and coffee roasting industries to show how aggressive advertising was used to encourage consolidation and, hence, increase concentration in those industries. Notably, Sutton himself utilized the food sector to provide empirical support for this theory. Evidence to support the Connor et al. and Sutton views on the role of advertising is contained in various food industry studies [e.g., Pagoulatos and Sorensen (1981) and Wills and Mueller (1989)], where the industry advertising-sales (A/S) ratio was generally found to be positively associated with profit or price level. Pagoulatos and Sorensen (1981) dealt with concerns about simultaneity in the profit, advertising, and concentration re-

lationship by specifying a system of linear equations to explain price–cost margin, A/S, and CR4. Results of application to U.S. food manufacturing showed a positive effect for advertising intensity on both concentration and profitability. Vlachvei and Oustapassidis (1998) used the same methodology and obtained the same results for Greek food manufacturers.

The view that advertising represents an entry barrier and is inimical to market performance does not go unchallenged. The contrary viewpoint is that advertising provides valuable information to consumers and represents a way for entrants to draw attention to their products, thereby facilitating entry [Nelson (1970, 1974)]. Although inter-industry SCP studies have generally found a positive correlation between advertising and concentration, some intra-industry studies in the food and tobacco sector have reached an opposite conclusion. Eckard (1991) analyzed the impact of the television advertising ban on concentration in the U.S. cigarette industry and concluded that the ban tended to reduce competition, and Sass and Saurman (1995) concluded that state-level advertising restrictions were associated with higher levels of concentration in malt beverage sales. As Sass and Saurman admit, local beer ads in, say, newspapers probably have higher informational content than do national TV ads, which seem geared primarily to persuade. Thus, the views of Connor et al. (1985) as to the effects of TV advertising on national beer concentration and the results of Sass and Saurman on the effects of banning local beer advertisements are not inconsistent.

The concept that new product introductions and proliferation of brands may be utilized to create entry barriers emerged as a key food policy issue in the U.S. in 1972 when the Federal Trade Commission (FTC) issued a complaint against the four largest manufacturers of ready-to-eat (RTE) breakfast cereals alleging that proliferating brands and intensive advertising resulted in high barriers to entry in the industry. Schmalensee (1978) and Scherer (1979) provided analyses of the case that were generally supportive of the FTC's position.

Schmalensee utilized a spatial market model wherein existing brands occupied fixed locations in economic space. New brands must seek out profitable location niches given the location of existing brands. Schmalensee argued that incumbents have several advantages relative to entrants in terms of selecting profitable locations. First, incumbents are familiar with each other and are better able to judge each other's reactions than is an entrant. Second, there are economies of size in brand introduction. Thus, whereas entrants have to simultaneously find a sufficient number of profitable niches for entry in order to attain the minimum efficient scale, an incumbent can exploit individually each marginal niche she or he discovers. The outcome is an equilibrium wherein incumbents continuously introduce new brands in advance of *de novo* entrants and compete primarily through brand proliferation and advertising rather than price. Although the Schmalensee analysis has considerable appeal, the FTC complaint was vacated in 1981, leaving the *status quo* to reign in the industry.

Connor (1981) tested the impact of new product introductions during 1977–78 in 102 U.S. food product classes. He found that the number of new product introductions was positively related to both the industry CR4 and A/S, results that are consistent with

Schmalensee's theory. Another important empirical question relative to Schmalensee's theory of entry deterrence is the effect of new product introductions on price-cost margins. Zellner (1989) addressed this issue by adding Connor's regression model for new product introductions to Pagoulatos and Sorensen's (1981) simultaneous equations model. New product introductions were positively correlated with CR4 but negatively correlated with A/S and the price-cost margin. More recently, Putsis (1997) focused directly upon the linkage between price and brand proliferation for 135 food product categories. Number of brands was positively related to both brand and private label price, but concentration among brands, as measured by a branded products Herfindahl index, was associated with lower brand prices.

Empirical studies such as Pagoulatos and Sorensen (1981) and Zellner (1989) shed light indirectly on the determinants of entry, but in some instances it is possible to study the entry/exit decision itself.⁵⁷ MacDonald (1986) examined rates of entry from 1976–82 for 46 U.S. food products industries. The industry growth rate was found to be a positive and significant factor influencing entry, while the asset value of the minimum efficient scale of plant and the relative cost penalty for building a smaller-than-efficient plant were significant deterrents to entry. The industry advertising–sales ratio, conversely, had no significant effect. Cotterill and Haller (1992) studied entry into grocery retailing in 129 U.S. markets from 1971–81. The market growth rate was again a positive determinant of entry, while CR4 and the number of chains operating in the market were negative factors. Chevalier (1995) studied the impact of supermarket leveraged buyouts (LBO) on entry into local grocery markets. She concluded that LBO activity encouraged both entry and expansion by rivals, thus supporting a theory that LBOs lessen or “soften” price competition.

As food and beverage processing and distribution becomes more concentrated, exit rather than entry is the phenomenon observed most often. Anderson et al. (1998) studied the determinants of exit from the U.S. beef processing industry between 1991–93. A probit model showed that plant characteristics (age and capacity) and firm characteristics (single versus multiple plant, and whether the firm was horizontally or vertically integrated) were more important determinants of exit than were market structure variables such as the Herfindahl index. These results support a view that rising concentration in beef packing has been caused primarily by technological change that has increased the minimum efficient plant scale (rising exogenous sunk costs) coupled with declining demand and is not a result of strategic behavior by dominant packers.

7. Evaluation of empirical analyses of market power in agriculture

What have we learned from the various empirical studies of market power in agriculture? First, in highly concentrated industries, a positive (negative) correlation between

⁵⁷ Siegfried and Evans (1994) provide a general survey of empirical research on entry and exit.

concentration and selling (purchasing) price exists. This correlation has been found rather consistently across many SCP studies of food processor oligopoly and oligopsony power and food retailer oligopoly power. Some debate remains as to whether the correlation reflects market power or is a spurious correlation. Further debate concerns the policy implication of the results if, in fact, they do reflect market power. These points are addressed in this and the next section.

The NEIO studies of processor behavior have generally tended to find some statistical evidence of market power, although the measured departures from competition have mostly been small, with point estimates of θ or ξ often being less than 0.2 (the market power equivalent of that produced in a five-firm symmetric Cournot equilibrium). Because these studies have naturally been conducted in industries where structural conditions suggest the possible presence of market power, these results on the whole tend to suggest that market power has not been a very important factor in the food processing sector.

Various criticisms can be leveled against this body of work. The most well known are the critiques of the SCP studies. These include the Demsetz (1973) critique of the interpretation of profit-structure studies and Fisher and McGowan's (1983) critique of the use of accounting data to infer market power. Although responses to these critiques can and have been made, the drift of the SCP literature away from such studies and to the analysis of price-structure relationships within a single industry is appropriate.⁵⁸ In our view, studies of the price-structure relationship that focus on a single industry and control effectively for factors besides structure that may influence price provide some of the most convincing evidence of market power in the food chain. Cotterill (1986) and MacDonald (1987) are good examples of work that meets these criteria.⁵⁹ Nonetheless, a modified version of the Demsetz critique has been leveled against the SCP studies of price based on a quality argument. According to this reasoning, the most successful firms provide the best quality products and related service, thereby receiving price premiums or paying discounted prices and attaining large market shares. For example, in the context of the beef sector studies, it might be argued that large buyers offer better service than small buyers (e.g., prompt and reliable payment, secure market outlet, technical assistance), thereby enabling them to pay lower prices. A similar argument can be constructed for why large sellers may earn price premiums.

Perhaps due to their more recent vintage, there has been less formal criticism of the NEIO studies, although some criticisms of the SCP studies [e.g., Fisher and McGowan (1983)] apply equally to NEIO studies [Cotterill (1993)]. One aspect that has been discussed critically has been the conceptual underpinning or lack thereof provided by the conjectural variations framework. These criticisms are rather unimportant

⁵⁸ A good source for the debate between the SCP analysts and their critics is Part Five of Cotterill (1993).

⁵⁹ MacDonald studied market power in rail transport of grain. He concluded that moving from one firm (monopoly) to two firms (duopoly) in rail shipping was associated with an 18 percent decline in rates. Addition of a third firm resulted in a further decline of 11 percent.

as they pertain to the empirical research. Conjectural variations attempt to model a dynamic phenomenon (i.e., action and reaction) within a static framework. An example of this problem is the tendency of the conjectured behavior to fail to coincide with rivals' actual optimal response. As it pertains to the theory, the profession has moved to address dynamic interactions with explicitly dynamic models. As to empirical work, recent practice has been to specify first-order conditions such as (8) without any reference to θ or ξ representing conjectural variations. They are simply empirical indices that measure the departure of a given market from competitive outcomes. A "neutral" interpretation is that θ or ξ measure the gap between price and marginal cost or price and marginal value product. This gap is plausibly interpreted as a measure of market power which is the outcome of an unknown game [Karp and Perloff (1996)]. The converse of this practice is the approach of Gasmi and Vuong (1991) and Gasmi, Laffont and Vuong (1992) to econometrically impose the parameter restrictions implied by specific oligopoly/oligopsony models and use nonnested methods of hypothesis testing to distinguish among the various models.

Two general criticisms can be leveled against empirical work on the food and beverage industries conducted within the NEIO framework. The first is that essentially all of the studies have relied on maintained functional forms for market demand and/or supply and processor technology. The researcher is, thus, always testing a joint hypothesis – whatever is intended to be tested plus the maintained hypothesis of functional form. This criticism applies, of course, not just to studies of market power, and is the launching point for nonparametric analyses of demand, production, and market power. The problem is mitigated partially when the researcher utilizes flexible functional forms. In NEIO studies, the processing technology is often represented by such functions, but retail or wholesale demand and/or farm supply are usually represented by simple linear or double log functions, or else the needed elasticities are obtained from extraneous estimates.

Even more vexing is the issue of technical change in food processing. Most applications of the NEIO models proceed with annual data at the industry level. In order to obtain sufficient observations, these applications may study 30 or more years of industry data, during which time significant technical change will almost inevitably have occurred. NEIO studies have addressed technological change, if at all, through very simple means such as time trends. Incorporating more sophisticated methods is not necessarily straightforward because of data limitations and convergence problems in the highly nonlinear empirical models.

Another dimension of the functional-form argument that arises mainly in agricultural applications concerns the elasticity of substitution, σ , between the farm input and other inputs in producing a finished product. Most authors have assumed that no such substitution exists, whereas others such as Gardner (1975), Wohlgenant (1989), and Holloway (1991) have considered substitution possibilities to be an integral part of agricultural market models. Muth (1996) and Muth and Wohlgenant (1999) have attributed several

authors' empirical finding of market power in the beef industry in part to their failure to allow for substitution in their model frameworks.⁶⁰

A second criticism of the NEIO studies generally has been their architects' failure in many cases to think carefully about the markets they intend to analyze before conducting the actual analysis. Antitrust actions that evolve around market power begin with definitions of the relevant market, both in geographic and in product form dimensions. Only when these issues are settled does the action proceed to assess the actual exercise of market power. This sequence is fundamental to studying market power. Of what relevance is it to ask whether a group of firms exercises market power without having first answered what are the relevant geographic and product markets within which the firms operate? Most NEIO applications in agriculture have treated market definition issues superficially at best. The work on meats provides examples of the problem. Some applications have studied meat packing in aggregate. Others have focused on specific meats. Despite evidence that cattle are seldom shipped as far as 300 miles, various studies have investigated packer oligopsony power using data aggregated to the national level, without questioning whether the relevant geographic markets are regional in scope.⁶¹

A related concern is the tendency of the NEIO studies to investigate processor oligopoly or oligopsony power on one side of the market while maintaining an assumption of perfect competition on the other side of the market. Although there may be good economic rationale for this decision, often there is not because structural bases for concern about oligopoly power usually imply parallel concerns about oligopsony power and vice versa. How does an erroneous assumption about competition on one side of the market affect inferences about market power on the other side of the market?

More research is needed on the implications of the various maintained hypotheses for our ability to draw inferences about market power. Additional Monte Carlo studies along the lines of Hyde and Perloff (1994) and Raper, Love and Shumway (1998)

⁶⁰ Gardner (1975) offers examples of how substitution might occur. Labor can be used to reduce grain wastage and use of pest and spoilage control may be increased in response to a relative increase in the farm price of grain. More recent attempts to justify nonzero σ have, however, relied on arguments that pertain to what in reality are issues of multiproduct technologies or matters of technological change. The boxed beef technology, for example, has been offered as a way in which capital and labor substituted for raw beef. Indeed the boxed beef technology may well permit beef to be processed with less wastage than the traditional packing technology, but the two technologies are quite distinct, and this type of technological improvement has nothing to do with Hicks' σ , which refers to movements along an isoquant for a given technology. Similarly, σ pertains to a single-product production technology. Allocations of a given raw product to multiple product forms, some of which will use relatively more or less of the raw product than others, also have nothing to do with σ .

⁶¹ A contributing factor to poorly defined product or geographic markets is that many NEIO and aggregate SCP studies use data collected for reasons other than economic analysis such as the U.S. SIC data. Data at the four-digit level of aggregation often contain a variety of products which are mostly linked through a common agricultural input, not by end use. For example, SIC 2015 is poultry and egg processing, and Bhuyan and Lopez (1997) found moderate oligopoly power ($\theta = 0.289$) in this category for the period 1972–87. Five-digit SIC categories within SIC 2015 include young chickens, turkeys, other poultry, and liquid, dried, and frozen eggs.

could help to answer these questions. Also helpful will be more studies patterned after Genesove and Mullin (1998), who utilized cost and price data and a demand elasticity estimate for the U.S. cane sugar industry to compute a direct estimate of θ using (8'). Estimates of θ derived from alternative NEIO approaches were then compared to the "true" value and were found to comport quite closely and to be insensitive to the functional form of demand.

8. Implications of imperfect competition in agricultural markets

This section considers the implications of imperfect competition in agriculture for public policy and for the conduct of research in the area of food marketing. The latter topic involves the consequences of constructing and utilizing economic models which do not reflect properly the structure of competition in an industry.

8.1. Implications for public policy and antitrust

Most work in the SCP tradition has emphasized the welfare implications of market power and resulting policy implications. The set of studies intended to measure the welfare costs of market power in the food system comprises a significant literature in its own right. Most such studies have focused on U.S. food manufacturing and on the implications of seller rather than buyer market power. Exceptions to the U.S. focus are Marttila's (1996) and Lavergne, Réquillart and Simioni's (2001) analyses of Finnish and French food manufacturing, respectively.

Measuring static welfare loss from seller market power is not difficult conceptually. Given the volume of output, Q^* , in an industry, one needs to obtain an estimate of the markup of price over cost and an estimate of the elasticity of demand in the market in order to compute the deadweight loss or "Harberger" triangle. In Figure 3, this is the area B, given demand $P_1(Q)$, and the area B + C, given demand $P_0(Q)$. An immediate issue is whether to also include the rectangle A of profits in Figure 3 transferred to the food manufacturers (the so-called Posner (1975) rectangle). The various arguments in support of including the rectangle are that monopoly power encourages resource waste or X -inefficiency and wasteful expenditures such as advertising and lobbying to achieve and maintain the monopoly position and that these costs can be approximated by the profit rectangle.

Parker and Connor (PC) (1979) estimated welfare losses in each U.S. food manufacturing industry by first estimating SCP models of the price-cost margin and then using fitted values from the estimation to calculate the monopoly overcharge in each industry. One controversial approach pioneered by PC and also by Nickell and Metcalf (1978) involves use of brand name and private label price differences as a proxy for the price-cost differential. PC produced loss estimates including the Posner rectangle of about 5.7 percent of U.S. food expenditures in 1975.

In contrast to the empirical approach of PC, Gisser (1982) generated welfare loss estimates from a conceptual oligopoly model that assumed 36 percent of firms in an

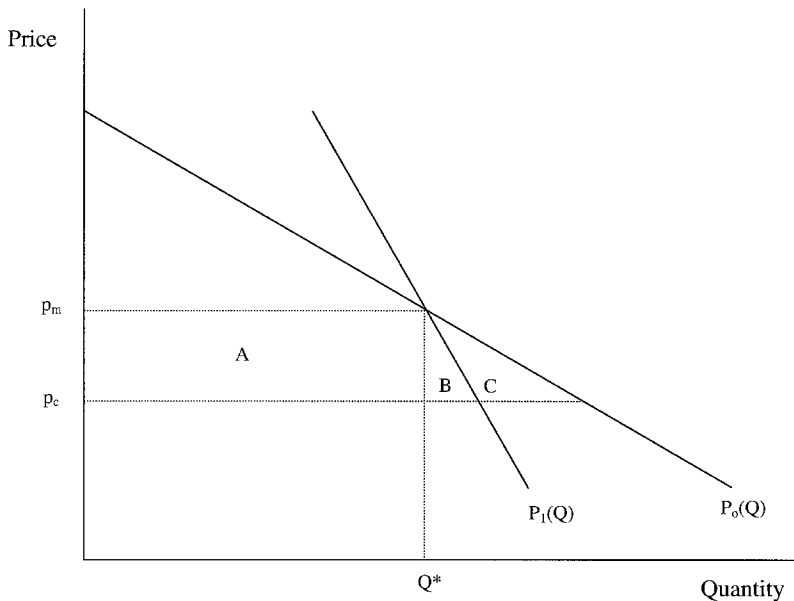


Figure 3. Impact of the choice of demand elasticity on the calculation of welfare loss due to imperfect competition.

industry acted as collusive price leaders and the remaining 64 percent operated as a competitive price-taking fringe.⁶² He adduced gross losses including the Posner rectangle similar to those of PC. However, Gisser also analyzed the determinants of factor productivity in food manufacturing and found it to be positively associated with increases in food industry concentration. Incorporating these cost savings into the welfare analysis caused the welfare losses due to oligopoly power to disappear. Young (1997) provides a detailed critique of the use of the dominant firm price leadership model to estimate welfare loss.

Recent welfare loss studies for the U.S. food sector include Bhuyan and Lopez (1995) and Peterson and Connor (1996). Peterson and Connor utilized results from a study of brand name versus private label price differences in food manufacturing by Connor and Peterson (1992) to estimate price-cost margins in each industry from which the Harberger triangle and the Posner rectangle were computed. Losses on average were 6.9 percent of the value of 1979–80 food shipments.⁶³ Bhuyan and Lopez (1995) inferred a value of θ for each U.S. food manufacturing industry from published data on

⁶² The justification for this assumption was that 36 percent was the weighted CR4 in food manufacturing for 1972.

⁶³ The key measure of concentration in Connor and Peterson (1992), the Herfindahl index divided by the industry elasticity of demand, was subsequently found to have the erroneous sign [Hinloopen and Martin (1997)]. The loss estimate reported here is based on the correct sign.

industry sales and costs. Given additional data on elasticity of demand in each industry from a study by Pagoulatos and Sorensen (1986) and the Herfindahl index and an assumption of constant marginal production costs, they then estimated the resulting welfare loss in terms of the Harberger triangle only. They pegged the average loss at 3 percent of total sales for 1987, with nearly 40 percent of that loss coming from the tobacco industries alone.⁶⁴

Given that no consensus has been reached on the importance of market power in the food system, it is not surprising that little agreement exists on the welfare costs of market power. An important difference among analysts concerns market power's effect on costs. Some believe market power breeds inefficiency and waste and, thus, justifies inclusion of Posner rectangle as a welfare loss. Others of a Chicago School persuasion believe market power is mostly efficiency driven and, thus, those benefits must be measured and weighed against the costs of any supracompetitive pricing. The demand elasticity also ends up playing a crucial role in studies such as Gisser (1982) or Bhuyan and Lopez (1995) that derive the price-cost margin from a structural oligopoly model rather than by estimating it from an SCP regression. Under the latter methodology the elasticity plays only a minor role in calculating the Harberger triangle, *given* the estimated price-cost margin, as in the area B versus the area B + C in Figure 3. In the structural models, the imputed elasticity value is crucial to *deriving* the price-cost markup, given the assumed mode of oligopoly behavior – see Equation (8'). Notably absent from the literature are studies which attempt to measure welfare losses due to the buying and selling power of food retailers or to the power of food processors as buyers of farm products.

Overall, this body of work is too ambitious in attempting to apply the same set of methods, whether SCP paradigm or structural, across many, diverse industries. Studies that focus on the welfare implications of market power in individual industries are likely to yield more accurate indications of the welfare costs of market power. Recent examples of such work include Azzam and Schroeter (1995) and Azzam (1997) on the tradeoff between efficiency gains and losses from oligopsony power from consolidation in the U.S. beef industry, and Triffin and Dawson (1997) on the losses from oligopoly in frozen potato products in the U.K.⁶⁵

The policy implications of market power in the food chain are not clear despite the significant amount of work done to estimate the departures from competition and the attendant welfare costs. Key unresolved issues include the following:

- How often are departures from competitive pricing observed and how quantitatively important (in the sense of generating large welfare losses and/or redistributions of income) are those cases of imperfect competition?

⁶⁴ Bhuyan and Lopez (1998) subsequently used a regression model to explain variations in deadweight loss across industries as a function of several variables including concentration, advertising intensity, and economies of scale.

⁶⁵ Azzam (1997) estimated that oligopsony power increased with rising concentration in beef packing but that the costs of market power were more than offset by the reduction in packing costs due to economies of size.

- What are the efficiency implications of increasing concentration? Is increasing concentration primarily efficiency driven, or does monopoly power breed inefficiencies and wasteful competition?
- How important is countervailing power as an endogenous market response to monopoly or monopsony power?
- Even if monopoly and/or monopsony power is significant in the food marketing sector, how effective can antitrust actions or regulations be in curtailing it?

As the discussion in this chapter has indicated, most of the resources among agricultural economists have been directed, with only limited success, to this first issue. Although the economic bases for economies of size, X-inefficiencies, excessive advertising, and product differentiation are well established, there is little empirical evidence of their actual effects in reinforcing or offsetting welfare costs from supracompetitive pricing. Countervailing power is only now re-emerging as an important subject of economic inquiry following years of neglect after the famous exchange between Galbraith (1952) and Stigler (1954). Key issues are the extent to which farmers can countervail buyer power through collective action and the extent to which the power of food manufacturers and food retailers offset in their mutual dealings.

Finally, as to the subject of antitrust, the current practice of enforcement in the U.S. is far from the activist policy advocated by the pioneers of industrial organization analysis in agriculture such as Hoffman (1940). Compare, for example, the subdued tone and modest recommendations contained in the recent report by the USDA Advisory Committee on Agricultural Concentration [USDA (1996b)] with the activist recommendations issued 30 years earlier in a similar report by the National Commission on Food Marketing. Although markets are generally much more concentrated now than 30 years ago, the Advisory Committee's main recommendation is for enhanced disclosure and improved reporting of information, and the Committee distances itself from recommendations that would "ultimately stunt opportunities for growth within the industry" (p. 15), or "slow or prevent the industry's need to adapt to a changing market place" (p. 15).⁶⁶

8.2. *Implications for modeling*

Several recent studies have explored the modeling implications of imperfect competition in food processing and distribution. First, consider the literature on the returns to agricultural research summarized by Alston, Norton and Pardey (1995). Until recently, this work had assumed that products were produced and sold in competitive markets. The first studies to examine the effects of market power on agricultural research benefits

⁶⁶ Ironically, mandatory disclosure of terms of trade such as price can have anticompetitive consequences, presumably not what the Committee intended. In markets such as live cattle where prices are set through buyer bidding, mandatory disclosure of bids is an excellent device to reinforce bidder cartels [McAfee and McMillan (1987)].

were by Kim et al. (1987) on the adoption of mechanical tomato harvesting in California, and Dryburgh and Doyle (1995) on improved productivity in the U.K. dairy industry. Kim et al. utilized a monopsony model, whereas Dryburgh and Doyle investigated both processor monopsony and farmer monopoly through a statutory marketing board. However, even when we have reason to believe that agricultural markets are imperfectly competitive, there is usually little basis to support pure monopoly or monopsony models. Indeed, the gist of the empirical research summarized here is that departures from perfect competition are often relatively modest as measured by θ or ξ values of 0.2 or less.

Huang and Sexton (1996) applied a general conjectural variations oligopoly/oligopsony model to study behavior in the Taiwanese tomato processing industry and to estimate the benefits from adopting mechanical harvesting technology in Taiwan. They found evidence of imperfect competition in both farm product procurement and domestic product sales, with results indicating that processors' exercise of market power would reduce total benefits from adopting the new technology by 25 percent compared with competition. Furthermore, processors, who would receive no benefits under competition, would capture over half of the total benefits from mechanical harvesting through the exercise of oligopsony power.

Alston, Sexton and Zhang (1997) and Hamilton and Sunding (1998) studied the impacts of oligopoly and/or oligopsony power on the magnitude and distribution of research benefits under a broad range of scenarios. The most important effects of processor market power were on the distribution of benefits from research rather than on the total benefits. For example, using the estimates for meat processing by Azzam and Pagoulatos (1990) ($\theta = 0.178$ and $\xi = 0.223$), Alston, Sexton and Zhang estimated that processors would capture about a third of the benefits from a farm sector innovation that produced a parallel shift outward in the supply curve as opposed to none under perfect competition (assuming a constant returns processing technology), but total benefits were only 3 percent less than under competition.

Suzuki et al. (1993, 1994a) have considered how the apparently modest exercise of oligopoly power implied by the empirical estimates can affect the market's response to changes in government policy. In an application to Japan, a simulated decrease in price supports reduced fluid milk prices within the imperfect competition model by only about half of what was implied under a perfect competition model. Conversely, the relative differences in policy effects between imperfect and perfect competition models were much smaller in a U.S. application. Suzuki et al. (1994b) applied the same methods to study the impact of generic milk promotion in Japan. Here, failure to incorporate the implied modest exercise of oligopoly power caused marginal promotion benefits to be understated by 23–27 percent. Subsequent work by Chen and Weerahewa (1998) applied to the Canadian butter industry emphasized the importance of the functional form of demand in determining the error in estimation of advertising benefits from erroneously assuming perfect competition in the processing sector.

A final example concerns the impact of government trade policies under perfect versus imperfect competition. Lanclos and Hertel (1995) examined the effect of a tariff under perfect competition and imperfect competition for selected industries in the U.S. food processing sector. Results indicated that a tariff increase on intermediate inputs across all industries resulted in a decrease in total industry output that was much larger under market power than under competition: 74 percent for fruits and vegetables, 76 percent for milled consumption goods, 60 percent for confectionery, 73 percent for beverages, and 74 percent for other goods.

McCorriston and Sheldon (1996a) examined the relative effect of tariffs and quota on welfare of domestic consumers and producers when markets are oligopolistic. In an application to the German banana market, McCorriston and Sheldon first calibrated a model which showed modest departures from competition that were less than those implied by Cournot behavior. The authors then argued that imposition of a quota regime as opposed to an otherwise-equivalent tariff would cause the traders to behave in a Cournot fashion (i.e., outputs would be fixed by the quota). The quota, thus, causes a reduction in competition and welfare that is not present under a tariff. McCorriston and Sheldon estimated that consumer welfare losses were 19 percent greater for the quota than for the tariff, and firm profits were 170 percent greater for the quota than the tariff. McCorriston and Sheldon (1996b) showed how imperfect competition in the EC for bananas would diminish the pass-through of tariff reductions to consumers from the 100 percent level attained under competition to 80 percent under the estimated oligopoly structure.

Collectively, these studies suggest that even modest departures from perfect competition may be important in applied analyses, and failure to take into account the actual market structure can introduce serious biases. Although competition policy and antitrust are the focus for many students of the industrial organization of the food and beverage sector, the behavioral effects and attendant implications for model development of imperfect competition should be important to agricultural economists generally.

9. Concluding comments

We hope this chapter has provided an evenhanded assessment of an important and controversial field of research in agricultural economics. We expect the topics discussed here to increase in importance over time as trends towards increasing horizontal concentration and vertical coordination in the food and beverage sector continue. Although there is disagreement as to the frequency of departures from perfect competition and the importance of those departures in terms of welfare effects and implications for public policy, it seems indisputable that even modest departures from competition may influence market equilibria in important ways that researchers need to take into account. We hope this chapter is useful to both specialists in the field as a perspective on the current state of industrial organization research in agricultural markets, and to nonspecialists as a relatively comprehensive introduction to the field.

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MARKETING MARGINS: EMPIRICAL ANALYSIS

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Abstract

The marketing margin, characterized as some function of the difference between retail and farm price of a given farm product, is intended to measure the cost of providing marketing services. The margin is influenced primarily by shifts in retail demand, farm supply, and marketing input prices. But other factors also can be important, including time lags in supply and demand, market power, risk, technical change, quality, and spatial considerations. Topics for future research include improved specifications for margins and demand and supply shifters, retail-to-farm price transmission of retail demand changes, and impacts of vertical integration and policy interventions.

JEL classification: Q13

1. Introduction

Few areas of agricultural economics have received as much public scrutiny as marketing margins, yet there is little consensus on the sources of changes in margins and whether such changes over time have led to a deterioration or improvement in the welfare of farmers and consumers. The purpose of this chapter is to summarize the current state of knowledge on marketing margins in agricultural economics, and to indicate areas that show promise for future research.

The marketing margin, or the farm-to-retail price spread, is the difference between the farm value and retail price. It represents payments for all assembling, processing, transporting, and retailing charges added to farm products [Elitzak (1996)]. Table 1 shows the declining trend over time in the farmer's share of consumer expenditures for domestically produced food products. Figure 1 shows the components of the food marketing bill in the United States for 1994. Aside from the raw farm product, labor and packaging are the major components of food marketing. Other factors, including before tax profits, account individually for only a small share of the retail food dollar.

Among the questions often asked about marketing margins are the following: Are marketing margins too large? Why are margins different among products? How have margins changed over time? Are margins scale-dependent, i.e., do they vary systematically with the quantity handled or marketed? Are margins determined via markup pricing? What is the incidence of marketing costs on retail prices and farm prices? How quickly are farm prices transmitted to the retail level, and how quickly are retail price changes transmitted to farmers? A long-standing issue in agriculture has been a mistrust

Table 1
Farm value share of consumer expenditures
for domestically produced farm foods, selected
years

Year	Share (%)
1950	41
1955	35
1960	33
1965	33
1970	32
1975	33
1980	31
1985	25
1990	24
1991	22
1992	27
1993	22
1994	21

Source: Elitzak (1996, Table 18).

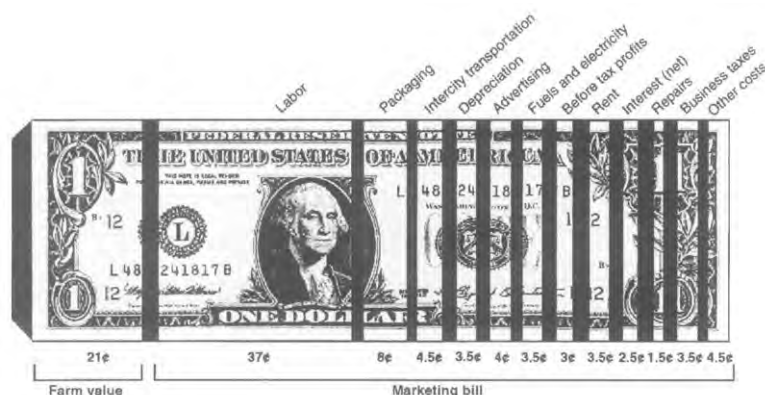


Figure 1. What a dollar spent for food paid for in 1994. Source: Elitzak (1996, Figure 4).

by farmers of middlemen. What is the relationship between concentration and market power? Is increased concentration detrimental or beneficial to producers?

The literature on marketing margins is closely related to the economic literature on value-added functions [e.g., Bruno (1978)]. The essential difference between the concept of margin and value-added in manufacturing, however, is that value-added focuses on the contribution of intermediate inputs to GDP, whereas marketing margins only subtract the value of the farm input. In addition, the marketing margin is typically defined for a specific product at a given point in time. Specifically, the margin is calculated by subtracting the net farm value equivalent of food sold at retail of the farm product (farm value less the value of any by-product) from the retail price. For food product groups (e.g., meat products) and for food as an aggregate, the price spread is calculated as the difference between retail cost of a given market basket and the farm value of foods in that category. The market basket contains the average quantities of domestic, farm-produced foods consumed by urban households in a base period [Harp (1987); Elitzak (1996)]. The literature on marketing margins is also related to the so-called price-cost margin literature [e.g., Cowling and Waterson (1979)], although price-cost margins are best viewed as net margins because they are net of labor and other variable costs of marketing.

As emphasized in this chapter, an empirical analysis of marketing margins should be first and foremost an economic analysis of the determinants of retail and farm price for a given commodity. There are a variety of ways to characterize the marketing margin [Gardner (1975)], but the marketing margin, like price, is best viewed as an equilibrium entity, defined as some function of the difference between the equilibrium retail price and equilibrium farm price. The next section lays out the basic theoretical framework for summarizing past developments in the analysis of marketing margins. This section is followed by a discussion of the determinants of margins under competitive conditions with both fixed and variable factor proportions. In the fourth section, attention then fo-

cuses on the influence of market power on margins. The fifth and sixth sections examine other factors influencing marketing margins, including short-run lags in food price determination, risk, technical change, quality, and spatial considerations. The final section concludes with an assessment of the literature and provides some observations on the future direction for research on marketing margins.

2. Determinants of retail and farm prices

In order to summarize past developments and recent advances in the methodology of analyzing marketing margins and derived demand for agricultural commodities, it is useful to advance a theoretical framework. Such an approach enables us to link the theoretical framework with the literature, to identify testable hypotheses, and to point to future areas for research.

Initially, the prototypal model used to characterize marketing margins is based on the assumption of price-taking behavior in both the output market for the final product and input markets for all the inputs, including the market for the agricultural raw product. Later this assumption will be relaxed as we consider the potential impact of imperfect competition in both the output market and market for the agricultural raw product. I will focus on the single product case in the marketing sector, but allow for interrelationships between retail products in the product demand specification. Also, it is customary to assume that all inputs in food marketing other than the agricultural raw input are unspecialized to the industry in question, so prices of these inputs will be taken as exogenous unless otherwise indicated. Observable variables that are endogenous to the industry include retail and farm prices of the product in question, and different relationships among these prices depicting the marketing margin. Comparative statics of the reduced forms for retail and farm price (and relationships among these prices) are used to identify the key factors affecting measurement of marketing margins.

2.1. Model specification

The endogenous variables of the model include industry quantity of the retail product (Q_r), retail price (P_r), industry quantity of the farm product (Q_f), farm price (P_f), and industry quantities of the marketing inputs (X). Exogenous variables include retail demand shifters (Z), marketing input prices (W), other exogenous marketing sector shifters (T), and farm product supply shifters (C). These variables are assumed to be linked through the following structural specification of demand and supply:

$$Q_{rd} = D_r(P_r, Z) \quad (\text{retail demand}), \quad (1)$$

$$Q_{rs} = S_r(P_r, P_f, W, T) \quad (\text{retail supply}), \quad (2)$$

$$Q_{fd} = D_f(P_r, P_f, W, T) \quad (\text{farm input demand}), \quad (3)$$

$$Q_{fs} = S_f(P_f, C) \quad (\text{farm input supply}), \quad (4)$$

$$X_d = D_x(P_r, P_f, W, T) \quad (\text{marketing input demand}), \quad (5)$$

$$W \quad \text{exogenous} \quad (\text{marketing input supply}), \quad (6)$$

$$Q_{rd} = Q_{rs} = Q_r \quad (\text{retail market clearing}), \quad (7)$$

$$Q_{fd} = Q_{fs} = Q_f \quad (\text{farm market clearing}), \quad (8)$$

$$X_d = X_s = X \quad (\text{marketing input market clearing}), \quad (9)$$

where the superscripts d and s refer to demand and supply, respectively. Equations (1) and (2) describe demand and supply for the retail product, Equations (3) and (4) describe demand and supply for the farm input, Equations (5) and (6) describe demand and supply conditions for the marketing input, and Equations (7)–(9) indicate the equilibrium conditions. As indicated, the industry in question is assumed to describe a closed economy with no provision made for imports or exports. It is straightforward to extend the model to allow for trade [see, e.g., Chambers (1983); Sumner and Wohlgenant (1985)]; the assumption of no trade is made here simply for analytical convenience.

The retail demand function, $D_r()$, is assumed to be the usual Marshallian demand function, reflecting both substitution and income effects of price changes for own-price changes. Price effects of related goods, income changes, population changes, and taste changes are subsumed in the Z variable. Changes captured by Z could be thought of in terms of a vector or, as shown below, to reflect the impact of a given horizontal shift in retail demand. Equations (2), (3), and (5) are the industry output-price constant supply and input demand functions derived by horizontally summing an individual firm's output supply and input demand functions [Heiner (1982)]. Equation (4) is the farm input supply function, which represents the output supply decisions of primary producers of the agricultural product.

Under the usual regularity conditions (i.e., downward-sloping demand curves and upward-sloping supply curves), there will be a unique equilibrium for given values of the exogenous variables. At this equilibrium, values of the endogenous variables, and hence the marketing margin, are determined. As discussed by Gardner (1975), the marketing margin, or farm-to-retail price spread, can be measured in many different ways, e.g., as the difference between retail and farm value of the commodity, by the ratio of retail to farm price, by the farm value share of total retail value ("farmer's share of the retail dollar"), or by the percentage marketing margin (i.e., marketing margin as a percentage of retail or farm price). Gardner (1975) focuses on determinants of the ratio of retail to farm price and the farm value share. Fisher (1981) examines the incidence of marketing costs on farm price as a proportion of the sum of the effects on retail and farm prices. As indicated previously, the farm-to-retail price spread is intended to measure the per (retail product) unit costs of assembling, processing, distributing, and retailing foods from the farm and is similar to the concept of value added used elsewhere in economics. Our focus here will be on the general form of the farm-to-retail price spread (M):

$$M = P_r - (Q_f/Q_r)P_f, \quad (10)$$

where the ratio (Q_f/Q_r) is not necessarily constant, but will in general change as market conditions change. The advantage of allowing the input-output ratio to change and not be a constant (as is the case with USDA's price spread data) is that, under quite general conditions, Equation (10) represents efficient utilization of marketing inputs [Reed and Clark (1998)].¹

Equations (1)–(10) indicate quite clearly that, in general, the retail and farm prices and quantities, as well as the marketing margin, are jointly determined by the exogenous shifters of the underlying demand and supply functions: Z , W , T , and C . While one could proceed directly in this manner by formulating reduced-form equations for the endogenous variables, derived from the implicit solutions to (1)–(10), more insight into the relationship between retail and farm prices can be gained by focusing on the partially reduced form equations:

$$P_r = P_r(Z, W, T, Q_f), \quad (11)$$

$$P_f = P_f(Z, W, T, Q_f), \quad (12)$$

$$M = M(Z, W, T, Q_f), \quad (13)$$

where these equations are the implicit solutions to (1), (2), (3), (6), (7), and (8), holding Q_f constant.² One motivation for this specification of the linkage between retail and farm prices is the nature of agricultural production, whereby production of the farm product lags price changes due to biological and other natural causes. Indeed, it is frequently the case that supply of the farm input can be viewed entirely as a function of lagged rather than current period prices so that quantity can be assumed to be econometrically predetermined with respect to the current period farm price.

Equations (11)–(13) resemble closely the approach taken historically by agricultural economists to estimation of the linkage between retail and farm prices. For example, Fox (1951) and Waugh (1964) estimate partially reduced form equations of retail price and farm price as simple linear or log linear functions of income (to represent changes in Z and W), quantity of the farm product (or retail product), and sometimes a linear time trend. Often retail quantity (Q_r) is used in place of the farm quantity (Q_f) in Equation (11) under the assumption that the ratio of farm to retail quantity has remained constant over the sample period. If this assumption is valid, then Equation (11) can be thought of as the inverse retail demand function (see Equation (1)).

¹ Price spread data published by the USDA do not strictly reflect changes in margins with fixed input-output coefficients, but rather are best viewed as a hybrid of margins with fixed coefficients and margins computed according to Equation (10). This is because USDA periodically revises farm product equivalents for individual commodities. In addition, weights of the items that make up market baskets for product groups and food as an aggregate are periodically revised as new consumer expenditure surveys become available. See Harp (1987) for details on the nature and frequency of such revisions.

² Partially reduced form equations refer to equations obtained by eliminating one or more equations and one or more endogenous variables from the model [Hildreth and Jarrett (1955); Foote (1958)].

2.2. Comparative statics

The implicit solutions for retail and farm price, Equations (11) and (12), may be viewed as the solutions to Equations (7) and (8) after substituting for Equations (1)–(3), i.e.,

$$D_r(P_r, Z) - S_r(P_r, P_f, W, T) = 0, \quad (14)$$

$$D_f(P_r, P_f, W, T) - Q_f = 0. \quad (15)$$

Because the values for P_r and P_f that satisfy (14) and (15) are the implicit solutions given by (11) and (12), the comparative statics of (11) and (12) can be characterized by totally differentiating Equations (14) and (15) and converting to elasticity form to obtain:

$$\begin{aligned} (\eta - \xi_{rr}) d(\log P_r) + \eta_z d(\log Z) - \xi_{rf} d(\log P_f) - \xi_{rw} d(\log W) \\ - \xi_{rt} d(\log T) = 0, \end{aligned} \quad (16)$$

$$\begin{aligned} \xi_{fr} d(\log P_r) + \xi_{ff} d(\log P_f) + \xi_{fw} d(\log W) + \xi_{ft} d(\log T) \\ - d(\log Q_f) = 0, \end{aligned} \quad (17)$$

where $d(\log P_r) = dP_r/P_r$, etc., and the η 's and ξ 's represent the partial elasticities of the demand and supply functions evaluated at the initial equilibrium; i.e., $\eta = (\partial D_r / \partial P_r)(P_r/Q_r)$,

$$\begin{aligned} \eta_z &= (\partial D_r / \partial Z)(Z/Q_r), & \xi_{rr} &= (\partial S_r / \partial P_r)(P_r/Q_r), \\ \xi_{rf} &= (\partial S_r / \partial P_f)(P_f/Q_r), & \xi_{rw} &= (\partial S_r / \partial W)(W/Q_r), \\ \xi_{rt} &= (\partial S_r / \partial T)(T/Q_r), & \xi_{fr} &= (\partial D_f / \partial P_r)(P_r/Q_f), \\ \xi_{ff} &= (\partial D_f / \partial P_f)(P_f/Q_f), & \xi_{fw} &= (\partial D_f / \partial W)(W/Q_f), \text{ and} \\ \xi_{ft} &= (\partial D_f / \partial T)(T/Q_f). \end{aligned}$$

Solving (16) and (17) for $d(\log P_r)$ and $d(\log P_f)$ yields

$$d(\log P_r) = \pi_{rz} d(\log Z) + \pi_{rw} d(\log W) + \pi_{rt} d(\log T) + \pi_{rf} d(\log Q_f), \quad (18)$$

$$d(\log P_f) = \pi_{fz} d(\log Z) + \pi_{fw} d(\log W) + \pi_{ft} d(\log T) + \pi_{ff} d(\log Q_f), \quad (19)$$

where

$$\pi_{rz} = \xi_{ff}\eta_z/D, \quad (20a)$$

$$\pi_{rw} = (\xi_{ff}\xi_{rw} - \xi_{rf}\xi_{fw})/D, \quad (20b)$$

$$\pi_{rt} = (\xi_{ff}\xi_{rt} - \xi_{rf}\xi_{ft})/D, \quad (20c)$$

$$\pi_{rf} = \xi_{rf}/D, \quad (20d)$$

$$\pi_{fz} = \xi_{fr}\eta_z/D, \quad (20e)$$

$$\pi_{fw} = (-\xi_{fr}\xi_{rw} + [\xi_{fr} - \eta]\xi_{fw})/D, \quad (20f)$$

$$\pi_{ft} = (-\xi_{fr}\xi_{rt} + [\xi_{fr} - \eta]\xi_{ft})/D, \quad (20g)$$

$$\pi_{ff} = -(\xi_{fr} - \eta)/D, \quad (20h)$$

$$D = -(\xi_{fr} - \eta)\xi_{ff} + \xi_{rf}\xi_{fr}. \quad (20i)$$

Note that in this form, Equations (18) and (19) show the relationship between the logarithmic changes in retail and farm prices and logarithmic changes in the demand and supply shift variables Z , W , T , and Q_f . The reduced-form coefficients, the π 's, are total elasticities and are related to the partial elasticities of demand and supply according to (20a)–(20i). Theil (1980, Chapter 2) indicates that this approach is useful to formulating equations for econometric estimation because no algebraic specifications of the demand and supply functions are required, and the decision to parameterize the model is postponed until the point at which differentials are replaced by finite differences. Regardless of how one proceeds in econometric analysis, however, it is important to stress that Equations (18) and (19) and the resulting total elasticities (20a)–(20i) may be regarded as general comparative static results of (16) and (17) for arbitrary specifications of demand and supply.

In an analogous fashion, the comparative statics of the marketing margin, Equation (10), can be characterized in logarithmic changes as follows:

$$\begin{aligned} (M/P_r) d(\log M) &= (1 - S_f) d(\log M) \\ &= d(\log P_r) - S_f d(\log P_r) - S_f d(\log Q_f) + S_f d(\log Q_r), \end{aligned} \quad (21)$$

where S_f is the farm value share (i.e., $P_f Q_f / P_r Q_r$). Note that if the ratio between the farm quantity and retail quantity is fixed, then (21) is reduced to simply the first two terms,

$$(1 - S_f) d(\log M) = d(\log P_r) - S_f d(\log P_f). \quad (22)$$

In the more general case when the farm and retail quantities are not fixed, the logarithmic differential of the retail demand function (1), $d(\log Q_r) = \eta d(\log P_r) + \eta_z d(\log Z)$, can be substituted for $d(\log Q_r)$ on the right-hand side of (21) to obtain

$$\begin{aligned} (1 - S_f) d(\log M) &= (1 + S_f \eta) d(\log P_r) - S_f d(\log P_f) \\ &\quad - S_f d(\log Q_f) + S_f \eta_z d(\log Z). \end{aligned} \quad (23)$$

In either case of fixed proportions, Equation (22), or variable proportions, Equation (23), total elasticities of the marketing margin with respect to Z , W , T , and Q_f can be eval-

uated through substituting (18) and (19) for $d(\log P_r)$ and $d(\log P_f)$ in (22) and (23). I will return to a discussion of the determinants of Equations (22) and (23) subsequent to a discussion of the determinants of (18) and (19).

By comparative static results from economic theory, it is possible to place some interpretation on and determine the signs of the total elasticities of the logarithmic differentials of retail and farm prices given by Equations (18) and (19). First, the reciprocal of π_{ff} is the industry derived demand for the farm product, holding prices of other inputs constant. Heiner (1982) proves that in the short run the sign of this elasticity is unambiguously negative, given that the retail demand curve is negatively sloped. The intuition of this result is that aggregate factor demand response is bounded by the two extreme cases when demand for the retail product is perfectly inelastic and when demand for the retail product is perfectly elastic. That is, the industry derived demand for the farm product lies between two demand curves: one constructed as the horizontal summation of the constant output demand responses and the other constructed as the horizontal summation of the output-price constant demand responses, which are both unambiguously negatively sloped.³ As proved by Heiner (1982), this result is in no way conditional on the similarity of firms in the industry. In particular, industry derived demand curves constructed in this manner (holding other input prices constant) are unambiguously negatively sloped with dissimilar firms in the short run [Heiner (1982)] or in the long run [Braulte (1987)], where entry and exit from the industry occur.

In addition to establishing that the industry elasticity of derived demand for the farm product, $E_{ff} = 1/\pi_{ff}$, is unambiguously negative when $\eta < 0$, we can also establish that the total elasticities (20a), (20d), and (20e) will ordinarily be positive, negative, and positive, respectively. The theory of the firm establishes that the retail supply elasticity ξ_{rr} is positive, and that the factor demand elasticity ξ_{ff} is negative. Thus, because $\pi_{ff} < 0$, we see from (20i) that $D > 0$ and from (20a) that π_{rz} has the same sign as η_z , which we would expect to be positive when interpreted as a horizontal increase in retail demand. If the farm input is a normal factor – which seems plausible for the commodity aggregates typically analyzed – then the elasticity of retail supply with respect to farm price ξ_{rf} is negative. In addition, the cross elasticity ξ_{fr} would be positive in view of the symmetry relation between retail supply and farm input demand, $\xi_{rf} = -s_f \xi_{fr}$ [see Wohlgenant and Haidacher (1989, p. 17)].⁴ Thus, from (20d) we expect the total elasticity of retail price with respect to farm quantity π_{rf} to be negative, and the total elasticity of farm price with respect to Z , π_{fz} , to be positive. Finally, the signs of the effects of W and T on retail and farm prices are generally indeterminate because the signs of ξ_{fw} and ξ_{ft} are indeterminate.

³ See Friedman (1976, p. 184) for an intuitive discussion of the nature of industry factor demand response.

⁴ The symmetry relationship derives from the result in the theory of the firm that $\partial S_r / \partial P_f = -\partial D_f / \partial P_r$ [Mosak (1938)].

2.3. Elasticity of price transmission

In addition to providing information about total elasticities of retail and farm price, Equations (18) and (19) can be used to derive an expression for the elasticity of price transmission, i.e., the logarithmic change in retail price divided by the logarithmic change in farm price.⁵ Solving Equation (19) for $d(\log Q_f)$, substituting for $d(\log Q_f)$ in (18), setting $d(\log Z) = d(\log W) = d(\log T) = 0$, and solving for $d(\log P_r)/d(\log P_f)$ yields

$$E_{rf} = \pi_{rf}/\pi_{ff}, \quad (24)$$

where E_{rf} is the proportionate change in retail price for a proportionate change in farm price, holding Z , W , and T constant.

The concept of elasticity of price transmission has played a crucial role in obtaining estimates of derived demand elasticities for agricultural commodities. George and King (1971), for example, use the result (derived assuming fixed proportions between the retail and farm quantity) that the elasticity of derived demand equals the product of the elasticity of price transmission and retail demand elasticity to derive a matrix of own- and cross-price elasticities of demand for food products at the farm level. As pointed out by Waugh (1964), for example, one important implication of this specification is that so long as retail price is larger than farm price, demand at the farm level will be more inelastic (less elastic) than demand at retail level.

2.4. Elasticity of derived demand

To see conceptually how the derived demand elasticity, $E_{ff} = 1/\pi_{ff}$, is related to the elasticity of price transmission, E_{rf} (defined by Equation (24)), and elasticity of retail demand, η , we can use these definitions to show that

$$E_{ff} = E_{ff}^c + E_{rf}\eta\xi_{fr}/\xi_{rr} \quad (25)$$

[Wohlgenant and Haidacher (1989, p. 21)], where $E_{ff}^c = \xi_{ff} - \xi_{rf}\xi_{fr}/\xi_{rr}$ is the industry derived demand elasticity for the farm quantity, derived holding industry retail quantity constant, i.e., it describes the change in input demand for a change in price when the

⁵ Hildreth and Jarrett (1955, p. 110) define elasticity of price transmission as "... the relative change in retail price to the relative change in producers' price when other factors affecting processor behavior are held constant". On the other hand, George and King (1971, p. 61) define the elasticity of price transmission as "... the ratio of relative change in retail price to the relative change in the farm-level price". The measure used here is conceptually the same as George and King's because it depicts the total change in retail price for a total change in farm price. In addition to marketing margins, the concept of elasticity of price transmission is used in international trade to describe the response of foreign prices to changes in the U.S. price of a given commodity [e.g., Bredahl et al. (1979)].

farm input is substituted for other inputs in producing the retail product. Equation (25) says that, in general, there is not a fixed relationship between elasticity of derived demand at the farm level and elasticity of demand at the retail level. In order for the elasticity of derived demand to equal the product of the elasticity of price transmission and elasticity of retail demand, two conditions must obtain: $E_{ff}^c = 0$ and $\xi_{fr} = \xi_{rr}$. This can be shown to occur if and only if the ratio between the farm and retail quantities is fixed, i.e., that the industry production function for the retail food product is of the Leontief fixed-proportions type, $Q_r = \min\{Q_f/a, X/b\}$, where a and b are constants.

Another interesting special case of (25) occurs when the industry production function exhibits constant returns to scale. In this case (and assuming only two inputs, the farm input and a single marketing input), Gardner (1975) and Wohlgenant (1989, p. 248) show that the elasticity of demand at the farm level has the form

$$E_{ff} = -(1 - S_f)\sigma + S_f\eta, \quad (26)$$

where σ is the elasticity of substitution between the farm and marketing inputs. This case is especially interesting because it shows that it is possible for demand at the farm level to be less inelastic (more elastic) than demand at the retail level. In addition, Equation (26) indicates that the elasticity of price transmission with constant returns to scale (and with perfect competition) equals the farm value share. Equation (26) especially makes transparent that the relationship between the elasticities of derived demand and retail demand hinges crucially on whether the farm and marketing input are combined in variable or fixed proportions.

2.5. Symmetry and constant returns to scale

Theoretical restrictions of homogeneity and symmetry imposed by theory of the firm and consumer imply certain restrictions on the partially reduced form elasticities in (20a)–(20i). In particular, the fact that retail demand is homogeneous of degree zero in prices and income and that retail supply and farm input demand are each homogeneous of degree zero in output and input prices means that the partially reduced form functions (11)–(13) are each homogeneous of degree one in all nominal variables. This implies that the sum of the elasticities for P_r and P_f with respect to all nominal variables in Z and W (i.e., π_{rz} , π_{rw} , π_{fz} , and π_{fw}) should equal one. As discussed above, there is also a symmetry relationship between the retail supply function and farm demand function, $\xi_{rf} = -S_f\xi_{fr}$, implying from (20d) and (20e) that

$$\pi_{rf} = -S_f\pi_{fz}/\eta_z. \quad (27)$$

When $d(\log Z)$ is measured as a one percent horizontal change in retail demand, $\eta_z = 1$, this relationship reduces to

$$\pi_{rf} = -S_f\pi_{fz} \quad (28)$$

[Wohlgenant (1989, p. 244)]. Depending upon how Z is measured, either (27) or (28) would be the relevant restriction to impose on the reduced-form equations under perfect competition. As shown below, existence of imperfect competition in the market for the retail and/or farm product would be expected to alter this relationship. Therefore, symmetry restrictions of the type indicated by (27) and (28) can be used under certain circumstances to test for the existence of imperfect competition.

Existence of an aggregate constant-returns-to-scale production function also imposes some additional restrictions on the reduced-form elasticities in (20). For the reduced-form elasticities associated with Z , W , and Q_f , constant returns to scale, when $\eta_z = 1$, implies

$$\pi_{rz} = -\pi_{rf}, \quad (29a)$$

$$\pi_{fz} = -\pi_{ff} \quad (29b)$$

[Wohlgenant (1989, p. 244)].

2.6. Fixed versus variable input proportions

In combination with (28) and (29a) and (29b), fixed input proportions (i.e., $\sigma = 0$) implies

$$\pi_{rw} = 0 \quad (30)$$

[Holloway (1991)]. In addition, as indicated previously, the industry derived demand elasticity equals the product of the farm value share (which equals the elasticity of price transmission in this case) and the elasticity of retail demand (see Equation (26)).

Aside from the assumption of price-taking behavior, the theoretical framework used to develop restrictions on the reduced-form parameters of (18) and (19) is very general. In particular, in its most general form, indicated by the form of the elasticities in (20a)–(20i), no restrictions are placed on the degree of conformity of behavior among firms. In other words, aside from assuming that the number of firms is constant for any given time period, no restrictions are placed on the similarity or dissimilarity of firms within the industry. As shown by Wohlgenant and Haidacher (1989, pp. 16–17), this means that the elasticities of retail supply and input demands can be thought of as share-weighted sums of the corresponding elasticities of individual firms. For example,

$$\xi_{rr} = \sum_i \xi_{rr}^i (Q_r^i / Q_r),$$

where $\xi_{rr}^i = (\partial S_r^i / \partial P_r)(P_r / Q_r^i)$ is the elasticity of retail supply of the i th firm, and Q_r^i is quantity of retail output of the i th firm. Among other things, this means a distinction needs to be made between industry and firm response. Diewert (1981) shows that input substitution at the industry level is larger than at the firm level when firms are dissimilar.

This means there can be input substitution at the aggregate level even if there is no input substitution by individual firms. So long as individual firms use different input proportions of the same factor of production, there will be change in intensity of input use in the aggregate as the composition of input use changes among firms in response to a factor price change.

As discussed by Wohlgenant and Haidacher (1989, pp. 8–9), existence of dissimilar firms is not the only potential source of input substitutability. In addition to the common view that input substitution results from reduction in amount of wastage and spoilage of the raw product as the price of the farm product rises [e.g., Tomek and Robinson (1981)], input substitution can occur because of ability of firms to choose among different production processes, or technologies, at any time. For example, fresh produce, like lettuce, could be shipped by truck, rail, or even boat, depending upon the particular location of production and proximity to the market. Since modes of transportation entail different transport costs (equivalently, different amounts of marketing services per unit of the raw input), the ratio of farm product to retail product would be expected to change from switching between transport modes.

Because many food commodities analyzed by agricultural economists are really not homogeneous commodities but are composites of many individual commodities, inter-product substitutability is another source of input substitutability. For example, beef is really a composite commodity consisting of such single commodities as ground beef, roast, steaks, etc. Given the ability of meat packers to produce greater or smaller proportions of each of these commodities from a given carcass, there exists an incentive for firms to produce relatively more of those commodities which use more of the raw material (e.g., ground beef) in response to a decrease in the relative price of the agricultural input (i.e., cattle). In such cases, the overall effect is to observe an increase in the ratio of the quantity of the agricultural raw product to the quantity of the retail product [Wohlgenant and Haidacher (1989, p. 8)]. Indeed, Wohlgenant (1999) has shown that substitutability between inputs for a composite commodity can be viewed as a weighted average of substitutability in production and substitutability in consumption.

In a general sense, consumer demand for any food commodity can be viewed as a joint demand for the purchased agricultural input and food marketing services [Waldorf (1966)]. That is, each food product can be viewed as embodying a certain proportion of marketing services and a certain proportion of the raw agricultural product. A meal purchased in a restaurant is different than one prepared at home because it contains more purchased services (e.g., meal preparation time, dining service, etc.) per unit raw material. As the price of the raw product rises (falls) there exists an incentive to substitute marketing services (raw product) for the now relatively more expensive raw product (marketing input), so that the overall effect would be to see a decrease (increase) in the ratio of the quantity of the farm product to the quantity of the retail product.

2.7. *Generality of model*

Two other points about the generality of the theoretical framework depicted by (18) and (19) are worth mentioning. First, the specification in its most general form can ac-

commodate industry behavior exhibiting other than constant returns to scale. Indeed, as discussed above, constant returns to scale results as a special case when the restrictions indicated by (29a) and (29b) obtain. Allowing for a more general specification of industry returns to scale may be important, as other than constant returns to scale have been observed in some settings [e.g., Ball and Chambers (1982)]. Second, for many agricultural commodities, data on retail consumption are not directly observable. Rather, consumption data are derived from essentially production data by applying fixed conversion factors to the amount of production available for consumption (i.e., disappearance data). Thus, in essence, the technology underlying the data is assumed to be of the fixed proportions variety, regardless of the true technology that generates the retail quantities.⁶ Because the retail-to-farm linkage specification in (18) and (19) does not require retail data, one can mitigate the effects of statistical bias by focusing on estimation of partially reduced form retail and farm price equations rather than on the economic structure indicated by Equations (1)–(4) [Wohlgenant (1989)]. As shown below, taking a more flexible approach to estimating retail-to-farm price linkages such as the one outlined here is absolutely essential when trying to understand and isolate the myriad of factors that influence marketing margins.

3. Determinants of marketing margins

The preceding discussion provides a useful backdrop to analyzing the determinants of the marketing margin, Equation (13).

3.1. Marketing margins – fixed input proportions

In the special case of fixed input proportions, we can substitute Equations (18) and (19) into Equation (22) to obtain

$$(1 - S_f) d(\log M) = (\pi_{rz} - S_f \pi_{fz}) d(\log Z) + (\pi_{rw} - S_f \pi_{fw}) d(\log W) \\ + (\pi_{rt} - S_f \pi_{ft}) d(\log T) + (\pi_{rf} - S_f \pi_{ff}) d(\log Q_f). \quad (22')$$

But existence of a fixed proportions technology means that the π 's in (22') must satisfy (28), (29a), (29b), and (30), implying (22') becomes

$$(1 - S_f) d(\log M) = -S_f \pi_{fw} d(\log W) + (\pi_{rt} - S_f \pi_{ft}) d(\log T). \quad (22'')$$

⁶ This should not be taken to imply that the fixed proportions assumption is necessarily wrong in some instances, but only that the retail quantities are not actual consumption amounts but are derived assuming one particular production process applies to all firms at the same point in time. Revisions are made periodically as new information on technologies and production processes becomes available [see, e.g., Putnam and Allshouse (1994)].

Thus, in the special case of fixed proportions, the marketing margin depends only upon marketing input prices (W) and other exogenous shifters (T).

Empirical evidence is rarely consistent with the prediction of Equation (22''), however, as margins often change as quantity of the volume processed changes [Tomek and Robinson (1981)]. To accommodate margin behavior that allows for changing margins as the volume marketed changes, we could relax the assumption that the marketing input supply curve is horizontal. In logarithmic differential form, the inverse supply function for the marketing input has the form

$$d(\log W) = (1/\varepsilon_x) d(\log X) = (1/\varepsilon_x) d(\log Q_f)$$

because with fixed proportions, $d(\log X) = d(\log Q_f)$.⁷ Substituting this expression for $d(\log W)$ in (22'') we obtain:

$$(1 - S_f) d(\log M) = -(S_f \pi_{fw}/\varepsilon_x) d(\log Q_f) + (\pi_{rt} - S_f \pi_{ft}) d(\log T). \quad (22''')$$

Because $\pi_{fw} < 0$ when $\sigma = 0$ [Wohlgenant (1989, p. 244)], we expect to observe a positive relationship between the margin and quantity marketed when the supply curve of the marketing input is upward-sloping, i.e., when $\varepsilon_x > 0$.⁸ However, empirical evidence often contradicts this predicted margin behavior. Quite often, margins are negatively related to quantity marketed and positively related to retail price [Buse and Brandow (1960); Waugh (1964); George and King (1971); Tomek and Robinson (1981)]. With a purely competitive marketing structure and fixed proportions, this margin behavior could result from a negatively sloped supply curve of the marketing input, as Equation (22''') shows. While this result can occur in the long run when there are external economies to the marketing sector, such a specification of margin behavior is inconsistent with short-run competitive pricing. Thus, the competitive theory of marketing margin behavior with the fixed input proportions assumption – even allowing for a non-horizontal supply curve of the marketing input – seems too simplistic [Wohlgenant and Haidacher (1989, pp. 2–4)].

3.2. Marketing margins – variable proportions

If we simply relax the assumption of fixed input proportions between the farm input and marketing input, the type of margin behavior typically observed can be accounted for by a purely competitive market structure with exogenously determined marketing input

⁷ For convenience, supply shifters have been omitted from this expression.

⁸ Gardner (1975) analyzes the more general case where the price of the marketing input is endogenous and where the two inputs are allowed to be combined in variable proportions. Because no new analytical insights are offered for that case over the case of fixed proportions analyzed here, I retain the simpler assumption.

prices. Substituting (18) and (19) into (23), and substituting for π_{rz} from (27) when $\eta_z = 1$, we obtain

$$\begin{aligned} (1 - S_f) d(\log M) = & ([1 + S_f\eta]\pi_{rz} + \pi_{rf} + S_f) d(\log Z) \\ & + ([1 + S_f\eta]\pi_{rw} - S_f\pi_{fw}) d(\log W) \\ & + ([1 + S_f\eta]\pi_{rt} - S_f\pi_{ft}) d(\log T) \\ & - S_f([1 + S_f\eta]\pi_{fz} + \pi_{ff} + 1) d(\log Q_f). \end{aligned} \quad (23')$$

Because, in general, the total elasticities of M with respect to Z , W , T , and Q_f will be non-zero, Equation (23') says that the same variables that influence both retail and farm price separately can be expected to influence the marketing margin. Moreover, because $\eta < 0$, $\pi_{ff} < 0$, and $\pi_{fz} > 0$, the relationship between M and Z and between M and Q_f is generally indeterminate.

It is interesting to examine the implications of (23') further when it is assumed that the industry production function exhibits constant returns to scale. Imposing the restrictions (29a) and (29b) on (23'), the change in the marketing margin when $\eta_z = 1$, can be shown to equal

$$\begin{aligned} (1 - S_f) d(\log M) = & S_f(1 - S_f\eta/E_{ff}) d(\log Z) \\ & + ([1 + S_f\eta]\pi_{rw} - S_f\pi_{fw}) d(\log W) \\ & + ([1 + S_f\eta]\pi_{rt} - S_f\pi_{ft}) d(\log T) \\ & - S_f(1 - S_f\eta/E_{ff}) d(\log Q_f), \end{aligned} \quad (23'')$$

where E_{ff} is defined by (26). As can be seen from the structure of the total elasticities of M with respect to Z and Q_f , M will depend on Z and Q_f so long as $S_f\eta/E_{ff} < 1$ and $\eta < \infty$. From Equation (26), this will occur if and only if the elasticity of substitution between inputs, σ , is non-zero, i.e., that the retail product is produced with variable input proportions. In addition, Equation (23'') predicts a positive relationship between M and Z and a negative relationship between M and Q_f .

There is much empirical evidence to corroborate the predictions of model (23'') with respect to the relationship between the margin and quantity of the farm input, as well as between the margin and shifts in retail demand. Both Fox (1951) and Waugh (1964) estimated positive relationships between margins and income for a wide range of food commodities over different time periods. In addition, they tended to find a negative relationship between margin and quantity. The results obtained were found either by estimating directly equations like Equation (11) and (12) and then deriving the implied marketing margin relationship by subtracting farm price from retail price, or by directly estimating relationships like Equation (13). Two criticisms of this approach to estimating margin relationships are that (a) they did not account for the separate effects of marketing input price changes, so that the effects of income likely reflect a combination of retail demand shift and marketing cost changes, and (b) they assumed fixed input pro-

portions in their retail price specification by including retail quantity in Equation (11) instead of farm quantity.

3.3. Markup pricing

Another common approach to estimating marketing margins and retail-to-farm price linkages for food commodities has been to assume that margin behavior depends on the pricing practices of market middlemen. This approach, which is summarized by George and King (1971, pp. 55–59), assumes that margins consist of a combination of absolute amounts and constant percentages of retail prices, i.e.,

$$M = \alpha + \beta P_r, \quad (31)$$

where α and β are constants. Justification for this specification of margin behavior is mainly empirical. Thomsen (1951), Buse and Brandow (1960), Dalrymple (1961), Shepherd (1962), and Waugh (1964) all cite evidence of margin behavior of this type. The most extensive analysis has been provided by George and King (1971), who found that a significant number of commodities displayed combinations of both constant absolute and constant percentage margins.

Equations of the type indicated by (31) with an additive error term appended (and possibly with provisions made for changes in marketing input prices and other factors) have been utilized extensively in agricultural economics for estimating the relationship between farm and retail prices. Regressions of margin on retail price, or equivalently farm price on retail price, derive from the view that, in the long run, prices are determined at the retail level first by what consumers are willing and able to pay for what is marketed, and then farm prices are determined by subtracting all marketing costs from retail prices [Waugh (1964, p. 20)].

USDA's measure of M [Elitzak (1996)] assumes a fixed transformation between the farm and retail quantities, i.e., $M = P_r - a P_f$. Substituting for M on the left-hand side of (31), solving for P_f , and differentiating with respect to P_r yields

$$d(\log P_f)/d(\log P_r) = (1 - \beta)/S_{f0}, \quad (32)$$

where $S_{f0} = P_f a / P_r$. Thus, so long as $\beta > 0$, we would expect the elasticity of the farm price with respect to retail price to be less than the reciprocal of the farm value share (measured with respect to the fixed input-output ratio a). Is this relationship (which is equivalent to saying that the elasticity of price transmission is larger than the farm value share) consistent with the purely competitive market structure? The answer is yes if (32) is viewed as describing an exogenous change from a vertical shift in retail demand [Wohlgenant (1993, pp. 645–646)]. To see this, note that if $\eta_z d(\log Z)$ describes the logarithmic horizontal change in retail demand, then $(-\eta_z/\eta) d(\log Z)$ describes the

logarithmic vertical change in retail demand. Letting $d(\log \delta)$ denote this vertical shift in retail demand, Wohlgenant (1993, p. 646) shows that

$$d(\log P_f)/d(\log \delta) = \eta/E_{ff},$$

which according to (26) will be less than the reciprocal of the farm value share if and only if $\sigma > 0$. The interpretation of this result is that a one percent increase in retail price (holding Q_f constant) leads to a farm price increase of $\eta/E_{ff}\%$. This is equivalent to saying that a 1 cent increase in retail price leads to a $S_f\eta/E_{ff}$ cent increase in farm price, which will be less than 1 cent when $\sigma > 0$. Thus, existence of variable factor proportions leads to reconciling theory with commonly observed markup pricing behavior depicted by (31).

Although many researchers have estimated equations of the type (31) (modified to account for changes in marketing input prices and other factors affecting marketing group behavior), this approach generally lacks theoretical justification. As shown by Equation (22'') when there are fixed input proportions, the margin does not depend upon retail price. However, when there are variable input proportions (such that Z is quantified as a vertical shift in retail demand, i.e., retail price), then Equation (23'') indicates that in order for the margin to be related to P_f in a fixed way, changes in retail demand and farm supply must be collinear. As Gardner (1975, p. 406) remarks, "... no simple markup pricing rule – a fixed percentage margin, a fixed absolute margin, or a combination of the two – can in general accurately depict the relationship between the farm and retail price". This is because even if such an equation as (31) should perfectly fit changes generated by shifts in, say, the farm supply function, such a model could not account simultaneously for shifts in retail demand and farm supply. Wohlgenant and Mullen (1987) show that competitive price behavior implies that the elasticity of price transmission can vary systematically with the volume of the commodity marketed and processed. In their empirical application to beef they find that the data are supportive of the proposition that the markup pricing rule is misspecified, thus corroborating Gardner's observation. Based at least in part on this analysis, it seems best to approach econometric estimation of retail-to-farm price linkages through estimation of equations of the general form depicted by (11), (12), or (13).

3.4. Empirical work

Recent empirical evidence is consistent with theory indicating significant input substitution between farm and marketing inputs. Wohlgenant (1989) estimated Equations (18) and (19) where the elasticities were assumed to be constant, where the logarithmic differentials were replaced by first-differences in the logarithms, and where $d(\log Z_i)$ was defined as a one percent horizontal increase in retail demand.⁹ The model was applied

⁹ The variable $d(\log Z_i)$ was defined as

$$d(\log Z_i) = \sum_{j \neq i} \eta_{ij} d(\log P_j) + \eta_{iy} d(\log Y) + d(\log \text{POP}),$$

to eight commodities (beef and veal, pork, poultry, eggs, dairy products, fresh fruits, fresh vegetables, and processed fruits and vegetables), and the restrictions of symmetry, Equation (28), and constant returns to scale, Equations (29a) and (29b), were separately imposed and tested.¹⁰ For all eight commodities, the symmetry restriction was found to be consistent with the data, suggesting compatibility with the basic theory of competitive behavior. In addition, with the sole exception of fresh fruits, the results were also found to be consistent with constant returns to scale. Substantial input substitutability was found for all but one commodity, poultry. Except for poultry, derived demand elasticities were found to be at least 40 percent larger than those obtained assuming fixed input proportions. Point estimates of elasticities of substitution, derived using Equation (26) for given values of S_f and η , ranged from 0.25 for eggs to 0.96 for dairy.

An alternative approach to estimating Equations (18) and (19) directly would be to estimate a structure like (1)–(10) and then derive relationships like (20a)–(20i) from the estimated structure. This was the approach taken by Dunn and Heien (1985) who, instead of estimating supply and demand functions like (2) and (3) directly, estimate the inverse supply function (i.e., the relationship between price and marginal cost) and output constant factor demand functions, i.e.,

$$P_r = C_r(P_f, W, T, Q_r), \quad (33a)$$

$$Q_f = C_f(P_f, W, T, Q_r), \quad (33b)$$

$$X = C_w(P_f, W, T, Q_r), \quad (33c)$$

where $C_r()$ is the marginal cost of output, $C_f()$ is the partial derivative of cost with respect to farm price, and $C_w()$ is the partial derivative of cost with respect to W .¹¹ Dunn and Heien (1985) used the translog specification of cost and estimated share equations for five farm outputs (meat, dairy, poultry, fruits and vegetables, and other foods) and four marketing inputs (labor, packaging, transportation, and all other). In their specification, Dunn and Heien (1985) also allowed for jointness in production (by making (33a)–(33c) a function of all four retail outputs). Their test results indicated no evidence of jointness and only limited substitutability between farm inputs and marketing inputs. A major limitation of this study was that they used USDA disappearance data for retail food commodities. As indicated previously, these data are generally inappropriate for estimating input substitutability because they are constructed by assuming fixed input

where η_{ij} is the cross-elasticity of demand for good i with respect to the price of good j , η_{iy} is the income elasticity of good i , Y is per capita income, and POP is population. Values for the elasticities are extraneous estimates obtained from previous studies.

¹⁰ Because Equation (28) does not hold globally when the elasticities of (18) and (19) are constants, this restriction was imposed only locally at the sample means of the farm value shares. In addition, an exogeneity test indicated that farm quantities could be taken as predetermined, although estimation of Equations (18) and (19) could easily be undertaken assuming the farm quantities are jointly determined with prices.

¹¹ Equation (33b) and (33c) result from Shephard's lemma [see, e.g., Diewert (1974)].

proportions.¹² One novelty to their approach is that they include a capital stock measure to reflect short-run input fixity of processor behavior. This is also the approach taken by Lopez (1985).

More recently, Goodwin and Brester (1995) estimated factor demand relationships in the U.S. food and kindred products industry for aggregate processed food output using U.S. Department of Commerce data. They find large and significant input substitution between five inputs: labor, capital, food materials, energy, and other inputs. In their analysis, they use switching regression techniques to allow for gradual technical change. In addition to concluding that accounting for technical change in food processing leads to greater input substitutability, their results strongly suggest that the approach to estimating factor demand relationships with value-added data [e.g., Huang (1991)] is generally inappropriate because it assumes a fixed relationship between materials and nonfood inputs.

4. Influence of market power

Another possible explanation for observed margin behavior of the type depicted by (31) with $\beta > 0$ is existence of market power. Historically, there has been concern about existence of oligopoly and/or oligopsony power in food and agricultural markets [e.g., National Commission on Food Marketing (1966); Connor et al. (1985); Rogers and Sexton (1994); USDA (1996)]. Generally two approaches have been taken in identifying and estimating oligopoly market power (or departures from perfect competition): structure-conduct-performance (SCP) studies and new empirical industrial organization (NEIO) studies. SCP studies focus primarily on the relationship between profitability and concentration, while NEIO studies focus primarily on the determinants of the gap between price and marginal cost [Bresnahan (1989)]. SCP studies have mainly used cross-sectional data to estimate the relationship between accounting profits (or so-called price-cost margins) and concentration ratios to draw inferences about the presence of market power and performance of an industry. The NEIO approach is motivated in part by dissatisfaction with the SCP approach's inability to link industry profitability to industry structure. In other words, high accounting profits can indicate either good or bad performance and the number of firms may bear no relationship to market structure [Demsetz (1968); Baumol (1982)]. Because the NEIO approach is first and foremost an econometric study of an industry, this approach has a firm grounding in economic

¹² This is not strictly true because the proportions are revised from time to time, as new technologies (e.g., boxed beef) become widely adopted. In addition, for some commodities (e.g., meats) data are available separately at the farm and wholesale levels. However, the retail data are still for all practical purposes production, not consumption, data. What is needed for retail quantity data (as well as margin data) are constant dollar series, such as those developed by the U.S. Department of Commerce, which are conceptually more correct in that they "... accept the judgment of the market" [Waldorf (1966, p. 59)].

theory so that one can rely on theory to aid in specification and interpretation of the findings [Bresnahan (1989, p. 1013)]. Given its distinct advantages and current popularity, the following discussion will focus on the NEIO approach.¹³

4.1. NEIO structural approaches

A typical approach to incorporating market power into the model would be to modify equation (33a) by replacing output price, P_r , by perceived marginal revenue. Usually, a fixed-proportions technology is assumed so that marginal cost in (33a) would be replaced by $aP_f + \partial C_p(W, Q_r)/\partial Q_r$, where $C_p(\cdot)$ represents the non-agricultural (processing) portion of total marketing costs. If we also allow for the possibility of market power in the market for the farm input, the relationship between price and marginal cost could then be written as

$$P_r(1 + \theta/\eta) = aP_f(1 + \phi/\varepsilon) + \partial C_p/\partial Q_r \quad (34)$$

[see, e.g., Schroeter (1988)], where $\theta = (\partial Q_r/\partial Q_r^i)(Q_r^i/Q_i)$ is the representative firm's so-called conjectural elasticity with respect to industry retail quantity, and $\phi = (\partial Q_f/\partial Q_f^i)(Q_f^i/Q_f)$ is the representative firm's conjectural elasticity with respect to industry farm quantity. With fixed proportions, $\theta = \phi$, so Equation (34) can be rewritten as

$$P_r(1 + \theta/\eta) = aP_f(1 + \theta/\varepsilon) + \partial C_p/\partial Q_r. \quad (34')$$

More generally, θ may be thought of as an index of market power. If $\theta = 0$, then we have price-taking or competitive behavior; if $\theta = 1$, then we have pure monopoly/monopsony. Values of θ between 0 and 1 would reflect different degrees of oligopoly/oligopsony power.

A significant feature of (34') is that it can be used to define Lerner's indexes for monopoly and monopsony power [Schroeter (1988)]. For monopoly power, Lerner's index, L , is retail price minus marginal cost as a proportion of retail price, i.e.,

$$L = -\theta/\eta. \quad (35a)$$

Analogous to L , the gap between P_f and marginal net revenue product as a proportion of the farm price can serve as a measure of monopsony power and can be written as

$$N = \phi/\varepsilon = \theta/\varepsilon, \quad (35b)$$

where the second equality holds only when the technology is fixed proportions.

¹³ A thorough review of the advantages and limitations of these different approaches can be found in Bresnahan (1989) and Azzam and Anderson (1996).

Given an explicit functional form for processing costs, demand for output (Equation (1)), and supply of the farm input (Equation (4)), the parameters of Equation (34') can be estimated to determine the incidence and magnitude of market power. For example, Schroeter (1988), in evaluating the degree of market power in the beefpacking industry, used the General Leontief functional form for the processing cost function to generate an econometric model between farm and wholesale levels for beef. In addition to Equation (34') and double logarithmic specifications for wholesale beef demand and farm supply, he also included a specification for labor demand, derived from the cost function via Shephard's lemma. His results indicated small, but significant, evidence of market power in both the output and input markets. Variations on this basic formulation of market power have been applied in other contexts [e.g., Schroeter and Azzam (1991); Wann and Sexton (1992)] with somewhat mixed results, although on balance indicating the presence of market power in both markets for the processed output and the agricultural input.

Schroeter's (1988) model is an extension of Appelbaum's (1982) model to allow for both oligopoly and oligopsony power, but it assumes fixed proportions between the agricultural input and marketing inputs. Azzam and Pagoulatos (1990) have extended Schroeter's model to allow for both oligopoly/oligopsony power and variable input proportions. Their model is based on the first-order condition for profit maximization that the representative firm's perceived marginal revenue product equal its perceived marginal factor cost, i.e.,

$$P_r(1 + \theta/\eta)\partial f(Q_f, X)/\partial Q_f = P_f(1 + \phi/\epsilon), \quad (36)$$

where $\partial f(\cdot)/\partial Q_f$ is the marginal product of the farm input. Using the translog production function, Azzam and Pagoulatos (1990) applied this model to data for U.S. meatpacking. They found significant evidence of market power in both the output and input markets, and that the monopsony distortion (35b) was much larger than the monopoly distortion (35a). One serious limitation of this study is their use of fixed values of demand and supply elasticities from previous studies, which causes an overstatement of the significance of monopoly power. In addition, because quantity data on non-agricultural inputs are often lacking, the applicability of Equation (36) is likely to be quite limited.

An alternative approach to (36) would be to use duality theory to replace the marketing input quantity (or quantities) with input price(s). This is the approach taken by Muth and Wohlgenant (1999a) in the context of estimating oligopsony power in the beefpacking industry. Specifically, the unobservable X in (36) can be replaced by the conditional factor demand function, $X = X(Q_f, W, P_r[1 + \theta/\eta])$, so that (36) can be rewritten as

$$P_r(1 + \theta/\eta)\partial g(Q_f, W, P_r[1 + \theta/\eta])/\partial Q_f = P_f(1 + \phi/\epsilon), \quad (36')$$

where $\partial g()/\partial Q_f = \partial f(Q_f, X(Q_f, W, P_r[1 + \theta/\eta]))/\partial Q_f$.¹⁴ Under certain conditions, given a functional form for $\partial g()/\partial Q_f$, Equation (36') can be estimated jointly with specifications for demand and supply, and the significance and incidence of market power can be determined from the estimated market power parameters.¹⁵

In general, certain conditions must obtain before the market power parameters, θ and ϕ , are identifiable. As shown by Bresnahan (1982) and Lau (1982) in the case of monopoly power and by Just and Chern (1980) and Muth (1997) in the case of monopsony power, output demand (respectively, input supply) must be non-separable in at least one of the exogenous shifters of demand (respectively, input supply) in order to identify, and thereby estimate, the degree of market power. In other words, industry output demand (respectively, industry input supply) must shift in a pivotal manner, rather than a parallel manner, in order to identify the degree of market power. Alternatively, if certain components of marginal cost (or marginal revenue product) are observable [e.g., cigarette taxes, Sumner (1981)], then the degree of market power is also identifiable. In the context of marketing margins, this will occur when there is a fixed proportional relationship between the retail and farm products, as shown by Equation (34'). However, with variable factor proportions, additional information about the nature of the demand/supply shift is required for identification.

4.2. Testing for market power

If one is simply interested in accounting for the presence of market power and for testing for its existence, then less stringent conditions can be placed on the nature of the demand and supply shifts. In order to see this, and at the same time to extend the general theoretical framework discussed previously to incorporate the effects of monopoly/monopsony

¹⁴ Following Diewert (1974, 1978), replace average market prices P_r and P_f by their marginal or shadow prices, $\tilde{P}_r = P_r(1 + \theta/\eta)$ and $\tilde{P}_f = P_f(1 + \phi/\varepsilon)$. Net revenue, NR, of the representative firm is

$$NR = \tilde{P}_r f(Q_f, X) - \tilde{P}_f Q_f - WX.$$

Maximizing with respect to X yields the conditional demand function(s)

$$X^* = X(Q_f, W, \tilde{P}_r).$$

Optimal net revenue, conditional upon Q_f , is then

$$NR^* = \tilde{P}_r f(Q_f, X^*) - \tilde{P}_f Q_f - WX^*.$$

Maximizing with respect to Q_f , using the Envelope theorem, we obtain

$$\frac{\partial NR^*}{\partial Q_f} = \tilde{P}_r \frac{\partial f}{\partial Q_f} - \tilde{P}_f = 0$$

which is equivalent to (36').

¹⁵ This approach is similar to that of Murray (1995), who uses a variable profit function approach by equating marginal factor cost with the shadow value of the input to the representative firm. In this case, the shadow value is obtained by differentiating the variable profit function with respect to quantity of the factor. See Stiegert, Azzam, and Brorsen (1993) for a similar approach in the context of the cattle market.

power, consider Equations (33a) and (33b) in the presence of potential market power, where average market prices, P_r and P_f , are replaced by marginal or shadow prices, $\tilde{P}_r = P_r(1 + \theta/\eta)$ and $\tilde{P}_f = P_f(1 + \phi/\varepsilon)$ [Diewert (1974, 1978)], i.e.,

$$\tilde{P}_r = C_r(\tilde{P}_f, W, T, Q_r), \quad (37a)$$

$$Q_f = C_f(\tilde{P}_f, W, T, Q_r). \quad (37b)$$

If we also assume the existence of an aggregate constant-returns-to-scale production function, then Equations (37a) and (37b) can be written as

$$\begin{aligned} \tilde{P}_r &= P_r(1 + L) = c(\tilde{P}_f, W, T)Q_r \\ &= c(P_f[1 + N], W, T)D_r(P_r, Z), \end{aligned} \quad (38a)$$

$$Q_f = c_f(\tilde{P}_f, W, T)Q_r = c_f(P_f[1 + N], W, T)D_r(P_r, Z) \quad (38b)$$

[Diewert (1981)], where $L = -\theta/\eta$ from (35a), $N = \phi/\varepsilon$ from (35b), $c(\cdot)$ is the unit total cost function, and $Q_r = D_r(P_r, Z)$ from (1).

As in the case of purely competitive behavior, it is useful to evaluate the partially reduced form equations of (38a) and (38b). In general, because neither the conjectural elasticities nor the demand and supply elasticities are constant, it is necessary to define functional relationships for L and N . Without loss in generality, define

$$L = L(P_r, Z, L_0), \quad (39a)$$

$$N = N(P_f, C, N_0), \quad (39b)$$

where L_0 and N_0 denote exogenous determinants of market power (e.g., concentration ratios) for the output and input markets. Given (39a) and (39b), the implicit solutions to (38a) and (38b) for given Q_f are

$$P_r = P_r(Z, W, T, Q_f, C, L_0, N_0), \quad (40a)$$

$$P_f = P_f(Z, W, T, Q_f, C, L_0, N_0). \quad (40b)$$

In comparison with the perfectly competitive market structure depicted by (11) and (12), Equations (40a) and (40b) indicate that we should also entertain variables to represent C , L_0 , and N_0 as possible determinants of retail and farm prices.¹⁶ As in the purely competitive case, the comparative statics of (40a) and (40b) can be characterized by totally differentiating Equations (38a) and (38b). These comparative static results, though

¹⁶ Another way that these equations differ is that Q_f must now be viewed as a strictly endogenous variable if monopsony power is present, for otherwise N would be undefined. This presents no problems empirically so long as (40a) and (40b) are estimated jointly with the farm supply function (4), or an appropriate simultaneous equation estimator like three-stage least squares is used.

complicated, can be used to show that when $L = N = 0$, the conditions of price-taking behavior result. Specifically, when $L = N = 0$, the variables C , L_0 , and N_0 disappear from (39a) and (39b). In addition, when $\eta_z = 1$, we find that the symmetry restriction (28) and the constant-returns-to-scale restrictions (29a) and (29b) hold.¹⁷ This says that, aside from the potential influence of C , L_0 , and N_0 as explanatory variables of the partially reduced form price equations, a test for price-taking behavior is equivalent to a joint test of the restrictions (28), (29a), and (29b).

There are two additional aspects of the above specification of retail-to-farm price linkages that are noteworthy. First, the above model includes as a special case Holloway's (1991) test for monopoly power. Holloway (1991) derived the test result that monopoly power, with price-taking behavior in the market for Q_f , implies that

$$\pi_{rz} - \pi_{fz} = -(\pi_{rf} - \pi_{ff}).$$

Under the conditions of price-taking behavior in both the markets for the retail product and farm product, this condition can be seen to result directly from conditions (29a) and (29b), which, as indicated above, are two of the conditions required for price-taking behavior. Second, when the conjectural elasticities and elasticities of retail demand and input supply are constant, L and N are constants (see (35a) and (35b)) so that a test for oligopoly/oligopsony behavior reduces to Wohlgenant's (1989) joint test of the restrictions (28), (29a), and (29b). This means that, under certain conditions, the joint test for symmetry and constant returns to scale for a purely competitive market structure can be used to test for the presence of market power.

One criticism that could be leveled against the above test for market power is that with respect to the restrictions (29a) and (29b), it becomes a joint test for market power and constant returns to scale. Thus, it would seem prudent to develop a test for market power within this framework without imposing the restriction of constant returns to scale on the industry production function. Such an approach could be implemented by starting with the more general specification (14) and (15) instead of (38a) and (38b), replacing average prices by marginal prices, and then proceeding as before to derive comparative static results for the reduced-form price Equations (40a) and (40b). These comparative static results yield the same testable implications as (45a) and (45b), save for the restrictions (29a) and (29b). In other words, aside from the presence of the additional variables C , L_0 , and N_0 in (40a) and (40b), the unique restriction detecting the presence of market power is the symmetry restriction, Equation (28).

Aside from the application of Holloway (1991), who found no evidence of monopoly power, there have been no formal tests of market power using this framework. However, the results of Wohlgenant (1989), which indicate compatibility of food-pricing behavior

¹⁷ Given constant returns to scale, these restrictions hold if and only if there is price-taking behavior in both the retail and farm markets.

for a wide range of food commodities with restrictions (28), (29a), and (29b), indicate no evidence of either monopoly or monopsony power.¹⁸

5. Non-structural approaches

Hall (1988) has proposed a nonstructural approach to estimating monopoly power, through estimating the residual between output growth and labor growth, to infer the magnitude of the markup of price over marginal cost. Hall's model, which is derived assuming constant returns to scale and assuming Hick's neutral technical change, can be easily extended to the case of monopsony power by reinterpreting the monopoly markup as a monopsony "markdown" [Hyde and Perloff (1994)]. While Hall (1988) finds evidence of monopoly power in the food and kindred products industry, Basu and Fernald (1997) show that his estimates of the markup are likely positively biased because of the use of value-added data, which assume the materials-to-output ratio remains constant over the data period, i.e., which assume a Leontief fixed proportions technology between materials and other inputs in producing the final product. Furthermore, simulation results of Hyde and Perloff (1994) indicate that deviations from constant returns to scale can produce serious biases. Nonparametric methods [Ashenfelter and Sullivan (1987); Love and Shumway (1994)], which do not require estimates of supply and demand parameters, could also be used to test for market power, but such tests are not statistically based and require specifications for unknown technical change. While such tests can be quite robust over a wide range of market structures, they are likely to lead to false indication of market power under perfect competition and technical change [Love and Shumway (1994, p. 1160)].

6. Lags in food price determination

The discussion so far has focused only on static changes in prices and margins. In the short run, there may be temporary changes in margins from lagged responses by market middlemen to changes in producer supply or retail demand [Tomek and Robinson (1981)]. The common observation about such behavior in the short run is that retail prices lag farm price changes. In addition, it is sometimes claimed that retail prices respond more quickly to increases than to decreases in farm prices [e.g., Ward (1982); Kinnucan and Forker (1987)]. A major concern of farmers is that when they increase production and farm price falls, middlemen don't decrease output prices enough. Not only do they believe that such behavior is exploitive but sticky retail prices stifle consumer response, which exacerbates the supply adjustment problem.

¹⁸ Muth and Wohlgenant (1999b), utilizing the profit function approach, estimated supply and demand functions (2) and (3) with average prices for retail and farm prices replaced by marginal prices. Their application to the U.S. beef processing industry concerning market power was inconclusive.

Causes of lagged price adjustment hypothesized include (a) costs of changing prices [Parish (1967); Heien (1980)], (b) costs of holding inventories [Heien (1980); Wohlgenant (1985)], and (c) imperfect competition [Parish (1967); Ward (1982)]. In the case of asymmetry of price transmission, government policy, whereby a binding price floor exists on the farm price, also can be a cause of differential price response [Kinnucan and Forker (1987)].

The typical approach to modeling short-run pricing and margin behavior begins with a specification of the relationship between retail and farm price (Equation (33a)) with constant returns to scale and fixed input proportions, which can be written as

$$P_{\pi} = a P_{ft} + b W_t, \quad (41)$$

where a and b are the fixed coefficients associated with the Leontief production function, $Q_t = \min\{Q_f/a, X/b\}$; and where t denotes the time period. Given (41), the contemporary raw product price, P_{ft} , is then replaced by a distributed lag in current period and past raw product prices, where justification for the distributed lag specification is based on disequilibrium price adjustment and causality tests with time series data [e.g., Heien (1980)]. Typically, monthly or quarterly time series data are used in estimation, so that the assumption of fixed proportions becomes more tenable [Heien (1980)]. In addition to inclusion of lagged raw product prices, other variables to represent demand pressure are often included (e.g., unemployment rates [Heien (1980)]; lagged prices of substitute products, income [Lamm and Westcott (1981); Freebairn (1984)]; marketing margins of competing products [Griffith (1974)]). Usually, dummy variables are used to capture seasonal effects (monthly or quarterly effects), and often separate dummy variables to represent periods of increasing and decreasing prices are included [e.g., Heien (1980)]. Because of the large share of labor costs in nonfarm input costs, especially in the short run, wage rates are often used as a proxy for nonfarm input costs.

A major criticism of the above approach is that it is ad hoc and lacks a firm theoretical foundation. Wohlgenant (1985) developed a general model of short-run food price determination by linking inventory holding to price expectations and short-run margin specifications. In particular, in the presence of inventories, Equation (41) should be extended to include the costs of inventory holding. Under fairly general conditions, these costs can be shown to equal the interest costs of the raw product, so that Equation (41) would be changed to

$$\bar{P}_{\pi} = a P_{ft} + b W_t + g(1 - \beta)a P_{ft}, \quad (42)$$

where the last term, $g(1 - \beta)a P_{ft}$, represents marginal costs of holding inventories; where $\beta = (1 + r)^{-1}$ is the discount factor (with r equal to the real interest rate); and where g represents the average length of time for storage (i.e., desired inventory-to-sales ratio). Equation (42) becomes the long-run, or steady-state, price equation; it specifies that retail price must equal the unit raw product costs plus the full marginal costs of processing, distribution, and storage. In the short run, however, retail price will not

adjust instantaneously to changes in raw product prices because of costs of inventory adjustment, so that retail price adjusts to its long-run level according to the specification

$$P_{rt} = \bar{P}_{rt} + \beta ga(P_{ft} - E_t P_{ft+1}), \quad (43)$$

where P_{ft} is defined by (42) and where $E_t P_{ft+1}$ is expected farm price for next period, conditional on information at time t . This specification of price behavior, which is derived from a dynamic model of the firm, indicates that the current retail price will deviate from its long-run level whenever firms expect the current farm price to differ from next period's expected price. When next period's price is expected to rise (fall) relative to the current period price, retail price will be below (above) its steady-state value. Because of imperfect information, expectations will be based (at least in part) on past market conditions. This means that any change that causes actual price to deviate from expected price will cause retail price changes to lag raw product price changes.

As discussed by Wohlgenant (1985), expectations can be modeled using the rational expectations framework, thereby providing justification for a variety of distributed lag specifications, including purely extrapolative predictors (i.e., solely a function of current and lagged raw product prices) as well as inclusion of lagged demand shifters. Most significantly, Equation (43) indicates that the manner in which retail price changes depends on the stochastic structure generating next period's raw product price, in addition to changes in current period costs. This is important because it says that theory can account for all types and forms of price configurations, including periods in which retail price is rising when farm price is falling – an occurrence which often leads to calls for Congressional investigations into pricing policies of market middlemen. Wohlgenant (1985) applied the model to estimation of monthly wholesale-retail price spreads for beef and found consistency of the theory with the data, as well as rejection of the standard markup pricing model, Equation (41).

7. Other factors affecting marketing margins

In addition to the aforementioned factors affecting marketing margins, other factors (as reflected by the variable “ T ” in Equation (13) may also affect the difference between retail and farm prices. Other factors that may be important include price risk, technical change and other structural change, product quality, and seasonality.

7.1. Risk

Brorsen et al. (1985), Schroeter and Azzam (1991), and Holt (1993) all examine the effect of risk on marketing margins for agricultural products. Using Sandmo's model of the firm facing output price uncertainty, processor behavior, and therefore the marketing margin, can be shown to be influenced by output price uncertainty. With decreasing absolute risk aversion, Brorsen et al. (1985) show that the margin can be expected to be

positively related to output price risk. The studies differ in their measurement of price risk: Brorsen et al. (1985) use a distributed lag of absolute values of past price changes, while Schroeter and Azzam (1991) and Holt (1993) use ARCH and GARCH models. All three authors find risk to be significant for the commodities analyzed (i.e., wheat, pork, and beef). Schroeter and Azzam (1991) simultaneously allow for both output price risk and oligopoly/oligopsony power. Interestingly, they find that failure to include risk would have led to the erroneous inference of the presence of imperfect competition in the pork industry.

In all three risk studies cited, there is a conspicuous absence of demand shift variables, although output quantity is included in the specifications. In addition, all three studies assume fixed proportions between the retail and farm quantities. In light of the fact that with variable proportions the marketing margin depends on demand shifters (Z) as well as supply of the farm input (Q_f) – see Equation (23') or Equation (23'') – the output price risk variable may well be representing the effect of omitted demand shifters. In fact, as shown by Wohlgenant and Mullen (1987), under fairly general conditions, it is possible to model the marketing margin as both a function of the quantity of the farm input processed and retail price.¹⁹ With an expected positive effect of output price on the marketing margin and a positive correlation between price and the measure of price risk, one would expect a positive bias of price risk when output price is omitted from the model. Thus, significance of price risk could be erroneously signaling the impact of demand shifts on the marketing margin. In a recent study of the U.S. lamb industry, Brester and Musick (1995) extend the model of Wohlgenant and Mullen (1987) to include risk and concentration ratios as factors affecting the marketing margin. While both risk and concentration ratios are found to be statistically significant, their effects are found to be small, therefore confirming the relative importance of more fundamental demand and supply shifters in explaining changes in marketing margins.

7.2. *Technical change and structural change*

As Equation (23') indicates, technical change can affect marketing margins. While we might expect technical change in the marketing sector to reduce the marketing margin and increase farm price [Tomek and Robinson (1981)], Equations (20c) and (20g) indicate that the effect is generally ambiguous. Modeling technical change is also complicated by the fact that technological progress may be biased. Biased technical change not only shifts retail supply and farm level demand curves directly, but it also shifts these curves through induced changes in input prices [Miedema (1976); Perrin (1997)].

Empirically, the main way researchers have attempted to quantify technical change is through use of a trend variable as a proxy for this effect. Such an approach can make it difficult to separate scale effects from technical change [Ball and Chambers (1982)],

¹⁹ A margin specification as a function of both farm input quantity and retail price could be viewed as a special case of (23') when Z is represented as a vertical shift in retail demand.

although disaggregating capital into “office and information technology” and “other capital” may help [Morrison (1997)]. Goodwin and Brester (1995) focus on the timing and speed of adjustment to technical changes using Bayesian inferential procedures. Technical change can also be confounded with increased concentration through cost savings from plant scale or multiplant economics [Azzam and Schroeter (1995)].

Marketing margins may also be affected by other structural changes including vertical integration, cooperative behavior, and government programs. Hennessy (1995) shows that the quality of information in food processing can provide incentives for vertical integration. While vertical integration would be expected to reduce costs to the integrator through improved marketing efficiency, the comparative static results (20c) and (20g) indicate that the effect on farm prices is unclear due to potentially offsetting substitution and output effects.

Existence of cooperatives and/or government programs such as marketing orders also can influence marketing margins. Richards et al. (1996) show that existence of buyer market power causes retail-FOB margins for lemons to widen during periods of pro-rata suspension on California and Arizona lemons. On the other hand, Thompson and Lyon (1989) found that suspension of the pro-rata on California–Arizona naval oranges decreased FOB-retail price spreads.²⁰

7.3. *Quality and seasonality*

Other factors influencing marketing margins include quality and seasonality. Berck and Rausser (1981), using a model of monopolistic competition, show that product heterogeneity can lead to an ambiguous relationship between marketing margins and retail demand shifts. In addition, they show that such a theory can explain a negative relationship between marketing margins and raw product prices. Parker and Zilberman (1993) show that competitive margins can be affected by product quality characteristics in addition to marketing costs. In their empirical application to fresh peaches, they find a positive relationship between quality and marketing margins.

Quality changes can also occur through introduction of new products. If this is the source of quality change, though, the impact on the marketing margin is unclear. The reason is that a new product may have less of the raw product (and have more marketing services) so that the net effect is for marketing margin to increase and derived demand for the farm product to decline [Tomek and Robinson (1981, p. 128)].

Marketing margins can also be influenced by the season of the year. Typically, seasonal dummy variables are used to account for seasonality. Lyon and Thompson (1993) examine the influence of both temporal and spatial aggregation on marketing margins for fresh milk and find that model choice can also be affected by whether the data are

²⁰ See Rausser (1971) for a comprehensive analysis of cooperatives and federal marketing orders in the California–Arizona orange industry.

temporally or spatially aggregated. In particular, they used non-nested testing procedures to compare the empirical performance of four common empirical specifications of margin behavior:

$$M = f(P_r, W, T), \quad (44a)$$

$$M = f(P_r, P_r Q_f, W, T), \quad (44b)$$

$$M = f(Q_f, W, T), \quad (44c)$$

$$M = f(P_f, E_t[P_{ft+1}], W, T), \quad (44d)$$

where Equation (44a) is the general form of the markup pricing specification, Equation (31); Equation (44b) is the relative price spread or percentage marketing margin model of Wohlgenant and Mullen (1987); Equation (44c) is the general form of the marketing margin model with fixed proportions, but with changing quantity of farm output; and Equation (44d) is the general form of the rational expectations model of Wohlgenant (1985), i.e., Equation (43). The variable “ T ” includes the effects of a variety of dummy variables, including seasonal dummies, and trend variables. Lyon and Thompson (1993) applied Equations (44a)–(44d) to monthly, quarterly, and semiannual data for three markets: Kansas City, Minneapolis, and Philadelphia. Overall, the results showed model choice is sensitive to both temporal and spatial aggregation. While the simple markup pricing model, Equation (44a), performs quite well with monthly and spatially disaggregated data, it is outperformed by the relative price spread model, Equation (44b), with spatially aggregated data at some levels of temporal aggregation.

8. Conclusions

The concept of marketing margin, or farm-to-retail price spread, was developed to measure the cost of providing a bundle of marketing services. Although there are many ways to characterize the marketing margin, it is best viewed like price as an equilibrium entity, defined as some function of the difference between equilibrium retail price and equilibrium farm price of a given farm product. As this chapter shows, the relationship between retail and farm price can be influenced by a myriad of factors, not just from changes in marketing input prices. Since the nature and cause of many of these changes are not easy to identify, there is clearly room for additional empirical analysis of marketing margins.

One major conclusion of research on marketing margins is that the traditional approach to modeling marketing margins is flawed because it ignores input substitutability between the farm input and other inputs used in producing the retail product. This conclusion has implications both for the way in which we approach estimation of retail-to-farm price linkages as well as how we should measure price spreads for individual farm products. As recent studies reveal, empirical analysis should focus on the determinants of derived demand for the farm input and supply of the retail product and how

these two economic entities interact with farm supply and retail demand to determine the relationship between retail and farm prices. In principle, this more general approach to modeling marketing margins can account for virtually any type of margin behavior depending upon the nature of the technology that transforms the farm product into the retail product. Therefore, as a conceptual approach to understanding marketing margins, the competitive theory of the firm offers a rich and useful set of tools to model the relationship between retail and farm prices.

The empirical significance of variable proportions technologies in food processing and marketing industries suggests that the farm-to-retail price spread, calculated assuming a fixed input-output ratio between the farm product and the corresponding retail product, will not accurately reflect efficient changes in marketing inputs [Reed and Clark (1998)]. How biased the estimates are will depend upon how much of a departure the true underlying production technology is from a Leontief fixed-proportions technology. One significant determinant of bias is product aggregation, i.e., the more aggregated the product under consideration the more likely the farm input-retail output ratio will not remain unchanged from changes in the relative farm price [Wohlgenant (1999)]. Such aggregation bias can be minimized by considering other measures of price spread [e.g., measures which uses value weights rather than fixed input-output coefficients, Waldorf (1966)], or by constructing such measures from estimated parameters of the partially retail and farm price equations (e.g., Equation (23')). Because of gaps in retail consumption data, marketing margins will be unobservable in a number of instances. While the general approach to modeling price spreads (i.e., Equations (11)–(12)) can be used to circumvent this problem, there are still formidable measurement problems to address related to the specification of the relevant supply and demand shift variables and stochastic specifications in the partially reduced form retail and farm price equations.

The second major conclusion from past research on marketing margins is that factors other than shifts in retail demand, farm input supply, and marketing input prices can be important. Equations (40a) and (40b) indicate that other variables (e.g., market power, risk, technical changes) are potentially important factors to account for in empirical analysis of marketing margins. Indeed, much of the attention in recent years has focused on testing for the presence of market power, as well as estimating the degree of market power. With increased concentration of several agricultural industries in recent years – particularly in the markets for farm inputs – there has been heightened interest in testing for the presence of monopsony power [Azzam and Anderson (1996)]. While researchers often look at concentration ratios as evidence of market power [e.g., Rogers and Sexton (1994)], researchers need to be cautioned that the number of firms may bear no relationship to the degree of competitiveness because concentration ratios ignore the existence of scale economies [Demsetz (1968); Baumol (1982); Goodwin (1994)]. Indeed, there is evidence to suggest that the degree of market power and scale economies can be confounded, and that ignoring scale economies can lead to erroneous conclusions regarding the welfare effects of increased market power [Azzam and Schroeter (1995)]. Clearly, more research is needed in this area, but such research must account for the

effects of capital investment and technological changes on firm and industry growth [Morrison (1997)].

Other important areas for research include study of price transmission from retail to farm level, study of the role of new institutions and government/policy interventions of price spreads, and study of international comparisons of marketing margins. Retail-to-farm price transmission studies are not only important from the standpoint of understanding the price transmission process better, but also from the standpoint of estimating the effects of retail demand changes like commodity advertising on farm prices [Wohlgenant (1993, 1994)]. Many agricultural industries are undergoing dramatic changes due to increased vertical integration/coordination. Whether farmers and consumers will benefit from these changes is an important topic for future research. Changes in government commodity programs, as well as the impact of relaxing trade barriers and implementation of new food safety regulations, are also fertile areas for future research. Finally, it would be useful to consider marketing margin behavior in countries outside the U.S. to see if farmers' concerns elsewhere are similar and to see if margins or related measures of changes in price spreads can be used for international comparisons of efficiency in the food marketing sector.

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SPATIAL PRICE ANALYSIS

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Abstract

Agricultural commodities are typically produced over an extensive spatial area and are costly to transport relative to their total value. These characteristics yield a complex set of spatial price linkages which are often studied to gain insights into the performance of markets. An extensive literature has addressed a wide range of issues relating to spatial price linkages. Issues relate to market conduct and performance, regional and international trade relationships, efficiency, and developing economy market performance. This chapter reviews issues related to economic and empirical models of spatial price linkages. The relative weaknesses and merits of each approach are identified.

Keywords

spatial equilibrium, price analysis, law of one price, market integration, market efficiency

1. Introduction

Agricultural commodities are typically produced over an extensive spatial area and are costly to transport relative to their total value. Spatial patterns of marketing give rise to a complex web of relationships among prices throughout a market, and spatial price analysts study these relationships in order to gain insight into the workings of the market and evaluate its performance. For many markets, prices are the only data readily available to examine spatial relationships.

This chapter attempts to develop a common framework for spatial price analysis in order to shed light on what conclusions can be drawn about spatial market relationships. It attempts to carefully distinguish between economic models of price determination and the statistical techniques used to analyze price behavior. The bulk of empirical studies of spatial prices of homogeneous goods have been conducted using either correlation, static regressions, or dynamic regressions, such as vector autoregressions. Many studies of spatial prices express hypotheses about market efficiency and integration in terms of restrictions on the regression parameters. We develop a simple economic model to provide a better understanding of these restrictions and the conditions under which they are appropriate.

Tests that can be justified in the context of the simple model should be thought of as joint tests of market efficiency, market integration, and the equilibrium model. Presuming the model is correct, failure to pass these tests can be due either to a breakdown in the integration of the market or to some form of market inefficiency. An empirical model may, however, suffer from a variety of misspecification problems that may lead to erroneous inferences. For example, it is possible that an empirical model does not capture important features of the market being examined. Unfortunately, many of the methods that can be rigorously justified within the context of a simple model of spatial price formation cannot be supported when the assumptions of the model are relaxed.

In the remainder of this introduction we describe some of the main areas of application of spatial price analysis. We then discuss a number of concepts important in the study of spatial markets, including spatial arbitrage, the law of one price, market integration, and spatial market efficiency. The chapter then discusses the main theoretical models that underlie the study of spatial price behavior and that can be used to interpret the empirical work in this area. Alternative econometric approaches and empirical applications are then examined. The paper concludes with a summary and overall assessment of the literature.

1.1. Applications of spatial price modeling

1.1.1. Market definition and antitrust regulation

A considerable amount of early work in spatial price analysis in agriculture was devoted to defining markets. Many of these studies attempt to determine if spatial marketing patterns conformed with the then recently developed models of spatial equilibrium. For example, some studies analyzed either flow data or regional production and consumption

data along with transport cost data in an attempt to determine if inefficiencies existed in marketing patterns. It was also common in the 1950s and 1960s to construct spatial price surfaces to define regional commodity markets. This work is well described in the text of Bressler and King (1970) and the review article by Weinschenck, Henrichsmeyer and Aldinger (1969), and will not be further covered here.

Antitrust regulation, especially the regulation of mergers, turns on the definition of a market. Although the idea of a market is among the most basic concepts of economics, its precise definition is problematic. At issue is the extent to which firms located in spatially separated regions actively compete. A merger between competing firms may result in a significant loss of competition. If the regions are not currently engaged in active competition, the merger, presumably, would have no such anti-competitive impact. The U.S. Department of Justice's merger guidelines specify a 5 percent rule, defining an antitrust market to be one consisting of regions that, if controlled by a single firm, would result in a price increase of at least 5 percent. The notion of an antitrust market is distinct from the more familiar notion of an economic market, which is generally taken to mean a spatial area "within which the price of a good tends toward uniformity, allowance being made for transportation costs" [Stigler(1966, p. 85)].

Methods similar to those used to evaluate integration have been used to define markets for regulatory purposes. These include the use of numerous statistical criteria including simple price correlations [Stigler and Sherwin (1985)], as well as methods based on dynamic regressions including Granger causality and cointegration. Switching regime models have also been used to examine the extent of a market [Spiller and Huang (1986), Spiller and Wood (1988)]. Such price-based methods have also been criticized, notably by Werden and Froeb (1993).

Recently, several studies have applied spatial price analysis to examine market power in agricultural industries. Faminow and Benson (1990) used econometric tests usually used to examine market integration to draw conclusions concerning noncompetitive behavior in the Canadian pork industry. Several studies commissioned by the U.S. Packers and Stockyards Administration used a variety of methods, including cointegration and impulse analysis and the Spiller and Wood switching regime model, to define regional market boundaries for fed cattle [Hayenga et al. (1996)].

1.1.2. Regional and international trade modeling

The notion of spatially integrated markets, typically expressed as the Law of One Price (LOP) or Purchasing Power Parity, is an essential ingredient in modern and classical models of international trade and exchange rate determination.¹ Theories regarding international price equalization and symmetrical international price changes are usually

¹ Purchasing power parity is a version of the law of one price for aggregate prices. If an entire collection of traded goods' prices adhere to the law of one price, an index of these prices will satisfy an equivalent condition, which is referred to as purchasing power parity.

thought to have originated in the work of Cassel (1918). There are, however, much earlier references to the notion of price equalization through trade in international markets. There are numerous references to the idea of price parity throughout the works of the bullionist period and in Ricardo (1817), Mill (1848), and later in Marshall (1890).

As Chambers and Just (1979) note, most analyses of exchange rates and international trade explicitly assume adherence to the law of one price in absolute terms. Officer (1982) surveys much of the early literature and finds that support for the law of one price is limited, especially in the short run. Williamson (1986) noted that the law of one price has probably been more thoroughly discredited by empirical evidence than any other proposition in the history of economics.

Although the empirical evidence against the LOP in its simple form is strong, supportive evidence does exist for modified versions of it. For example, the LOP is more strongly supported for traded than non-traded goods [Officer (1986)] and in its long-run than its short-run form [Protopapadakis and Stoll (1986)]. Empirical studies that explicitly account for transactions costs also tend to provide support for the LOP [Crouhy-Veyrac et al. (1982), Goodwin (1992a), Michael et al. (1994)]. Indeed, ignoring transactions costs can lead to serious econometric problems [Davutyan and Pippenger (1990)].

Spatial integration of factor markets also has an important role in modern theories of international trade. Neoclassical trade theories hold that, under certain restrictive conditions, equalization of output prices through trade and arbitrage will ensure that input prices are also equalized, even if inputs are not tradable. The notion of factor price equalization was introduced by Samuelson (1949). Mokhtari and Rassekh (1989) found that factors influencing the integration of goods markets (such as trade openness and similar factor endowments) had an important impact on the integration of factor markets. The issue of integrated international factor markets became a topic of considerable debate during deliberations over the North American Free Trade Agreement (NAFTA). The theory predicts that, as trade barriers are lowered and output markets become more integrated, factor prices will converge. The implication for U.S. workers was taken to be that NAFTA would lower wages among unskilled manufacturing workers. Lawrence and Slaughter (1993) investigated real wage gaps and found that the predictions of the theory were not supported by the empirical evidence. Leamer (1994) provided an alternative interpretation of these findings and pointed out that they were not necessarily inconsistent with the predictions of Samuelson's (1949) theory in that certain restrictive assumptions inherent in the theory were unlikely to be satisfied.

The issue of equalization of land prices has received considerable attention in the empirical literature. Alston (1986) obtained results supporting factor price equalization for international real land prices. Benirschka and Binkley (1994) found that price variability for homogeneous parcels of land increased as the distance to output markets increased. They concluded that increased variance was due to the effect of the transactions costs associated with moving output to market on output prices received by farmers. Goodwin and Ortalo-Magne (1992) evaluated factor price equalization for wheat-producing regions in the U.S., France, and Canada. Their results indicated that significant differences in land prices existed, but that policy changes under the General Agreement on

Tariffs and Trade (GATT) that brought about integration of international wheat markets would bring about a tendency for land prices to move closer together in these regions.

In general, the conditions necessary for adherence to factor price equalization and thus integration of factor markets are much stronger than those required for the integration of output markets. In particular, input market integration requires output markets to be integrated. In addition, factor price equalization also requires identical technologies among countries, constant returns to scale, fewer factors than goods, homogeneous factors of production, and the absence of specific factors of production [see Dixit and Norman (1980) for more on these restrictions]. In light of the strength of these requirements, it is not surprising that evidence supporting factor market integration is weak.

A number of studies have attempted to go beyond tests of spatial arbitrage conditions and estimate spatial price transmission ratios [Bredahl et al. (1979), Roe et al. (1986)]. In general, these studies have concluded that, in cases where domestic production and consumption are insulated from the world economy, changes in world commodity prices do not result in corresponding changes in domestic prices. Gardner and Brooks (1994) examined within-country (regional) price transmission ratios in the former Soviet Union, and found them to be affected by the distance between markets and by regional policies that may inhibit the flow of commodities among regional markets.

1.1.3. Market integration in developing economies

Considerable attention has been given to the analysis of spatial market integration in the context of developing economies that are often characterized by market fragmentation due to poor transport and communications infrastructure, inadequate contract enforcement mechanisms, and unstable political environments. Early work in this area concentrated on examining price correlations, but this practice was strongly criticized [Harriss (1979)] and replaced by more sophisticated statistical measures. Recent work has tended to use dynamic regression analysis and has generally concentrated on testing specific hypotheses rather than measuring the degree of market integration.

A number of questions have been raised in this literature that relate to the extent of integration among regions. For example, the degree to which specific regions can withstand economic shocks (especially weather-induced supply shocks) depends, in part, on the reliability of trade linkages with other regions [Ravallion (1986)]. The impact of market liberalization on producer and consumer welfare both depends on and affects the degree of integration through the opening of new markets and reduction in risk [Barrett (1996)]. The extent of market integration is also of importance in designing agricultural price stabilization policies. Stockpiling policies, for example, may need to be implemented in a decentralized fashion if production regions are poorly integrated.

2. Definitions

A number of distinctly different concepts are used to describe market linkages across space, time, and form. Indeed, the terminology is often loosely applied, such that the

same words may involve distinctly different concepts in different studies. Before reviewing the literature, a consideration of the various terms and definitions applied in the literature is in order. Due to the lack of agreement on terminology, we shall attempt at the outset to define several terms that will be used throughout this discussion, as well as to note alternative usage of the terms.

2.1. Spatial arbitrage

Perhaps the least ambiguous concept in spatial price analysis is the notion that the actions of spatial arbitrageurs will ensure that the prices of a homogeneous good at any two locations will differ by, at most, the cost of moving the good from the region with the lower price to the region with the higher price

$$p_j - p_i \leq r_{ij}, \quad (1)$$

where r_{ij} represents the cost of moving the good from location i to location j (we will refer to this cost as the transport cost, although it includes all relevant costs of arranging transactions between spatially separate locations). Furthermore, the condition will hold as an equality if there is direct trade between the locations.

For many economists, the spatial arbitrage condition is the starting point for any model of spatial price behavior. It is important to recognize, however, that it is an equilibrium concept. Actual prices may diverge from this relationship but the actions of arbitrageurs will, in a well-functioning market, tend to move the price spread toward the transport cost. It is also important to point out that it is possible to construct equilibrium models that fail to satisfy the spatial arbitrage condition, especially if there are significant delays in transport. The simple statement of the spatial arbitrage condition also hides important details concerning how the price is defined. For example, at any location more than one price may exist due to the existence of a bid/ask spread representing the return to merchandising. In addition, so-called spot prices may actually account for standard delivery lags and hence contain a forward price component. Nonetheless, the spatial arbitrage condition is expected to hold approximately and deviations from it should be of a transitory nature.

2.2. The Law of One Price

The Law of One Price (LOP) holds that, abstracting from transactions costs, regional markets that are linked by trade and arbitrage will have a common, unique price. The LOP has a long tradition in economics. Marshall (1890, p. 325) wrote that "... the more nearly perfect a market is, the stronger is the tendency for the same price to be paid for the same thing at the same time in all parts of the market".² The fact that this concept is denoted to be a "law" reflects the considerable faith placed in its adherence.

² Marshall (1890, p. 325) went on to note the importance of transactions costs in stating that "... but of course, if the market is large, allowance must be made for the expense of delivering the goods to different

In spite of this prominence, there are actually several different versions of this “law”. On the one hand, some people do not distinguish between the LOP and the spatial arbitrage condition. We will refer to this view as the “weak” LOP. A stronger version of the LOP is that the spatial arbitrage condition holds as an equality (the presumption being that trade is continuous). An aggregate version of the LOP, stated in terms of price indices, is known as Purchasing Power Parity (PPP). The assumptions needed for PPP to hold are far more restrictive than for the LOP, even if PPP is applied only to bundles of traded goods.

It is the strong form of the LOP that is often tested; hence such tests must be interpreted not so much as tests of equilibrium conditions as tests that are conditional on assumptions regarding trade linkages. To emphasize the point, violations of the strong form of the LOP may indicate a lack of a stable trading relationship or a disequilibrium situation (or both).

2.3. Spatial market integration

Spatial market integration is a term whose meaning is even less agreed-upon than the LOP. In general, market integration refers to a measure of degree rather than a specific relationship. At one extreme are completely separated markets and at the other are perfectly integrated markets, which should exhibit the strong form of the LOP. To add to confusion, however, the term market integration is often used to refer to perfect market integration, and even to the weak form of the LOP (i.e., to the spatial arbitrage condition).

We adopt the view that the market integration is a distinct concept from the absence of arbitrage. Early usage of the term defined integration as the degree of co-movement of prices in different locations, specifically as measured by the correlation between the prices. Price co-movement for a given commodity can arise, however, for many reasons that have nothing to do with whether a trading network in the commodity links the regions. Furthermore, prices that satisfy the strong form of the LOP may not move together if transport costs are large and volatile.

Although no completely satisfactory definition has appeared in the literature, we propose that market integration is best thought of as a measure of the degree to which demand and supply shocks arising in one region are transmitted to another region. Consider a hypothetical shock, ε_A , that shifts the excess demand for a good in region A but not in region B. The price transmission ratio associated with this shock is

$$R_{AB} = \frac{\partial p_B / \partial \varepsilon_A}{\partial p_A / \partial \varepsilon_A}. \quad (2)$$

We take market integration to be a measure of the expectation of the price transmission ratio. Perfect market integration is said to occur if the expected price transmission ratio

purchasers; each of whom must be supposed to pay in addition to the market price a special charge on account of delivery”.

is 1. Notice that the ratio may not be symmetric (i.e., $R_{AB} \neq R_{BA}$), so that it is possible for one region to be more integrated with another region than is the other with it.

It is not necessary for two regions to be direct trading partners for a high degree of integration to be present. What is important is that the regions are part of a common trading network. Price shocks may therefore be transmitted indirectly through the network via the trading linkages that connect the regions. For example, if locations *A* and *B* are both regular suppliers to location *C*, they may be integrated just as strongly as if they were direct trading partners.

It is important, however, to distinguish between the term market integration and other forms of integration. For example, regions can be “economically integrated” in the sense that there are no border restrictions restricting the flow of goods, but not be integrated in terms of any specific market. For example, a highly perishable crop may be produced only for local consumption. The market for this good is not integrated because the cost of moving the good between locations is prohibitive. Economic integration may cause price co-movement, however, even among regions that have a low degree of market integration in a specific commodity [Harriss (1979)]. This is also true of regions that share common climatic conditions (a non-economic form of integration).

It is useful to point out that perfect market integration and the strong form of the LOP, as defined here, are distinct concepts. It is possible, for example, that the LOP holds even though regions have price transmission ratios of less than 1 (see Section 3 for some examples). On the other hand, unit price transmission ratios typically imply the strong form of the LOP. This leads to the following hierarchy of measures. Perfect market integration implies the strong form of the LOP which, in turn, implies the weak form of the LOP. Put in an equivalent form:

$$\text{Perfect Market Integration} \Rightarrow \text{Strong Form LOP} \Rightarrow \text{Weak Form LOP}.$$

Weaker and less restrictive notions of market integration are also present in the empirical literature. The recent literature has shown greater awareness of dynamic elements of price adjustment and spatial price linkages. A less restrictive notion of market integration acknowledges that short-run price differences may exist but that, in the long run, one-to-one correspondence of price changes across regional markets should exist. Tests also have been conducted for the lack of integration. Two markets for which there is no transmission of shocks can be said to be non-integrated or separated.

2.4. Spatial market efficiency

Market efficiency is a term even less clearly defined in the literature and one that encompasses a number of distinct concepts. In some studies it is taken as synonymous with the spatial arbitrage condition. Clearly regional or international markets characterized by arbitrage opportunities can be considered inefficient. However, markets should produce prices that accurately reflect all available information about demand and supply conditions as well as transactions costs.

The concept of spatial market efficiency can also encompass an assessment of the size of the transactions costs of trade. These costs may be excessively high for a variety of reasons that are beyond the power of individuals to influence. This is especially true in developing countries, where transactions costs can be high because of poor contract enforcement, inadequate police protection, corruption, excessively high taxes, and inadequate transport and communications infrastructure. Thus market efficiency can entail considerations beyond whether individuals are responding rationally to financial incentives.

Notions of market efficiency are usually used to motivate empirical studies of market integration. This is true in spite of the fact that a common, universally accepted definition of market efficiency is elusive. In general, efficiency is usually meant to imply that the allocation of resources is such that aggregate welfare cannot be further improved upon through a reallocation of resources. In terms of spatial arbitrage, market efficiency is usually interpreted as implying that no opportunities for certain arbitrage profits have been left unexploited by spatial traders.

An interesting observation, however, is that published empirical studies typically reject efficiency, whether the test is conducted in terms of spatial, temporal, or market form dimensions. An alternative interpretation of such empirical conclusions is certainly possible, however, and may be preferable to rejections of conditions implied by theory. If one takes, as a maintained hypothesis, the general notion of market efficiency, then empirical observations inconsistent with efficiency are better interpreted as reflecting the limitations of the modeling approach or specification used in the empirical tests. For example, because data on transactions costs are often difficult to obtain, it is often assumed that transportation costs are stationary around a proportional constant of output prices. If such an assumption is incorrect, one may find that logarithmic price differences are nonstationary, and thus may conclude that spatial price linkages reflect inefficiencies in the market when, in fact, it is the assumptions used in formulating the empirical model that are flawed.

Roll (1979) was one of the first to explicitly discuss the implications of efficient commodity markets for spatial price linkages, though the fundamental idea of efficiency certainly is implicit in much of the early work on market integration. Roll examined aggregate price linkages in international markets, though the concepts are entirely equivalent (and perhaps more appropriate) to considerations of spatial trade in a single commodity among regional markets.

Buccola (1989) discussed the general notion of price efficiency. He noted that "efficiency" in prices corresponds to the set of prices that result in an optimal (efficient) allocation of resources. This optimum is described as the allocation of resources that maximizes individuals' utilities of output, conditional on the available stock of resources. In addition, he notes that tests of spatial efficiency are typically based upon the augmenting hypothesis that markets are "efficient" (in terms of maximizing utility of output) in time and form domains. Buccola stresses the role of agents' costs in market efficiency studies and points out that some short-run inefficiencies may be optimal if their elimination requires large capital investments. He notes that price differences are often taken

to represent transactions costs and also points out that, given the difficulty in measuring agents' marketing costs, "the potential for circularity in efficiency research is great".

The most important point to emerge from a consideration of the terminology and definitions that characterize the extensive literature on spatial market integration is that common definitions of arbitrage, efficiency, and integration do not exist. Different authors invoke different definitions of these concepts and their empirical tests therefore involve different hypotheses about the market conditions implied by integration. The literature must be examined with careful attention to the specific conditions being evaluated and used to construct empirical tests. Evidence consistent with one author's view of integration might be taken as evidence against integration by another.

3. Economic models of price determination

A variety of models have been used to examine the behavior of spatial prices. These models are categorized by two distinguishing features. The first concerns the nature of dynamics used in the model. The most common approach to modeling spatial prices is based on one of several static spatial equilibrium models. Prices change over time due to exogenous shifts in model parameters; this results in a sequence of static equilibria. Other models incorporate dynamic relationships directly into the equilibrium model. For example, endogenous dynamics arise due to storage and temporal delays in arranging sales and in delivery. Although such models are more general in that they endogenize dynamics, they also tend to be more difficult to solve.

A second distinguishing feature concerns the nature of spatial arrangements. In the most general sense, spatial economic activity can be viewed as occurring over a two-dimensional continuum. Indeed, many early models of spatial activity took this view. Recently, however, network models consisting of a set of points or nodes connected by links over which commodities or people travel have been more the norm. Network models can be distinguished according to whether the links are used solely for the purpose of moving goods among the nodes or whether other activities occur along the links. We will refer to the former as point-location models and the latter as agents-on-links models.

3.1. Models with exogenous dynamics

3.1.1. Point-location models

The simplest model of spatial price determination is the static point-location model first discussed by Enke (1951) and Samuelson (1952) and extensively developed by Takayama and Judge (1964a, 1964b, 1971); a more recent discussion is Thompson (1989). Point-location models are appropriate for markets in which the nodes represent major collection, processing or distribution centers that deal directly with one another.

For example, the grain market in the United States includes a system of terminal elevator locations on major water and rail links. A study of prices at these locations could be appropriately modeled with a point-location model.

The basic n -location model can be easily described. It is characterized by an excess demand function

$$q = D(p) \quad (3)$$

that relates the excess amount demanded, q (an n -vector), to the price vector, p , and a matrix of constant marginal transport rates, with r_{ij} representing the cost of transporting one unit of the commodity from location i to location j . Two conditions characterize the equilibrium, the Law of One Price,

$$p_i - p_j + r_{ij} \geq 0, \quad s_{ij} \geq 0, \quad s_{ij}(p_i - p_j + r_{ij}) = 0 \quad (4)$$

(where s_{ij} is the amount shipped from location i to j) and an accounting identity that relates the excess demand to the shipment amounts,

$$q_i = D_i(p) = \sum_{j=1}^n s_{ji} - s_{ij}. \quad (5)$$

Inverting the D_i allows the LOP condition to be stated in terms of the shipment amounts alone:

$$\begin{aligned} D_i^{-1} \left(\sum_{j=1}^n s_{ji} - s_{ij} \right) - D_j^{-1} \left(\sum_{j=1}^n s_{ji} - s_{ij} \right) + r_{ij} &\geq 0, \quad s_{ij} \geq 0, \\ s_{ij} \left(D_i^{-1} \left(\sum_{j=1}^n s_{ji} - s_{ij} \right) - D_j^{-1} \left(\sum_{j=1}^n s_{ji} - s_{ij} \right) + r_{ij} \right) &= 0. \end{aligned} \quad (6)$$

The equilibrium conditions can therefore be written in the form

$$f(x) \geq 0, \quad x \geq 0, \quad x^T f(x) = 0, \quad (7)$$

a condition known as a complementarity problem.

The model can easily be generalized in several ways. First, the transport rates could be responsive to the shipment levels: $r = T(S)$, where r is the vector of transport rates and S the vector of commodity shipments. Second, multi-commodity and intertemporal systems could be developed by interpreting "location" to represent specific space/time/form characteristics. With the "transport" cost matrix represented by appropriate transformation cost functions, the basic form of the model remains the same. For example, costs of storage backwards in time are made arbitrarily large and therefore infeasible.

Much effort has been devoted to the development of efficient algorithms to solve such problems. In some cases it is possible to cast the problem as an optimization exercise. Specifically, if the Jacobian of D is symmetric (implying integrability of the excess demand function), there is an equivalent optimization problem associated with the competitive equilibrium. Takayama and Judge exploited this relationship in models with linear demand functions, showing that the equilibrium could be solved as a quadratic programming problem. An alternative approach was developed by Tramel and Seale (1959), with improvements by King and his associates [King (1963), King and Ho (1972)]. The so-called reactive programming algorithm allocated fixed quantities using a least-cost linear programming algorithm and then iteratively adjusted those quantities to ensure that prices satisfied arbitrage constraints. In recent years there have been significant improvements in algorithms for solving linear and non-linear complementarity problems, as well as related variational inequality problems. Large-scale complementarity problems can now be routinely solved using widely available software [Ferris and Pang (1997), Billups et al. (1997)].

3.1.2. *Agents-on-links models*

The point location model is a network model with the links between network nodes used only for commodity transport. Another important class of spatial network models has individual agents producing or consuming along the links, and with network nodes representing market centers. This framework has been widely used to study spatial competition among oligopolistic firms located at nodes, which compete for the business of agents on the links [see, for example, Faminow and Benson (1990)]. It has also been used to model competitive markets with nodes representing central markets where spatially dispersed producers transport and sell their goods [Dahlgran and Blank (1992)].

From a theoretical point of view, such agents-on-links models can be viewed as continuous extensions of the point-location model. As the nodes in a point-location model become dense, the model mimics the agents-on-links model. Therefore, one should expect that theoretical results applying to one model should be obtainable from the other. Some results, however, are more easily obtained using one or the other formulation and, in empirical work, one or the other will generally be a natural representation of a specific market.

3.1.3. *Dynamic linkages*

With either model type, an important issue concerns dynamic linkages. Linkages involving a time dimension occur for a variety of reasons including storage, transport delays, investment, seasonality (in production and consumption), demographic shifts, preference shifts, etc. With the exception of storage and transport delays (and possibly investment), price analysts generally treat these factors as exogenous and represent them as shifts in regional demand and supply functions. By treating dynamics as exogenous, equilibrium prices are determined by a sequence of static equilibria. Such models

are therefore termed "sequential equilibrium models". To illustrate how spatial price analysis is conducted using network models and to examine some of the implications of these models, we use a simple two-location model with linear excess demands. The basic conclusions, however, extend to more general models.

The first model is a point-location model with linear excess demand functions that depend only on the home price. At time t , the location i excess demand function is

$$q_{it} = b_i(a_{it} - p_{it}), \quad (8)$$

where q_{it} is the net imports (exports if negative), p_{it} is the price, and a_{it} is an exogenous shock that causes parallel shifts in excess demand. Assume that the per unit transport costs, denoted by r_{ijt} , are exogenous (i.e., their value does not depend on conditions in the commodity market).

The equilibrium conditions for such a model are that

$$-b_1(a_1 - p_1) = b_2(a_2 - p_2) \quad \text{and} \quad -r_{12} \leq p_1 - p_2 \leq r_{21} \quad (9)$$

with first (second) inequality holding exactly if $s_{12} > 0$ ($s_{21} > 0$). The first condition is a material balance equation, the second is the spatial arbitrage condition. Taken together these define a functional relationship between the four exogenous variables (a_{1t} , a_{2t} , r_{12t} , and r_{21t}) and the endogenous prices and shipment amounts.³

A sequential equilibrium model imposes the static equilibrium conditions at each point in time. Serial correlation in prices in sequential equilibrium models arises from the exogenous serial correlation of the exogenous variables (the excess demand shifters and transport costs). If these exogenous variables are serially independent, then prices will be as well. Generally, however, these variables will exhibit significant serial correlation; indeed they may exhibit long-run persistence (unit roots).

The natural occurrence of serial correlation in the shocks implies that the kind of informational efficiency tests developed for speculative asset markets may be improperly applied to commodity prices. Informational efficiency tests are usually based on a presumed lack of intertemporal arbitrage opportunities, a condition which often rules out serial correlation in returns. These tests are properly applied to excess returns on speculative assets which should be essentially unpredictable in an informationally efficient market because predictable excess returns would imply the existence of expected excess

³ The explicit solution for prices is:

$$\left. \begin{aligned} p_1 &= \omega_1 a_1 + \omega_2 a_2 - \omega_2 r_{12} \\ p_2 &= \omega_1 a_1 + \omega_2 a_2 + \omega_1 r_{12} \end{aligned} \right\} \quad \text{if } a_1 - a_2 \geq r_{12}, \quad \left. \begin{aligned} p_1 &= a_1 \\ p_2 &= a_2 \end{aligned} \right\} \quad \text{if } -r_{21} \leq a_1 - a_2 \leq r_{12},$$

$$\left. \begin{aligned} p_1 &= \omega_1 a_1 + \omega_2 a_2 + \omega_2 r_{21} \\ p_2 &= \omega_1 a_1 + \omega_2 a_2 - \omega_1 r_{21} \end{aligned} \right\} \quad \text{if } a_2 - a_1 \geq r_{21},$$

where $\omega_i = b_i / (b_1 + b_2)$, for $i = 1, 2$.

profits. Serial correlation in commodity prices, on the other hand, does not imply excess expected profits so long as there are real dynamic links. For example, intertemporal arbitrage in storable commodity markets ensures prices are expected to rise enough to cover storage costs, implying a high degree of serial correlation in prices. Indeed, the lack of serial correlation would be a sign of a malfunctioning market.

The dynamics of price behavior, even in the simplest spatial equilibrium model, can be quite complicated. In the model with two locations, qualitatively different behavior occurs in each of three possible regimes. Which regime occurs depends on the relative sizes of the reservation or autarky prices (the a_i) and the transport rates (in a model with more locations, explicit determination of the regime becomes far more burdensome).⁴ In markets for which a single regime can be assumed (i.e., the direction of trade flows does not change), the model has strong implications for dynamic price behavior. In particular, if the locations are mutually isolated, shocks arising in one location have no impact on the price in the other location. On the other hand, if the locations do trade, an excess demand shock arising in one location has an equal price impact in both locations.⁵ The intuition is that the spread between the prices does not change (it is equal to the transport rate) and therefore both prices must rise or fall by equal amounts. It is precisely this feature that is used to justify much of the empirical analysis of spatial price relations.

Unfortunately, the simple point-location model is a poor description of many spatial market structures and has a number of limitations. Although not relevant in a two-location model, multi-location versions result in, at most, a single route being used to connect any two locations. This rules out situations such as two deficit regions both being supplied by the same two surplus regions, or cases of goods moving between two locations via two or more transshipment regions. As a predictor of actual trade flows, the simple point-location model is extremely limited.

Furthermore, using price transmission ratios as a measure of market integration, the simple point-location model imposes the condition that, at a given time, any two locations are either fully integrated or are mutually isolated. There is, therefore, no possibility for partial integration unless the trading regime changes (e.g., if an exporting region becomes an importing region).

One way to address these concerns is with a model in which transport rates tend to rise as transport services are more heavily used. Consider the case in which location 1 ships to location 2 and the transport rate is a linear function of the amount shipped: $r_t = \rho_t + \phi s_{12t}$, where s_{12t} is the quantity shipped from location 1 to 2. The equilibrium arbitrage relationship for this market is

$$p_{2t} - p_{1t} = \rho_t + \phi s_{12t} \quad (10)$$

and the market-clearing condition requires that

$$s_{12t} = b_2(a_2 - p_2) = -b_1(a_1 - p_1). \quad (11)$$

⁴ See McNew and Fackler (1997) for the explicit solution in the three-location case.

⁵ This observation applies in multi-location models as well.

These conditions can be solved to express the two prices as functions of the underlying parameters:

$$p_t = \frac{1}{b_1 + b_2 + \phi b_1 b_2} \begin{bmatrix} b_1 + \phi b_1 b_2 & b_2 & b_1 \\ b_1 & b_2 + \phi b_1 b_2 & b_2 \end{bmatrix} \begin{pmatrix} a_{1t} \\ a_{2t} \\ \rho_t \end{pmatrix} \\ = \begin{bmatrix} \omega_1 a_{1t} + (1 - \omega_1) a_{2t} + (\omega_1 - 1) \rho_t \\ (1 - \omega_2) a_{1t} + \omega_2 a_{2t} + (1 - \omega_2) \rho_t \end{bmatrix}, \quad (12)$$

where $0 < \omega_i < 1$ and $\omega_1 + \omega_2 > 1$.

Three important implications for price behavior are implied by this model. First, shifts in the excess demand functions (i.e., changes in a_i) have a greater impact on the price in the location where they occur than in the other location:

$$1 - \omega_i = \frac{\partial p_{it}}{\partial a_{jt}} < \frac{\partial p_{jt}}{\partial a_{jt}} = \omega_j. \quad (13)$$

Thus a shock originating in one location is not fully transmitted to the other location. Instead, some of the shock is absorbed by changes in the transport rate. Second, a shift in the supply of transport services is not fully absorbed by the commodity price changes:

$$\frac{\partial(p_{2t} - p_{1t})}{\partial \rho_t} = \frac{b_1 + b_2}{b_1 + b_2 + \phi b_1 b_2} < 1. \quad (14)$$

Some of the supply shift is absorbed by the carrier in the form of reduced shipments. The price differences can be written as a weighted sum of the transport rate shock and the difference in the excess demand shocks:

$$p_{2t} - p_{1t} = \lambda \rho_t + (1 - \lambda)(a_{2t} - a_{1t}), \quad (15)$$

where $\lambda = (b_1 + b_2)/(b_1 + b_2 + \phi b_1 b_2)$, implying that $0 \leq \lambda \leq 1$.

The third implication is that there are more sources of market shocks than there are variables in the model. In the simpler model, the effect of an excess demand shock is the same regardless of its origin and hence aggregation of these shocks is possible. With quantity responsive transport rates, however, it is not possible to associate the effects of the price prediction errors (innovations) with specific sources. This complicates meaningful inferences regarding pricing efficiency using only price data.

Similar conclusions must be reached in the context of agents-on-links models. Consider a situation [as in Dahlgran and Blank (1992)] in which producers are located in rural areas and have a choice about where to market their goods. To examine this in the context of an agents-on-links model, suppose there are two demand centers and producers are evenly distributed along the transport link between the centers. Production

in each period is an exogenously determined amount s_t . Each of the demand centers has downward-sloping demand $q_{it} = b_i(a_{it} - p_{it})$. The distance between the centers is normalized to equal 1 and the transport cost per commodity and distance unit is r_t . If this market is integrated and in equilibrium, it satisfies the following set of conditions:

$$b_1(a_{1t} - p_{1t}) + b_2(a_{2t} - p_{2t}) = s_t \quad (\text{market clearing}), \quad (16)$$

and

$$p_{1t} - r_t B_t = p_{2t} - r_t(1 - B_t) \quad (\text{no spatial arbitrage}), \quad (17)$$

where B_t is the distance from location 1 of the producer who is indifferent between selling in locations 1 and 2. In this simple model, B_t is also the share of the production sold in location 1:

$$B_t = \frac{q_{1t}}{s_t}. \quad (18)$$

Solving these conditions for prices yields:

$$\begin{aligned} \begin{bmatrix} p_{1t} \\ p_{2t} \end{bmatrix} &= \frac{1}{(b_1 + b_2)s_t + 2b_1b_2r_t} \begin{bmatrix} (b_1a_{1t} + b_2a_{2t} - s_t)s_t - b_2(2b_1a_{1t} - s_t)r_t \\ (b_1a_{1t} + b_2a_{2t} - s_t)s_t - b_1(2b_2a_{2t} - s_t)r_t \end{bmatrix} \\ &= \begin{bmatrix} \omega_{1t}a_{1t} + (1 - \omega_{1t})a_{2t} - \frac{1 + b_2z_t}{b_1 + b_2 + 2b_1b_2z_t} s_t \\ (1 - \omega_{2t})a_{1t} + \omega_{2t}a_{2t} - \frac{1 + b_1z_t}{b_1 + b_2 + 2b_1b_2z_t} s_t \end{bmatrix}, \end{aligned} \quad (19)$$

where $z_t = r_t/s_t$ and $\omega_{it} = (b_i + 2b_1b_2z_t)/(b_1 + b_2 + 2b_1b_2z_t)$. The equilibrium prices are weighted averages of the reservation prices less a term that increases with the amount produced. The sizes of the weights vary over time (with z_t) as does the coefficient on the s_t term. To the extent that z_t is stable over time, this yields an equilibrium that is linear in three exogenous variables, the two demand reservation prices a_i and total production s_t .⁶

The agents-on-links model has features similar to that of the point-location model with upward-sloping transport supply. In particular, a shock originating in one location (a_i) has a larger price effect at home than at the other location ($(1 - \omega_j) < \omega_i$). Furthermore, price differences are functions of all of the shocks:

⁶ The stability of z_t is an empirical matter. It will be stable if transport rates increase proportionally with production and hence with the amount transported. It should also be noted that this model takes no account of the possibility of regime shifts that would arise if transport rates became low relative to the price. It would then be possible that some producers would elect to not ship at all because the price they receive, net of transport costs, would be negative.

$$p_{2t} - p_{1t} = \frac{2b_1b_2z_t}{b_1 + b_2 + 2b_1b_2z_t}(a_{2t} - a_{1t}) + \frac{b_2 - b_1}{b_1 + b_2 + 2b_1b_2z_t}r_t. \quad (20)$$

In the simple point-location model, the nature of price adjustment to shocks originating in one of the locations is quite simple. If the locations are linked by trade, both prices adjust equally; otherwise there is no adjustment. In slightly more complicated models, however, marginal adjustments can occur, so the adjustments can lie somewhere between all and nothing. Furthermore, price differences are not associated just with transport rate changes. How important such effects are has not been examined empirically.

The models discussed in this section have important implications for the interpretation of econometric analyses of spatial price behavior. With three (or more) interpretable sources of randomness (excess demand shocks in each region and transport rates) and only two observable prices, the effects of the demand and supply shocks cannot be identified. Furthermore, there is no expectation that a shock originating in one location will have the same effect on both prices. In general, shocks originating in one location have a larger price effect there than in the other location, so the transmission of shocks is less than complete. Even if the LOP holds strongly, the regions are less than perfectly integrated. The meaning of tests based on price co-movements will, therefore, need to be interpreted cautiously.

It should also be emphasized that the analysis of the effects of shocks here is local only (i.e., it applies only to small shocks). Large shocks have the potential to change the trading patterns among regions, which tends to reduce the degree to which shocks are transmitted, relative to markets with stable trade linkages.

3.2. Models with endogenous dynamics

In the spatial price determination models thus far examined, the nature of intertemporal linkages was essentially ignored. This may be appropriate when the shocks that affect a specific market truly arise beyond that market. For example, weather and fuel price variation fall into this category, as do shocks arising from macroeconomic events. There are other sources of intertemporal price linkages that are more closely tied to a particular market and may result in specific patterns of price variation that should be accounted for, even if spatial interactions are the primary focus of the analysis. One, in particular, is examined here: the effects of delivery lags. Similar conclusions can be reached using models with storage and trade [Williams and Wright (1991)].

To illustrate the problems raised by delivery lags, consider a very simple two-period, two-region model. Suppose that region 1 is a deficit region and 2 a surplus region, that it takes one period to deliver goods from 2 to 1, and that there is no forward pricing mechanism.⁷ Further, suppose that excess demand shocks in region 1 exhibit first order serial correlation:

$$a_{1t} = \rho a_{1t-1} + v_{1t}. \quad (21)$$

⁷ We assume that any shocks to the market are never large enough to change the import/export status of the two regions.

A positive value of v_{1t} will induce region 2 to ship more now, in order to respond to the higher demand in region 1 in the next period. In fact, other things being equal, we would expect that the period t price in region 2 should shift up by the same amount that region 1's price is expected to rise in the next period:

$$\frac{\partial p_{2t}}{\partial v_{1t}} = \frac{\partial E[p_{1t+1}]}{\partial v_{1t}} = \rho < 1. \quad (22)$$

In the first period, however, region 1 must absorb the whole shock, so

$$\frac{\partial p_{1t}}{\partial v_{1t}} = 1. \quad (23)$$

This implies a price transmission ratio from 1 to 2 arising from region 1 demand shocks of less than one:

$$\frac{\partial p_{2t}/\partial v_{1t}}{\partial p_{1t}/\partial v_{1t}} = \rho < 1. \quad (24)$$

Again, even in a simple model, it is not unusual to obtain a result in a well-functioning market that the price transmission ratio is less than one.

The problem is more fundamental, however. Consider a situation in which excess demands in the two regions are given by

$$q_{it} = b_i(a_i + v_{it} - p_{it}) \quad (25)$$

for $i = 1, 2$, where the v_i are i.i.d. white noise processes. As before, it takes one period to ship from region 2 to 1 at a cost of r_t . The lack of persistence in the noise processes means that the amount shipped bears no relationship to the shock in the importing region.⁸ Although the price in region 2 will vary with v_{2t} and r_t , it is unaffected by the

⁸ The equilibrium conditions for this model are

$$p_{2t} + r_t = \delta E_t[p_{1t+1}],$$

where $0 < \delta < 1$ is a discount factor, and

$$q_{1t+1} = -q_{2t}.$$

The equilibrium prices can be shown to satisfy

$$\delta P_{1t} = \delta \omega_1 a_1 + \omega_2(a_2 + v_{2t-1}) + \omega_2 r_t + \delta v_{1t}, \quad P_{2t} = \delta \omega_1 a_1 + \omega_2(a_2 + v_{2t-1}) - \omega_1 r_t,$$

where $\omega_1 = b_1/(b_1 + \delta b_2)$ and $\omega_2 = \delta b_2/(b_1 + \delta b_2)$. It can be readily verified that ratio of the effect of v_{2t} on the discounted importing price next period, δp_{1t+1} , is equal to the effect of v_{2t} on p_{2t} (essentially a discounted version of perfect price transmission). However, the effect of v_{1t} on p_{1t} is 1, whereas its effect on p_{2t} (at any time horizon) is 0. There is, therefore, an asymmetry in the effects of shocks in shipping and receiving regions.

magnitude of v_{1t} . The price transmission ratio from 1 to 2, therefore, is 0, even though the regions are well connected (trading every period). The shipping delay creates a situation in which there is no transmission of shocks from 1 to 2. Furthermore, although shocks in region 2 do affect the price in region 1, they do so only at a lag and the instantaneous transmission is zero. It should be noted, however, that a permanent shift in excess demand, i.e., a shift in a_1 or a_2 , is perfectly transmitted (when appropriately discounted), with shifts in a_1 having an immediate impact, and shifts in a_2 impacting region 1 one period later.

This suggests the need for a more dynamic approach to understanding market integration. Two points are in order. First, the speed with which shocks are transmitted will clearly depend upon response delay times. Second, the persistence of the shocks in the receiving regions interacts with the shipping delays to determine the degree to which the shipping regions will respond. More fundamentally, this example points out that the use of price variation, which is essentially the foundation of all empirical analyses of the LOP and market integration, can fail in the presence of shipping delays. In our simple example, the markets were integrated in the sense that they are connected by trade and by the fact that shipping region shocks were transmitted, but failed to be integrated in the sense that importing region shocks are translated forward. To date, the asymmetry of forward and backward linkages has not been addressed.

4. Empirical tests

In this section we provide a framework for understanding the numerous empirical studies of spatial price behavior. Most of the studies mentioned and many not explicitly referenced are listed in Table 1, along with their publication date, the commodity and country examined, and the main methodology used. These methodologies include simple regression and correlation analyses as well as a number of methods based on vector autoregressions and related approaches such as Granger-causality and cointegration analyses. More recent switching regime approaches are also discussed.

4.1. Simple regression and correlation analysis

Many early empirical studies of market integration, especially those applied to agricultural markets in developing countries, appealed to the simple idea that prices in spatially linked markets should be highly correlated. Perhaps the first study to make use of correlation analysis to evaluate market integration is the analysis of Punjab wheat prices by Mohendru (1937).

Mohendru reported pairwise correlation coefficients ranging from 0.43 to 0.86 for fortnightly prices observed over a period of six months at four important Punjab wheat markets. Jasdanwalla (1966) evaluated spatial linkages using monthly groundnut prices for terminal and local markets in India. He found that correlation coefficients were stronger among terminal markets than between terminal and local markets. Two early

Table 1
A summary of empirical dynamic spatial price analyses

Authors	Date	Location	Product	Method of analysis
Adamowicz, Baah and Hawkins	1984	Canada	Hogs	Granger causality
Alderman	1993	Ghana	Grains	Ravallion /Cointegration
Alexander and Wyeth	1994	Indonesia	Rice	Cointegration
Ardeni	1989	International	*	Cointegration
Baffes	1991	International	*	Cointegration
Baulch	1994	Philippines	Rice	Switching regime
Benson and Faminow	1990	Canada	Hogs	Granger causality
Benson, Faminow and Fik	1992	Canada	Hogs	Ravallion
Benson, Faminow, Maquis and Sauer	1994	Canada	Hogs	Cointegration
Bessler and Fuller	1994	U.S.	Wheat	Cointegration
Blank and Schmiesing	1988	U.S.	Corn	Granger causality
Brorsen, Chavas, Grant and Ngenge	1985	U.S.	Grains	Impulse analysis /Granger causality
Cummings	1967	India	Wheat	Correlation
Currie	1995	U.S.	Petroleum	Switching regime
Dahlgran and Blank	1992	U.S.	Hay	Ravallion
Dercon	1995	Ethiopia	Teff	Cointegration
Dries and Unnevehr	1990	International	Beef	Granger causality
Ejiga	1977	Nigeria	Cowpeas	Correlation
Faminow and Benson	1990	Canada	Hogs	Ravallion
Goletti	1994	Bangladesh	Rice	Cointegration /Multipliers
Goletti and Babu	1994	Malawi	Maize	Cointegration /Impulse analysis
Goletti and Christina-Tsigas	1995	**	Rice/Maize	Multipliers
Goodwin	1992	International	Wheat	Cointegration ^m
Goodwin and Grennes	1998	International	Wheat	Switching regime
Goodwin, Grennes and McCurdy	1999	Russia	***	Impulse analysis
Goodwin and Schroeder	1991	International	Wheat	Impulse analysis
Goodwin and Schroeder	1991	U.S.	Cattle	Cointegration
Gordon, Hobbs and Kerr	1993	Britain/France	Lamb	Granger causality
Gupta	1973			Correlation
Gupta and Mueller	1982	Germany	Hogs	Granger causality
Heytens	1986	Nigeria	Gari and yams	Timmer
Higginson, Hawkins and Adamowicz	1988	Canada/U.S.	Hogs	Granger causality /Impulse analysis
Jasdanwalla	1966	India	Groundnuts	Correlation
Jordan and Van Sickle	1995	U.S./Mexico	Tomatoes	Ravallion /Granger causality
Klein, Rifkin and Uri	1985	U.S.	Flour	Granger causality
Koontz, Garcia and Hudson	1990	U.S.	Cattle	Granger causality
Lele	1967	India	Sorghum	Correlation
Loveridge	1991	Rwanda	Dry Beans	Correlation
Lutz, Van Tilburg and Van Der Camp	1995	Benin	Maize	Cointegration /Ravallion

Table 1
(Continued.)

Authors	Date	Location	Product	Method of analysis
Mendoza and Rosegrant	1992	Philippines	Corn	Granger causality
Mendoza and Rosegrant	1995	Philippines	Corn	Granger causality /Multipliers
Mendoza and Rosegrant	1995	Philippines	Copra	Granger causality /Ravallion
Michael, Nobay and Peel	1994	International	Wheat	Cointegration
Mjelde and Paggi	1989	U.S.	Corn	Impulse analysis
Mohendru	1937	India	Wheat	Correlation
Palaskas and Harriss-White	1993	India	****	Cointegration
Prakash	1996	India	Rice	Switching regime
Ravallion	1986	Bangladesh	Rice	Ravallion
Sexton, Kling and Carman	1991	U.S.	Celery	Switching regime
Silvapulle and Jayasuriya	1994	Philippines	Rice	Cointegration
Slade	1986	U.S.	Petroleum	Granger causality
Spiller and Huang	1986	U.S.	Gasoline	Switching regime
Spiller and Wood	1988	U.S.	Gasoline	Switching regime
Teklu, von Braun and Zaki	1991	Sudan	Sorghum/cattle	Timmer
Thompson, Eales and Hauser	1990	U.S.	Grains	*****
Timmer	1987	Indonesia	Corn	Timmer
Tschirley	1995	Ecuador	Maize	Timmer
Uri, Chomo, Hoskin and Hyberg	1993	International	Soy	Granger causality
Uri, Howell and Rifkin	1985	U.S.	Flour	Granger causality
Webb, von Braun and Yohannos	1992	Ethiopia	Grains	Timmer
Williams and Bewley	1993	Australia	Cattle	Impulse analysis

* Wheat, wool, beef, sugarcane, tea, tin, zinc.

** Bangladesh rice and Malawi maize.

*** Eggs, milk, vegetable oil, potatoes.

**** Rice, potatoes, mustard.

***** Uses a spatial basis regression model.

studies of integration of Indian grain markets were presented by Cummings (1967) and Lele (1967). Both authors found correlation coefficients ranging from 0.65 to 0.9 and thus concluded that markets were highly integrated. A number of other similar studies [see, for example, Gupta (1973) and Ejiga (1977)] have used spatial price correlation coefficients to evaluate market integration.

A shortcoming of such an approach to empirical testing of market integration involves the influences of common components such as inflation, population growth, or climate patterns that affect all markets, regardless of the extent to which the markets are linked through trade in a specific commodity. Correlation in such cases may be of a spurious nature and may not reflect what one commonly assumes to be the implications of spatially integrated markets. Harriss (1979) notes this problem and points out that the extent to which individual price series are aggregated over time may affect the extent to which these systemic effects are problematic. In particular, she argues that more finely sampled data are likely to be more revealing of the actions of traders

rather than simply reflecting the systemic influences of aggregate factors. Blyn (1973) noted this limitation and recommended regressing raw price series on such systemic factors and using the resulting residuals to perform correlation tests. Such an approach, though statistically inefficient, can provide consistent estimates of correlation coefficients that are not subject to the spurious correlation effects, although one must be able to quantify and accurately measure the systemic factors in order to implement such a test. In tests using daily or weekly prices, such factors may be impossible to measure.

Harriss (1979) discussed a number of other shortcomings inherent in the price correlation coefficient approach to testing spatial market integration. She notes that monopoly procurement at fixed prices will yield correlation coefficients of 1.0, regardless of the actual degree of interaction between individual regional markets. Of course, the extent to which such a criticism damages the credibility of an empirical test depends upon one's definition of integration. A monopoly procurement agency that buys at identical prices from different regional markets may be interpreted as a strong mechanism for integrating markets, albeit in a noncompetitive environment. Harriss also points out the basic problems inherent in empirical tests arising because of heterogeneous goods, uncertainty, and inaccurate and missing price data. Such limitations are obviously important and are applicable to any empirical test of market integration.

Another shortcoming associated with the use of the correlation coefficient as an instrument for measuring integration between two markets involves the potential for independent variation of prices within the margin or band created by transactions costs. Indeed, many of the early authors seem aware of such limitations and attribute correlation coefficients that are far from 1 to transportation costs, bottlenecks, and uncertainty [see, for example, Cummings (1967) and Lele (1971)]. It is easy to show that any value of a correlation coefficient can be consistent with spatially integrated markets if transactions costs are large enough to prohibit profitable trade and thus permit independent variation of price differences within the transactions cost band. This general idea is not new [e.g., Adler and Lehmann (1983)], although methods for explicitly recognizing the importance of the transactions costs band have made their way into the empirical literature only in recent years. As will be discussed in detail below, explicit recognition of the transactions cost band requires either direct observation of transactions costs or the adoption of very restrictive assumptions regarding the behavior of transactions costs. Actual measurement of transactions costs is notoriously difficult because even the most basic components of transactions costs (e.g., transportation charges) are typically unknown. In this light, much of the recent research has taken the latter approach, adopting simplistic representations of transactions costs in empirical tests.

Closely related to the idea of correlation analysis is the literature that has implemented regression-based tests of spatial market integration. Indeed, it is straightforward to show that the concepts are nearly identical in terms of the mechanics used to de-

velop empirical tests, though the interpretation of the results is distinctly different.⁹ Econometric studies using regression methods do depend upon important causality assumptions both in estimation and in the interpretation of results. Recognition of this joint determination of prices has led researchers to adopt alternative regression methods utilizing instrumental variables techniques to obtain consistent parameter estimates. Unfortunately, many studies do not pay enough attention to issues of model identification and simultaneity, even though market integration may imply that prices are jointly determined.

A distinction between correlation coefficients and simple bivariate regression is also inherent in the approaches taken to inference under the alternative procedures. In small samples, the distribution of the sample correlation coefficient ρ_{12} is difficult to obtain, though adequate approximations are available for reasonably large samples. Inference in a simple regression model is straightforward, providing that causal patterns can be assigned.

Standard bivariate regression tests of spatial integration typically adopt some version of the model introduced by Richardson (1978):

$$P_{it} = \beta_0 + \beta_1 P_{2t} + \beta_2 T_t + \beta_3 R_t, \quad (26)$$

where P_{it} represents the price in market i , T_t represents transactions cost, R_t represents residual reasons for price differences, and the β_k 's are parameters to be estimated. In Richardson's model, cast in the framework of the law of one price, markets are taken to be perfectly integrated if $\beta_1 = \beta_2 = 1$ and $\beta_0 = \beta_3 = 0$. Such models are commonly evaluated in first-differenced or in logarithmic form. In levels or first differences, the coefficient on the price term represents the marginal effect on one price (the dependent variable) of a change in another price. Perfect integration is commonly assumed to imply that this coefficient is 1. If the analysis is conducted using a linear in logarithms specification, the coefficient represents the price transmission elasticity which, again, is assumed to have the value of 1 for perfectly integrated markets. It has been common to allow for fixed (in the linear model) or proportional (in the logarithmic model) differences in prices by relaxing the restriction that the intercept term β_0 must be zero. Such an assumption is often imposed as a crude means for representing transactions costs. In a linear model, it may be assumed that transportation costs have a constant mean and are uncorrelated with either of the prices. In the case of a logarithmic model, it is commonly assumed that transactions costs can be represented as a constant proportion of price and thus can be captured by a constant in the regression model. As a rule, such

⁹ In particular, one can note that, for a set of two prices, P_1 and P_2 , the correlation coefficient is given by $\rho_{12} = \sigma_{12}/(\sigma_1\sigma_2)$, where σ_{12} is the covariance between the two prices and σ_i is the standard deviation for the price in market i . Likewise, in a regression of the form $P_1 = \alpha + \beta P_2$, the least squares estimate of β is given by σ_{12}/σ_{22} , where σ_{22} represents the variance of P_2 . Clearly, $\beta = (\sigma_1/\sigma_2)\rho_{12}$ and thus ρ_{12} and β are proportional and are of the same sign.

models are inherently of a static nature in that arbitrage conditions are assumed to hold contemporaneously and no lags in adjustments are explicitly recognized.

All of the limitations inherent in the simple correlation coefficient approach are equally applicable to the simple regression model. The shortcomings associated with a neglect of transactions costs and price variation within the transactions cost band are especially obvious when the arbitrage condition is expressed in terms of a regression equation. Consider rewriting Equation (26) under the assumptions that the coefficient on the transactions cost term is 1 and the law of one price holds (i.e., that $\beta_1 = \beta_2 = 1$, $\beta_0 = \beta_3 = 0$):

$$P_1 - P_2 = T. \quad (27)$$

The fundamental flaw associated with this regression specification when price variation within a transactions costs band is frequent is the equality that is assumed to hold in the arbitrage condition. In reality, the zero-profit arbitrage condition imposes an inequality in place of the equality:

$$P_1 - P_2 \leq T, \quad (28)$$

that is, price differences should be less than or equal to transactions costs. Forcing this condition to hold as an equality in a regression test may result in a serious misspecification error and thus may lead to biases and misleading inferences. The significance of this bias is likely to be determined by the frequency with which price differences are at the boundary of the transactions cost band relative to the frequency that the price differences are within the band.

4.2. Dynamic regression models

Because of the very nature of the price data commonly used to examine spatial price relationships, dynamic time-series analysis techniques are frequently used to evaluate spatial market integration. These tests typically use one or more of the following techniques: Granger causality, dynamic regression tests, impulse response analysis of structural or nonstructural vector autoregressive (VAR) models, and cointegration analysis. The motivation for dynamic tests is obvious in light of the dynamic nature of interregional commodity trade and arbitrage activities. In particular, regionally traded commodities are often bulky and costly to transport and thus regional trade may often involve significant delivery lags and other impediments to adjustment. In this light, adjustments to regional shocks may take several periods to be complete and thus the effects of such shocks may be persistent. In situations where the flow of commodities is unidirectional (for example, from producing to consuming regions), the result of such delivery lags may be lead-lag relationships where price adjustments in one market lag those in another. Serial correlation in the exogenous shocks will also cause persistence in price relationships. Identifying the underlying causes of such persistence (i.e., auto-correlated shocks or delivery lags) may be difficult.

Dynamic regression models typically use some version of a vector autoregression model:

$$A_0 P_t = \sum_{k=1}^n A_k P_{t-k} + D X_t + e_t, \quad (29)$$

where P_t is a vector of prices, X_t a vector of exogenous factors affecting prices, the A_i are matrices of coefficients, and e_t is a vector of error terms representing exogenous, serially independent, but unobservable, market shocks (with $\text{cov}(e) = \Sigma$).

A large number of studies involve tests of the LOP or of perfect market integration that can be expressed as restrictions on the coefficients of the basic model. As we have discussed above, however, the model involves the simultaneous determination of prices and requires that careful attention be paid to model identification. This issue will be discussed in some detail in what follows. Many studies have not addressed the identification issue directly but have made implicit choices with implications that often are not fully considered. Some approaches do not depend on identifying assumptions but instead use the reduced form model in which $A_0 = I_n$. For example, Granger causality tests express the null hypothesis in terms of zero-restrictions on off-diagonal elements of the A_k . Price j fails to Granger-cause price i if the ij -th elements of all of the A_k ($k > 0$) equal zero.

Cointegration techniques also make use of reduced form parameter restrictions. Cointegration tests address the long-run tendencies of a dynamic system and have been used to evaluate long-run equilibria. Intuitively, cointegration occurs when prices are non-stationary but have linear combinations (across space and/or time) among them that are stationary. There has been some debate concerning what kinds of cointegration relationships should be expected in spatial prices. It is often claimed that bivariate cointegration is a necessary condition in efficient and integrated markets. Others have argued that the stronger condition that price differences be stationary (that a one-to-one long-run relationship between a pair of prices be maintained) is also necessary. Furthermore, in a system of n prices, the number of cointegration relationships present has been taken to be an indication of the degree of integration in the market as a whole. The following section examines these methods in light of a simple point-location model of spatial price determination.

4.2.1. Dynamic regression models based on a point-location model

To make dynamic regression models of spatial prices economically interpretable, it is desirable to have an explicit economic model that yields the model. One economic model that meets these criteria is a point-location model with linear excess demand functions:

$$q_{it} = b_i(a_{it} - p_{it}). \quad (30)$$

The equilibrium conditions for the two-location model in which location 1 always exports to location 2 can be written in matrix form as the linear equations¹⁰

$$\begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} p_{1t} \\ p_{2t} \end{bmatrix} = \begin{bmatrix} b_1 a_{1t} + b_2 a_{2t} \\ r_t \end{bmatrix}. \quad (31)$$

Notice that, although there are three forcing variables (a_{1t} , a_{2t} , and r_t), two of them always appear together. Suppose the forcing variables can be written as a VAR:¹¹

$$x_t = \sum_{k=1}^m B_k x_{t-k} + v_t, \quad (32)$$

where $x_{1t} = b_1 a_{1t} + b_2 a_{2t}$ and $x_{2t} = r_t$. Eliminating the forcing variables results in a VAR in prices:

$$\begin{aligned} \begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} p_t &= \sum_{k=1}^m \begin{bmatrix} B_{11k} & B_{12k} \\ B_{21k} & B_{22k} \end{bmatrix} \begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} p_{t-k} + v_t \\ &= \sum_{k=1}^m \begin{bmatrix} B_{11k}b_1 - B_{12k} & B_{11k}b_2 + B_{12k} \\ B_{21k}b_1 - B_{22k} & B_{21k}b_2 + B_{22k} \end{bmatrix} p_{t-k} + v_t. \end{aligned} \quad (33)$$

At issue is what restrictions, if any, spatial equilibrium imposes on the coefficients of this model. Four approaches to spatial price analysis using the basic dynamic regression model are discussed in this section: Granger causality tests of efficiency and market dominance, the market integration criteria of Ravallion and of Timmer, dynamic multiplier and impulse analysis, and cointegration. Table 1 contains a summary of a number of studies that use dynamic regression models to analyze spatial commodity prices.¹²

4.2.2. Granger causality and lead/lag relationships

Granger causality tests are typically conducted within the framework of a vector autoregression model where regional prices for one market are regressed upon lagged values

¹⁰ The model formulated here is expressed in terms of price levels and assumes that transport costs are absolute (not dependent on the commodity price). Many analysts use log price specifications, which can be justified if transport rates are expressed in percentage terms. It may be that transport rates are a mixture of these (e.g., insurance may be a percentage of the value of the shipment and freight rates are per unit). In the mixed case, the model must be modified and interpretation of dynamic regression is even more problematic.

¹¹ Henceforth the deterministic variables are eliminated to avoid notational clutter; equivalently, the variables are expressed as deviations around a deterministic function.

¹² A large literature exists dealing with market integration in other goods, especially in financial markets. This review concentrates on goods that are expensive to transport relative to their value, as is true of most agricultural products.

of prices in another market. Significant coefficients imply that shocks to prices in one market evoke significant responses in another, with a lag. Granger (1969) formalized the notion of causality in terms of lead and lag relationships among dynamically interrelated variables. The use of the terminology "causality" often leads to some misunderstanding about the implications of the tests since the tests allow inferences only about lead/lag relationships and have little to say about actual causal elements leading to dynamic adjustments. The reduced form, in terms of the economic model's parameters, can be expressed as

$$\begin{aligned}
 p_t = & \frac{1}{b_1 + b_2} \sum_{k=1}^m \begin{bmatrix} 1 & -b_1 \\ 1 & b_1 \end{bmatrix} \begin{bmatrix} B_{11k} & B_{12k} \\ B_{21k} & B_{22k} \end{bmatrix} \begin{bmatrix} b_1 & b_2 \\ -1 & 1 \end{bmatrix} p_{t-k} + v_t = \frac{1}{b_1 + b_2} \\
 & \times \sum_{k=1}^m \begin{bmatrix} B_{11k}b_1 - B_{12k} - B_{21k}b_1b_2 + B_{22k}b_2 & (B_{11k} - B_{22k} - B_{21k}b_2)b_2 + B_{12k} \\ (B_{11k} - B_{22k} + B_{21k}b_1)b_1 + B_{12k} & B_{11k}b_2 + B_{12k} + B_{21k}b_1b_2 + B_{22k}b_1 \end{bmatrix} \\
 & \times p_{t-k} + v_t.
 \end{aligned} \tag{34}$$

The hypothesis that p_1 fails to Granger-cause p_2 is the hypothesis that the lower left-hand elements of the coefficient matrices are all zero:

$$(B_{11k} - B_{22k} + B_{21k}b_1)b_1 - B_{12k} = 0 \quad \text{for all } k. \tag{35}$$

This hypothesis would be accepted if B_{12k} and either b_1 or $B_{11k} - B_{22k} + B_{21k}b_1$ are small enough. Similarly the hypothesis that p_2 fails to Granger-cause p_1 is

$$(B_{11k} - B_{22k} - B_{21k}b_2)b_2 + B_{12k} = 0, \tag{36}$$

which would be accepted if B_{12k} and either b_2 or $B_{11k} - B_{22k} + B_{21k}b_1$ were both small enough.

Granger and Elliott (1967) evaluated spatial price relationships among eighteenth century prices at several English wheat markets. Their results revealed significant interactions and suggested that adjustments to price shocks at spatially distant locations were often of a dynamic nature. Gupta and Mueller (1982) used Granger causality to examine price adjustments among spatially separated hog markets in Germany. They interpret the finding of causality to be suggestive of inefficient markets since it implies the existence of a lead/lag relationship. Such a conclusion is questionable in light of the potential for dynamics in the price adjustment process owing to delivery lags and other impediments to interregional trade.¹³ Indeed, Granger (1988) has shown that cointegration, which implies a long-run equilibrium relationship among a pair or set of economic

¹³ In fact, Granger (1980, 1988) has argued that instantaneous causality is unlikely for most economic variables and that results consistent with such a finding usually reflect inappropriate temporal aggregation or omitted variables.

variables and thus has often been used to evaluate market integration, implies the existence of Granger causality in at least one direction.

Gupta and Mueller (1982) argue that the failure of one price to be predictive of another when the second is predictive of the first (unidirectional causality) is an indication that the second price is not incorporating the price information from the first region. Unidirectional causality is, therefore, taken to indicate that a market is informationally inefficient. An alternative explanation for unidirectional causality is suggested by Brorsen et al. (1985, p. 1): "Supply/demand fluctuations in a location with a large volume of commodity trading represent a larger shift in aggregate supply/demand, thus these locations are expected to have a larger influence on prices in other locations".

This can be demonstrated by considering when the simple point-location model would produce such a result. B_{12k} will be small if lagged transport rates have little impact on excess demand shocks. This is not unreasonable and implies that one is likely to find that p_1 fails to Granger-cause p_2 when p_2 Granger-causes p_1 in a situation in which b_2 is much larger than b_1 (i.e., when the amount demanded is far more sensitive to a given change in the absolute price level at location 2 than at location 1). This tends to happen when location 2 is a much larger market than is location 1. Thus, a sufficient condition for one-directional Granger-causality in prices is that a dominant/satellite market structure exists. Garbade and Silber (1979) and Koontz, Garcia and Hudson (1990) used this kind of test to detect such market relationships.

Alexander and Wyeth (1994) used Granger causality tests within the context of cointegration tests to evaluate spatial integration for Indonesian rice markets. Their results revealed patterns of causality, in terms of lead/lag relationships among several spatially distant markets. Alexander and Wyeth (1994) emphasize that Granger causality tests are necessarily implicitly nested within dynamic regression models and thus patterns of Granger causality should be considered to enrich the inferences offered in empirical studies. In a similar vein, Goodwin, Grennes and McCurdy (1999) used Granger causality within the context of multivariate cointegrated systems to evaluate spatial linkages among regional food markets in the post-reform Russian Federation. Their results reveal significant dynamics in the adjustment of prices to shocks in other regions.

Although Granger causality tests may provide some inferences regarding the existence of statistically significant lead/lag linkages among regional prices, a number of shortcomings limit their usefulness. First, Granger causality tests, taken by themselves, indicate only whether a relationship among contemporaneous and lagged prices is statistically different from zero. Without appealing to other tests or other means for inference, nothing is said about the actual nature of the relationship (i.e., about the values of the parameters being evaluated). A statistically significant relationship that is totally inconsistent with conventional notions of market integration could exist and be taken as support for spatial integration by Granger causality tests. Thus, it is imperative that results of Granger causality tests be supplemented by other inferential procedures to ensure that mistaken inferences are not drawn.

The limitations associated with standard regression and correlation coefficient approaches to testing market integration are also applicable to Granger causality tests. In particular, the independent variation of prices within a transactions cost band could lead to parameter estimates that have any value (including zero) but are entirely consistent with fully efficient markets. Granger causality tests are also sensitive to omitted variables biases. Finally, it should be noted that Granger's (1969) original notion of causality was based upon improvements in the forecasting performance of structural or nonstructural time-series models that resulted from including additional variables.¹⁴ In standard tests, such forecasting is done within the same sample used to estimate the parameters of the forecasting model. A logical inconsistency is inherent in such an "in-sample" approach in that the parameter estimates underlying the forecasts are based upon information that is available only subsequent to the period being forecasted. As an alternative to this standard in-sample approach, Ashley, Granger and Schmalensee (1980) developed out-of-sample Granger causality tests which are based upon forecasts generated out-of-sample. These tests are closer to the spirit of causality originally discussed by Granger (1969) but have not, as yet, found their way into empirical analyses of causality among spatially separated prices.

The results of Granger causality tests should, therefore, be interpreted with caution. If one finds unidirectional causality in a market that should not exhibit dominant/satellite relationships, it would be an indication that the market should be analyzed carefully. At this stage, however, it would be premature to conclude that it indicates market inefficiency, as no convincing model of an inefficient market exhibiting this phenomenon has been developed.

4.2.3. Ravallion/Timmer market integration criteria

Ravallion (1986) and Timmer (1987) have proposed tests of market integration based upon dynamic regression models. In a general sense, these models can be interpreted as vector autoregressive models with tests of restrictions on the reduced-form parameters of the models. In this way, the dynamic regression models are alternative, dynamic versions of standard regression models and Granger causality tests. Ravallion's model is based upon regressions of the form

$$P_{it} = \sum_{s=1}^n a_{is} P_{it-s} + \sum_{s=0}^n b_{is} P_{1t-s} + X_{it}c_i + e_{it}, \quad (37)$$

where P_{it} is the price in regional market i in time t , P_{1t} is the price in a central market, and X_{it} represents a vector of characteristics influencing regional markets. Ravallion's test is cast in the framework of radial linkages among a number of hinterland

¹⁴ Granger (1969) defines causality between two time series, X_t and Y_t , as follows: X_t causes Y_t if X_t contains information not available in Y_t that helps forecast Y_t .

markets and a central reference market important for price discovery. Ravallion defines several criteria for integration. Short-run market integration exists between the central market and the regional market if $b_{i0} = 1$ and if $a_{is} = b_{is} = 0$ (for all $s = 1, \dots, n$), which implies that shocks in the regional market are immediately passed on to the i -th market price. Ravallion defines a weaker form of short-run integration to exist in cases where the lagged effects vanish on average, which requires only that $b_{i0} = 1$ and $\sum_{s=1}^n a_{is} + b_{is} = 0$. A long-run version of market integration exists when market prices are equalized over the long run, which requires that $\sum_{s=1}^n a_{is} + \sum_{s=0}^n b_{is} = 1$. It can be noted that short-run integration implies long-run integration but that the reverse is not true. Ravallion (1986) applies this test to first-differenced monthly price data to evaluate spatial linkages among Bangladesh rice markets. He finds that support for integration, even in the long run, is quite limited.¹⁵

Ravallion's three criteria for integration can be interpreted in terms of the structural econometric model. Recall that short-run integration implied that $b_{i0} = 1$ in (37). This is directly implied by the equilibrium condition. The added restriction that required that $a_{ij} = b_{ij} = 0$ (for all $j = 1, \dots, n$) in Equation (37), can be expressed in terms of the structural point-location model as

$$B_{22k} - B_{21k}b_1 = -B_{22k} - B_{21k}b_2 = 0 \quad \text{for all } k. \quad (38)$$

It is difficult to justify such a restriction. It is only true if $B_{21} = B_{22} = 0$ for all k , implying that transport rates exhibit no persistence. It is not surprising that this condition is virtually always rejected (transport rates, like many prices, tend to exhibit serial correlation). As noted above, lagged price effects do not in themselves indicate market imperfections.

Ravallion's weak-form short-run restriction, suggesting that the lagged effects vanish on average, can be written in terms of the econometric model implied by Equation (33) as

$$\sum_k (B_{22k} - B_{21k}b_1 - B_{22k} - B_{21k}b_2) = -(b_1 + b_2) \sum_k B_{21k} = 0. \quad (39)$$

If b_1 and b_2 are positive (demand is not perfectly elastic), this restriction can be expressed as $\sum_k B_{21k} = 0$. The B_{21k} measure the effect on the transport rate of lagged excess demand shocks. This restriction can be interpreted to say that excess demand

¹⁵ Faminow and Benson (1990) combine the agents-on-links framework with the existence of imperfect competition at the market centers and conclude that Ravallion-type tests should be reinterpreted. They argue that the short-run tests are symptomatic of a base point pricing system (collusion) in which one firm (location) sets a base price and other locations match that price net of transport costs. This conclusion rests on the assertion that competitive price adjustments must take time. Such adjustments could occur within a week or month, the intervals generally used in studies of spatial prices.

shocks have no long-run effect on the transport rate. To the extent that this is a reasonable assumption, the weak-form criterion can be derived in the context of this point-location economic model. It can be argued that an even stronger criterion may be justified if it is assumed that $B_{21k} = 0$ for all k , which is the same as saying that excess demand shocks do not Granger-cause the transport rate. If such an assumption is valid, then a revised strong-form short-run criterion requires only that $b_{i0} = 1$ and $a_{ij} + b_{ij} = 0$ for all j . It should be noted that the weak form criterion does not imply a weaker equilibrium condition but rather a weaker identification assumption concerning the driving forces.¹⁶

Ravallion also proposed a test for market isolation or segmentation. In isolated markets, prices are equal to the autarky prices (the a_i). As Harriss (1979) noted, the autarky prices may be correlated contemporaneously. They should, however, fail to Granger-cause one another. In the two-location model, isolated markets have the VAR structure

$$p_t = \sum_{k=1}^m \begin{bmatrix} R_{11k} & 0 \\ 0 & R_{22k} \end{bmatrix} p_{t-k} + v_t. \quad (40)$$

This leads to the testable restrictions that $R_{12k} = R_{21k} = 0$ for all k (i.e., that prices fail to Granger-cause one another).¹⁷

Timmer (1987) also used a dynamic regression model but adopted somewhat different assumptions. Timmer assumed that central market prices are predetermined relative to hinterland prices and that a first-order model is sufficient to capture the price dynamics. Timmer relates hinterland market prices to prices in the central reference market through the following equation:

$$P_{it} = c_0(P_{1t} - P_{1t-1}) + (c_0 + c_{1i})P_{1t-1} + c_{1i}P_{it-1}, \quad (41)$$

where P_{it} is the price in hinterland market i and P_{1t} is the price in the central reference market. In the context of this model, Timmer defined an index of market connectiveness (IMC) by

$$IMC_i = \frac{c_{1i}}{c_0 + c_{1i}}. \quad (42)$$

¹⁶ Ravallion (1986) also suggested that deterministic variables such as constants and seasonal terms should be zero in an integrated market. It is difficult to see how this assertion can be justified. A constant term in the arbitrage equation of the dynamic regression model should be present any time transport is costly. Furthermore, seasonality in transport rates, which is often present, will result in non-zero seasonal coefficients. Regime shift (dummy) variables and time trends can similarly be interpreted in terms of changes in transport rates.

¹⁷ Ravallion's (1986) criteria are not symmetric. His proposed market structure is one with a central market and hinterland markets. His market segmentation criterion requires that the central market price fails to Granger-cause the hinterland price. In a segmented market situation, however, Granger-causality should not be present in either direction.

Timmer argued that, in highly integrated markets, the lagged effects of regional market shocks should be small relative to current and lagged central reference market shocks and thus that the IMC should be close to zero.

Timmer's index of market connectiveness can also be interpreted in the context of a point-location model. Recall that Timmer argued that the IMC should be close to zero for highly integrated markets. A different interpretation of the index emerges from considering the measure in terms of the parameters of the economic model in the fully integrated case. In a two-location model,

$$IMC = \frac{B_{22} - B_{21}b_1}{1 - B_{22} - B_{21}b_1}. \quad (43)$$

If the identification restriction that $B_{21} = 0$ is imposed, the measure can be written as

$$IMC = \frac{B_{22}}{1 - B_{22}}. \quad (44)$$

Recall that B_{22} measures the autocorrelation coefficient on transport rates, which should lie on the $[0, 1]$ interval. This measure could therefore be interpreted as a measure of transport rate persistence; it is not clear how this relates to market integration.

Suppose, on the other hand, that the locations are actually isolated, so the reference price has no effect on the hinterland price, and

$$c_0 = c_{12} = 0. \quad (45)$$

In this case, Timmer's market integration index will be large (indeed, infinitely so), as it should be as an indicator of weakly integrated markets. This poses a dilemma. A large value of the IMC may indicate that the locations are not integrated or it may indicate that they are integrated and that transport rates exhibit a high degree of persistence. On the other hand, a low IMC suggests that the markets are not isolated but it is unclear how connected they are. Timmer's IMC, like Ravallion's strong form criterion, is useful only if one has independent confirmation that transport rates are white noise processes.

4.2.4. Impulse response analysis

Impulse responses represent the effects of exogenous shocks to variables in terms of a moving average representation of the VAR system. Impulse responses have been used in the framework of VAR systems comprised of a set of prices to examine dynamic issues related to spatial market integration. For a system of n regional prices, a set of impulse responses, reflecting the effects of exogenous shocks to prices in each of the n markets on prices, would be given by¹⁸

¹⁸ Deterministic terms are again suppressed.

$$p_t = \sum_{k=0}^{\infty} M_k e_{t-k}, \quad (46)$$

which expresses the prices as functions of current and lagged shocks (impulses). An impulse response function (IRF) traces the impact over time of shock j on price i ; the ij -th elements of the M_k expressed as a function of k . With n prices there are n^2 of these functions. Goodwin, Grennes and McCurdy (1999) evaluate spatial market linkages in post-reform Russia using impulse responses. They argue that such an approach provides richer inferences regarding the dynamics of price adjustments than standard regression analyses since the impulse responses evaluate the dynamic time-path of responses to market shocks. They also argue that impulse responses provide a dynamic alternative to standard “all-or-nothing” tests of market integration since they allow one to examine the extent of eventual price adjustment over time. Responses to price shocks in a regional market that are significantly different from zero but are not consistent with absolute price equalization may be taken as at least partial support for market integration. Williams and Bewley (1993) used impulse response analysis to examine spatial price relationships for Australian cattle markets.

A number of analysts have interpreted impulse response functions as dynamic disequilibrium adjustments. This interpretation can be justified only if the underlying shocks are serially uncorrelated. An alternative interpretation is that the impulse response functions reflect equilibrium adjustments to ongoing changes in economic fundamentals; this view is explicit in Equations (31)–(33). It is difficult to determine which of these alternatives is correct on the basis of price data alone due to identification problems.

In either case, to meaningfully interpret the IRFs, the shocks must be given an economic interpretation. A standard practice is to assume that the shocks are uncorrelated and that A_0 (in (29)) is triangular for some ordering of the variables, implying that prices form a causally recursive system. Such an approach assumes a set causal ordering of variables. A_0 can then be estimated as the Choleski decomposition of the reduced-form error covariance matrix. System recursivity, however, is a strong identifying assumption, implying a belief that shocks affecting some prices have no immediate impact on other prices. It is inherently untestable and, to be believable, must be justified on a priori grounds. A common approach in the literature is to examine several orderings in order to evaluate the sensitivity of the results to the ordering assumed for the system. Such an approach necessarily involves some degree of misspecification, however, and should not be assumed to provide an explicit test of the validity of assumed causal orderings. As Leamer (1985) points out, this is tantamount to the assumption that one is certain that instantaneous causality only flows in one direction but uncertain of the direction of that flow [see also Cooley and LeRoy (1985)].

There is another reason to interpret results based on a recursivity assumption with caution. In the context of a dynamic spatial price regression, recursivity amounts to imposing a particular kind of disequilibrium on the model. Shocks that originate in one location, it is assumed, have no immediate effect on prices at some of the other locations, which can be interpreted as an informational inefficiency. If the intent is to

study the efficiency of the market, it is not a good practice to impose inefficiency on the market a priori.

To our knowledge, no studies have been published that make use of non-recursive identifying assumptions in the context of a model of spatial prices. Indeed, we know of only one such application to agricultural markets: Myers, Piggott and Tomek (1990). A useful discussion is contained in Tomek and Myers (1993).

4.2.5. Cointegration analysis

In recent years, it has been recognized that many economic variables behave as if they are nonstationary, and unit-root nonstationarity seems to be particularly common.¹⁹ This is particularly true of nominal prices, which often trend and wander extensively over time. The presence of nonstationarity in the price series commonly used to test spatial market integration invalidates conventional approaches to inference. In particular, parameter estimates of common regression tests for cointegrated prices, based on a regression model such as Equation (26), though consistent, will have inconsistent standard error estimates.²⁰ Recognition of this issue and recent advances in econometric techniques appropriate to nonstationary variables has stimulated an extensive literature applying unit-root and cointegration tests to evaluations of spatial integration. Nearly half of the papers in Table 1 apply cointegration methods to spatial prices.

Cointegration tests typically evaluate the equilibrium parity condition implied by spatial arbitrage:

$$p_{1t} - \alpha - \beta p_{2t} = e_t, \quad (47)$$

where p_1 and p_2 represent prices in two spatially separated markets. As noted, if p_1 and p_2 are nonstationary, regression estimates of the standard errors on the estimates of α and β will not be consistent. Cointegration tests consider the time-series properties of the residual term e_t . If the residual is stationary, the implication is that, although p_1 and p_2 wander extensively on their own, they are linked in a long-run, stable equilibrium.

Although early analyses of cointegration were primarily of a bivariate nature, multivariate versions of cointegration relationships have also been considered. Consistency with the notion of a single price implies that a group of n prices should have $n - 1$ cointegration relationships (cointegration vectors).²¹ This implies that any one of the prices can be solved for in terms of any other single price or, equivalently, that any single price

¹⁹ A time-series variable is unit-root nonstationary if the characteristic equation associated with its autocorrelation function has a unit eigenvalue.

²⁰ See Engle and Granger (1987) for a detailed discussion of the properties of ordinary least squares estimates when variables are nonstationary, as well as a series of bivariate cointegration tests.

²¹ Cointegration relationships are often equivalently expressed in terms of the number of common stochastic trends that exist among the group of variables. For n prices, $n - 1$ cointegration vectors implies a single common trend.

is representative of the group. Of course, the values of the cointegration vectors are relevant to the nature of the relationship among prices. Multivariate cointegration tests are usually conducted in the context of the reduced form of a vector autoregressive (VAR) model (Equation (29) with $A_0 = I_n$):

$$p_t = A_1 p_{t-1} + \cdots + A_k p_{t-k} + v_t. \quad (48)$$

The appropriate approach to estimating this relationship depends upon whether the individual prices are stationary and, in the case of nonstationarity, whether cointegration relationships exist. If the prices are stationary, standard OLS estimation procedures can be applied and standard inferences regarding causality and impulse responses can be obtained. However, if they are nonstationary, standard estimation procedures may be inappropriate. Furthermore, if the data are cointegrated, first-differencing transformations may induce an important model misspecification and thus are not appropriate.

A frequently applied test for cointegration is the maximum likelihood approach of Johansen (1988) and Johansen and Juselius (1990). The VAR Equation (33) can be written in error-correction (first-differenced) terms as

$$\Delta p_t = G_1 \Delta p_{t-1} + \cdots + G_{k-1} \Delta p_{t-m+1} - B p_{t-m} + v_t. \quad (49)$$

If prices are nonstationary but are cointegrated, the matrix given by

$$B = I_n - A_1 - \cdots - A_m \quad (50)$$

will be of some rank r such that $r > 0$ and $r < n$. Johansen and Juselius's tests evaluate the rank of B . If the rank of B is r , then there are r unique cointegrating vectors among the n prices.

Cointegration-based tests are tests of long-run tendencies rather than of period-by-period equilibria. These tests are generally justified by the assertion that arbitrage opportunities prevent spatial prices from drifting too far apart. Within the context of a linear dynamic regression model, the only way that nonstationary prices can be assured of not drifting too far apart is to have stationary price spreads.

At first glance the notion that spatial prices cannot drift apart in an efficient market has some intuitive appeal. It should be noted, however, that at a minimum this assertion makes the implicit assumption that transport rates are stationary or, in the case of tests using logarithmic transformations, are proportional to prices. Clearly, if transport rates are non-stationary then prices that are observed to drift apart may not represent arbitrage opportunities at all. In the simple point-location model with stable trading patterns the price spread is equal to the transport rate and thus should reflect its stationarity properties. Thus cointegration is not a necessary condition for market efficiency and integration. Some evidence for this is found in Goodwin (1992a) who showed that wheat prices in three locations (U.S. Gulf, Rotterdam, and Japan) exhibited a cointegration

relationship which was potentially sensitive to ocean freight rates. Examination of the freight rates suggested that the Gulf–Japan rate was nonstationary.

One of the first applications of cointegration analysis to an evaluation of spatial market linkages is Ardeni's (1989) study of the law of one price for internationally traded agricultural commodities. Ardeni's study was motivated by neglect of the issue of nonstationarity in the literature as well as by the differencing transformations often used to address serial correlation in empirical work [e.g., Richardson (1978)].²² Ardeni argued that individual prices in spatially integrated markets may wander extensively on their own and may diverge from one another for brief periods of time but should not wander too far apart in the long run. Thus, he argued that prices should be cointegrated. His analysis found relatively limited evidence of cointegration in international commodity markets and thus he concluded that the law of one price was not supported in the international markets for basic commodities that he considered. Baffes (1991) pointed out that cointegration alone is not sufficient to conclude that the LOP holds. He suggested that the linear relationship between prices should have a slope of one, or, equivalently, that price spreads are stationary.

Goodwin and Schroeder (1991b) used a variety of cointegration tests to evaluate spatial linkages among regional U.S. cattle markets. Their results revealed strong linkages among weekly prices. Cointegrating parameter estimates were also consistent with a reasonably strong tendency toward price equalization. Using a similar approach, Alderman (1993) utilized cointegration tests and versions of Ravallion's (1986) regression tests to evaluate integration in Ghana grain markets.

Cointegration tests have the advantage of allowing consistent inferences to be drawn in situations where the individual price series are nonstationary. However, like other regression-based tests, cointegration tests are vulnerable to the problems associated with spurious regression results and transactions costs. An extensive discussion of the shortcomings of cointegration tests of spatial market integration is offered by McNew and Fackler (1997). A fundamental shortcoming associated with the cointegration approach lies in the possibility that transactions costs may be nonstationary. In general, deviations from a parity condition such as that implied in Equation (47) are generally assumed to reflect unobserved elements of transactions costs. If such elements are indeed nonstationary, a set of prices may not be cointegrated in spite of the fact that they are clearly linked in a long-run equilibrium and thus are consistent with conventional views of market integration. A limited number of studies have attempted to adjust price differentials for transactions costs.

It may also be the case that equilibrium prices are cointegrated in spite of the fact that markets are not directly linked with one another. Such a situation would most likely be observed in cases where the transactions cost band is relatively large and the price differential is stationary but always within the transactions cost band. In light of these

²² As Ardeni (1989) notes, differencing transformations may be inappropriate for cointegrated variables in that they may introduce an important misspecification in the empirical model.

limitations, one would intuitively expect that cointegration tests are most appropriate in applications where the transactions costs are small relative to the prices being evaluated.²³

Barrett (1996) notes that cointegration could be consistent with a negative relationship between prices when market integration suggests a positive correlation. This is indeed similar to the general problem (noted above in the context of Granger causality tests) of examining the significance of the relationship without considering the nature (direction) of the relationship. Thus, cointegration, taken without additional considerations (such as an evaluation of impulse responses or cointegrating parameters), provides limited and potentially misleading information about spatial market linkages.

If the transport rate is stationary, the simple point-location model can be used to derive testable restrictions on the price VAR. For example, one can show that, if $n - 1$ cointegrating relationships exist in an n -location model, an efficient and well-integrated market will exhibit stationary price spreads. Stationarity of price spreads can, therefore, be used to suggest that markets are efficient and integrated in the long run.

The relationship between cointegration and efficiency, however, is complex, even if the transport rate is stationary. In the alternative models considered (the switching regime, the point-location with upward-sloping transport supply, and the agents-on-links models), price spreads depend on all of the model's shocks. For example, with upward-sloping transport supply, the price spreads are given by Equation (15) and are a function of both transport rate and reservation prices. Transport rate stationarity, therefore, is not sufficient to ensure price spread stationarity in an efficient market. One must also have stationarity of excess demand shock differences as well. Although this is possible, spatial arbitrage cannot be the mechanism that ensures it. In the switching regime model, it is possible to have an efficient market with changing trading patterns and fail to observe cointegration or stationary price spreads [McNew and Fackler (1997)].

A tentative conclusion that emerges from these remarks is that price spread stationarity is consistent with a market in which locations are, in the long run, both efficient and fully integrated. This means that, in some sense, the market equilibrates in the long run (arbitrage opportunities are exploited) and that shocks originating in one location are eventually transmitted fully to the other location. On the other hand, a conclusion that the price spreads are not stationary is more difficult to interpret. It may imply that the markets are in a long-run disequilibrium situation. More likely, however, it may imply that integration is less than complete, either because the markets become isolated or because marginal adjustments occur. In this case, however, conclusions about the extent of integration are difficult to justify using linear dynamic regression, either because a switching regime regression is more appropriate or because the structural model is not identified using only price data.

Before leaving the subject of long-run equilibria, it is useful to remark on alternative views of the meaning of this concept. There are two ways of evaluating long-run

²³ For example, cointegration tests of asset prices and rates of return may be more appropriate in light of the very small transactions costs associated with trades in organized asset markets.

impacts in dynamic systems. The first uses what have been termed the long-run multipliers. These measure the eventual impact on an endogenous variable of a permanent incremental change in the value of an observable exogenous variable:

$$\lim_{h \rightarrow \infty} \sum_{i=0}^h \frac{\partial E_t[p_{t+i}]}{\partial x_t}. \quad (51)$$

The other long-run concept measures the eventual impact on an endogenous variable of a one-time incremental change in the value of one of the unobserved system shocks:

$$\lim_{h \rightarrow \infty} \frac{\partial E_t[p_{t+h}]}{\partial e_t} \quad (52)$$

(i.e., the time limits of the impulse response functions).

A number of analysts, including Ravallion (1986), use the former concept, implicitly treating a central market price as exogenous. Notice that a hinterland price can be written as

$$p_{2t} = \frac{c_0 - \sum_{k=1}^m c_{1k} L^k}{1 - \sum_{k=1}^m c_{2k} L^k} p_{1t} + v_t = S(L)p_{1t} + v_t. \quad (53)$$

If p_1 were exogenous the long-run impact multiplier would be equal to $S(1)$. Setting this equal to 1 yields Ravallion's long-run integration criterion. In an integrated market, however, the central market price cannot be assumed to be exogenous, because this would be tantamount to assuming that shocks originating in the hinterland never affect the central market price.

Viewed from the perspective of impulse analysis, a long-run version of the strong form of the LOP requires that there be a mechanism through which some linear combination of shocks affects all prices equally in the long run. This means that there exists a vector θ such that $M_\infty \theta$ is the unit vector, where M_∞ is the long-run impulse response matrix. This condition is always true if prices are nonstationary and are not cointegrated. If prices are cointegrated, however, the condition is equivalent to $A(1)$ being orthogonal to the unit vector, which is easily tested. Furthermore, in a market in which there is a single source of non-stationarity, this is equivalent to the stationarity of price spreads.

In short, cointegration tests of spatial integration are heavily dependent upon assumptions which may, in many cases, be quite strong. These assumptions principally pertain to transactions costs, which are often assumed to be stationary or capable of being represented in an ad hoc simplistic manner. In this way, cointegration tests share a limitation common to most other empirical tests of spatial market integration.²⁴

²⁴ Indeed, the neglect of transactions costs is a problem endemic to empirical economic analyses. Transactions costs are present in almost any exchange and may distort endogenous responses enough to significantly bias regression parameter estimates.

4.2.6. *Empirical determinants of market integration*

The overwhelming majority of analyses of market integration address only the question of whether, using whatever metric is deemed appropriate to the analysis, markets are integrated. Most often, such questions are posed in a discrete yes/no framework, although some papers discuss the issue in terms of a degree or extent of integration. A natural (but often neglected) follow-up question involves a consideration of the factors that affect the extent or degree of integration. Only a small number of studies have evaluated determinants of spatial market integration. Goodwin and Schroeder (1991b) followed up their cointegration analysis of spatial linkages in regional livestock markets with an investigation of the factors that tended to influence the extent of cointegration (integration) among a pair of markets. Their results revealed that, as would be expected, distance between markets has a significant, negative influence on the degree to which a pair of market prices tended to be cointegrated. Likewise, they found that increasing concentration of the meat packing industry over time corresponded to increased cointegration among regional prices. This result is particularly important in that increased concentration of an industry is often suspected to lead to the increased exercise of market power through spatial price discrimination, which could be characterized by diminished market integration and thus a tendency for less integration.²⁵ However, as has been noted by Faminow and Benson (1990), market integration could be due to noncompetitive basing-point pricing practices of large buyers or sellers.

Goletti and Christina-Tsigas (1995) discuss a general framework for evaluating determinants of the degree of market integration. They suggest that such factors as marketing infrastructure (transportation, communication, and credit), price policies, infrastructure (roads, phone system, etc.), and labor issues such as strikes may be relevant to observed patterns of integration. Goletti, Ahmed and Farid (1995) identified several structural factors affecting the integration of rice markets in Bangladesh. They found that distance between markets, telephone density, and the presence of labor strikes had negative impacts on various measures of integration. In contrast, road density and the degree of inequality in production levels (indicating more regional trade) positively affected the degree of market integration. Goletti (1993) found that severe supply shocks, such as major floods, had a negative impact on market integration.

In general, the fundamental question of market integration goes beyond simple considerations of whether prices are integrated. Inferences regarding factors affecting revealed patterns of integration are richer and perhaps more informative. As a general rule, however, such inferences are lacking in the empirical literature.

²⁵ Increased concentration of the livestock packing industry has brought about complaints that prices in regional livestock markets have been driven down and that spatial differences have increased as a result of discriminatory pricing practices.

4.3. Switching regime models

One difficulty with dynamic regression models is the lack of a clearly articulated alternative to the null hypothesis that markets are perfectly integrated. This is problematic when a market is imperfectly integrated because the network of trading linkages changes over time. Timmer (1987), for example, suggested that seasonal changes in the import/export status of regions would lead to difficulties in identifying the degree of market integration. This theme was echoed recently by Baulch.

A potentially more appropriate modeling approach has been developed using the switching regime regression model. Spiller and Wood (1988) suggested this approach in a model of northeast U.S. gasoline markets. They suggested that three regimes are possible in a two-location market, which, expressed in the notation of this chapter, are:

- (1) location 1 ships to location 2 if $a_{2t} - a_{1t} > r_{12t}$;
- (2) location 2 ships to location 1 if $a_{2t} - a_{1t} < -r_{21t}$;
- (3) no trade occurs if $-r_{21t} < a_{2t} - a_{1t} < r_{12t}$,

where r_{ijt} is the transport rate for shipping the commodity from location i to j at time t (it is possible that $r_{12t} \neq r_{21t}$).

Switching regime models provide estimates of the probabilities of being in each regime, both *ex ante* and *ex post* (conditional on the size of the observed price spread).²⁶ To make the model tractable, they impose quite strong assumptions on the dynamic processes generating the excess demand shocks and transport rates. In particular they assume that $a_{2t} - a_{1t}$, r_{12t} and r_{21t} are mutually and serially independent. Currie (1995) recently estimated a similar model that relaxes some of these assumptions.

In the Spiller and Wood (1988) approach, a test for market integration shifts from a test of regression coefficients within a regime to a test of the size of the regime probabilities. The hypothesis of a well-integrated market with a stable trade pattern (say with trade from location 1 to 2) is equivalent to the hypothesis that the associated regime probability equals 1 and that the others' regime probabilities are each zero.

Sexton, Kling and Carman (1991) examine the issue of market efficiency rather than integration. They study a market (U.S. celery) that can safely be assumed to be linked by unidirectional trade (say from location 1 to 2) and develop a switching regime model in which arbitrage conditions may be violated. Their model is similar to that of Spiller and Wood's in that they use a switching regime regression approach, but the three regimes are defined in the following way:

- (1) $p_{2t} - p_{1t} < r_{12t}$,
- (2) $p_{2t} - p_{1t} > r_{12t}$,
- (3) $p_{2t} - p_{1t} = r_{12t}$.

Only in regime 3 are the markets efficient, and hence efficiency is equivalent to the hypothesis that the probability of regime 3 is equal to one and the other regime probabilities equal zero. Baulch (1994, 1997) proposed an alternative switching regime model

²⁶ These models typically endogenize the probability of the market being in each of the possible regimes.

in which the regimes correspond to prices within the arbitrage band (no trade), prices at the arbitrage band (efficient trade), and price outside the arbitrage band (inefficient trade).

In all of these approaches the probability distribution associated with the price spread is a mixture of three distributions:

$$f(s_t|\theta) = \lambda_1 f_1(s_t|\theta_1) + \lambda_2 f_2(s_t|\theta_2) + (1 - \lambda_1 - \lambda_2) f_3(s_t|\theta_3), \quad (54)$$

where $s_t = p_{2t} - p_{1t}$, and θ_j are parameters defining the regime probability distributions, and λ_1 and λ_2 are the ex ante probabilities that the market will be in regimes 1 and 2, respectively.²⁷ In Spiller and Wood, $\lambda_1 + \lambda_2$ can be thought of as a measure of the degree of integration of the market. In Baulch it is a measure of the efficiency of the market (which he calls the integration of the market). In Sexton, Kling and Carman it is a measure of the inefficiency of the market.

Switching regime models are problematic, however, in that a far simpler interpretation for the "probabilities" exists when it is recognized that use of a mixture distribution is a standard way to flexibly model a probability distribution. These models can be viewed as nothing more than flexible models of the price spread distribution. The believability of the regime interpretation rests very strongly on the believability of the distributional assumptions. For example, both Spiller and Wood (1998) and Sexton, Kling and Carman (1991) assume that f_3 is normally distributed. Furthermore, in both papers the other two regimes are one-sided (support on only one side of the mean of f_3). The empirical results could therefore be interpreted as measuring the degree to which the price spread distribution deviates from normality above and below its mean. Inasmuch as economic theory generally has little to say about the normality of such a distribution, this seems to be a rather fragile approach with which to analyze spatial price patterns.

An additional problem with the switching regime models concerns the assumption of no serial correlation in the forcing variables (shocks to excess demand and transport rates). These models also use the size of price spreads as an indicator of connectedness. It is possible, however, for locations to be connected by having common trading partners. Small price spreads between integrated locations can arise in this situation.

Recently, a different variation on the switching regime model has been applied to spatial price models. Obstfeld and Taylor (1997) use a Threshold Autoregressive (TAR) model in which a fixed but unknown transport cost is assumed to act as a threshold. When the price spread exceeds the threshold, it exhibits reversion towards the threshold. When the spread is within the transaction cost band, however, it is assumed to behave in a serially independent fashion. The model was applied to Indian wheat prices by Prakash (1996).

²⁷ A distinction between the approaches is that Spiller and Wood (1988) treat the λ_i as endogenous (functions of the ω_j), whereas Sexton, Kling and Carman (1991) treat them parametrically.

The TAR model provides both a probability of being outside the band (a measure of the degree to which the market violates the spatial arbitrage condition) as well as a measure of the speed with which it eliminates these violations (a kind of market efficiency measure). The model, however, is very highly parameterized and requires modification to capture a number of the regularities exhibited by commodity markets. In addition, these models are typically specified by assuming that transactions costs impose a fixed band on absolute or proportional price differences. This limitation occurs because of the general inability to actually measure transactions costs. In a recent exception, Goodwin and Grennes (1998) estimate a threshold autoregression model that has a variable threshold which is defined using actual transportation cost data. Their results confirm that support for integration is stronger when threshold effects are recognized.

4.4. Rational expectations models

Dynamic models of spatial market integration recognize the potential for significant lags in price relationships brought about by delivery lags and adjustment costs. These dynamic models have, for the most part, neglected to consider the role of expectations. Delivery lags necessarily raise the issue of price expectations since agents must formulate expectations about prices at the time of delivery. Delivery lags raise the issue of uncertainty and information-gathering costs, which may be a significant determinant of transactions costs. The presence of delivery lags and adjustment costs may also raise the possibility of noncontemporaneous price linkages. For example, consider a case of Florida celery growers selling in the eastern U.S. with a delivery lag of one week and in the western U.S. with a delivery lag of two weeks. Prices in eastern and western celery markets may be integrated through their common supply source; however, price shocks may take an additional period to be realized in western markets. Thus, linkages are not contemporaneous but may instead involve lags.

A simple model of regional arbitrage can be used to illustrate the potentially important role of price expectations and noncontemporaneous price linkages. The simple arbitrage condition discussed above presumed that markets are integrated by the profit-seeking actions of commodity traders and arbitrageurs. As has been emphasized, the spatial arbitrage problem is inherently dynamic because of delivery lags, adjustment costs, and other impediments to instantaneous commodity arbitrage and trade. Consider an arbitrageur at location 1 in possession of a single commodity. The agent has opportunities to sell, perhaps with some lag in delivery, in another location. We will assume that the agent has no storage opportunities.²⁸ The agent will act to maximize expected profits, where profits are given by

$$\pi(q_{1t}, q_{2t}) = p_{1t}q_{1t} + (\delta^j E_t[p_{2t+j}] - r_t)q_{2t} - C(q_{1t} + q_{2t}), \quad (55)$$

²⁸ Storage can be added to the model with no loss of generality. With storage, arbitrageurs may choose to hold a commodity in storage at some positive costs rather than shipping it to a consuming market. In such a case, additional arbitrage conditions exist among expected prices, storage costs, and transportation costs.

where q_i is the quantity sold in market i ($i = 1, 2$), p_{it+j} is the price received upon delivery in market i , $C(\cdot)$ is a commodity arbitrage cost function representing the costs of acquiring and marketing the commodity, δ is a constant, real discount factor, and r_t is the per-unit transactions costs involved in marketing the commodity in location 2. Delivery lags are reflected by the fact that payment is received upon delivery after j periods.

First-order conditions for profit maximization for all $s > t$ are given by

$$p_{1t} = \delta^j E_t[p_{2t+j}] - r_t = C'(q_{1t} + q_{2t}). \quad (56)$$

In making the transition to an empirical framework, one must consider the appropriate representation of price expectations, noncontemporaneous price linkages, and dynamic correlation structures that may result from forecasts that are made over many periods. Representation of price expectations may not be straightforward. Goodwin (1988) used observed futures and forward market price quotes as expected prices and found reasonably strong support for the law of one price. Goodwin, Grennes and Wohlgenant (1990a) utilized generalized method of moments estimators to explicitly model price expectations. In that their application considered markets that traded almost continuously, the concerns relating to price differences within transactions costs bands for markets in autarky are mitigated. They also used actual transportation costs to model transactions costs. Their results suggested that adherence to the arbitrage conditions underlying conventional versions of market integration is much more likely when ex-ante price expectations are explicitly considered than when ex-post price realizations are used in empirical tests.

As noted above, attention to delivery lags raises the possibility that price linkages will be of a noncontemporaneous nature. Goodwin, Grennes and Wohlgenant (1990b) utilized model specification tests to evaluate whether noncontemporaneous price linkages received stronger support than did conventional specifications assuming contemporaneous price relationships. For a variety of internationally traded grains and oilseeds, their results suggested that a two-month delivery lag was supported by the data. In a similar analysis, Sexton, Kling and Carman (1991) used specification tests in an evaluation of celery market integration using weekly prices to determine whether noncontemporaneous price linkages were supported over the more conventional contemporaneous relationships. Specification testing results implied that price linkages were contemporaneous for markets relatively close to one another but were more likely to involve lags for distant markets.

Finally, it can be noted that rational expectation models with delivery lags can lead to conventional vector autoregressive models in which lagged prices are used as instruments to identify price expectations, as in Goodwin, Grennes and Wohlgenant (1990a, 1990b). Consider a contemporaneous relationship for expected prices of the form which would result from an evaluation of two import markets, linked through a common export market with identical delivery lags:

$$E[p_{1t+j}] - E[p_{2t+j}] = \alpha_t, \quad (57)$$

where α_t represents the expected differential in transport rates. The relationship is contemporaneous by virtue of the identical j -step-ahead delivery lags. Instrumental variables estimation of these relationships typically involves representing the expectations by using projections from a first-stage regression against instrumental variables. When lagged prices are used in the first stage, this relationship can be rewritten as

$$\sum_{k=1}^m A_{1k} P_{1t-k} - \sum_{k=1}^m A_{2k} P_{2t-k} = \alpha_t. \quad (58)$$

5. Conclusions

The various empirical tests that we have reviewed each have their own limitations and none has emerged as being preferable in all cases or circumstances. As is true with most (if not all) empirical tests of economic phenomena, the potential exists for misleading test results and invalid conclusions. This is primarily due to the fact that empirical tests are almost always conditional on a number of augmenting hypotheses or simplifying assumptions which may or may not be explicitly stated.

Probably the most serious factor influencing the validity of empirical tests of integration involves transactions costs. Most tests of spatial integration do not explicitly consider transactions costs. This omission reflects the fact that direct observation of transactions costs is usually impossible; data on transportation charges are generally unavailable. Even in cases where freight charges can be directly observed or when reasonable proxy measures of transportation charges exist, transactions costs may involve many intangible elements that elude direct observation. Such intangibles include risk premia, information-gathering costs, negotiation costs, and the costs associated with maintaining a presence in a regional market. Many empirical tests simply abstract from considering the effects of transactions costs on spatial market linkages and proceed to test market conditions that would be expected if transactions costs were zero. Many others invoke simplifying assumptions about transactions costs. Common assumptions include representing transactions costs as a constant or a constant proportion of product prices or that transactions costs are serially uncorrelated. As we have established in preceding discussions, neglect of transactions costs can produce biases and misleading inferences in empirical tests.

Furthermore, prices in efficient and integrated spatial markets are endogenously and simultaneously determined. Although this should lead to testable restrictions on the behavior of prices, attempting to derive such restrictions from fully specified models of price determination demonstrates that this is not as simple as it might seem. Only one simple, highly stylized model, the point-location model, is capable of generating any of the tests of efficiency and integration that have been proposed in the literature. The simple point-location model leads to tests similar to those proposed by Ravallion and provides some justification for cointegration-based tests. It also can be

used to demonstrate weaknesses in Timmer's perfect market integration criteria, impulse analysis based on recursive identifications, and Granger causality tests of market efficiency.

Although the point-location model is useful in generating a base-case model, it is difficult to see how it can justify the commonly used dynamic regression framework when the market fails to be well integrated and efficient. Some markets do not transmit local shocks on a one-to-one basis. For example, markets in which transport links break down in some periods or marginal adjustments occur in the transport linkages may fail to transmit local shocks to other markets. In such cases, it is not clear that a linear dynamic regression specification is appropriate. Thus, the dynamic regression model nests the null hypothesis but not reasonable alternatives. This makes it difficult to interpret test rejections, even when the tests are well founded under the null hypothesis of well-integrated and efficient markets.

Fortunately, these conclusions provide a basis for further investigation. The approach taken with the simple point-location model could also be applied to the other models of price determination. This would help to identify what kinds of price behavior should be expected given a richer set of assumptions about the price determination process.

Due to the interpretive difficulties in studies based on price data alone, a natural proposal is to use more complete market data to address spatial market issues. Barrett (1996) has argued that transport rate and trade flow data may be needed before some controversies are resolved. The discussion contained herein supports this view.

It is clearly essential that the limitations associated with unobserved transactions costs be recognized when empirical tests of integration are considered. To put such limitations in proper perspective, however, the wider role of transactions costs in empirical evaluations of economic phenomena should also be considered. Transactions costs are not just relevant to considerations of regional trade and arbitrage: they are present in any and every exchange. Likewise, despite their universal presence in every aspect of the market, transactions costs are usually ignored in empirical work. Regression analysis is typically used to estimate parameters (usually based upon derivatives) such as price transmission elasticities that describe and characterize the economic system of interest. As we have pointed out, transactions costs may result in discontinuities that complicate such inferences. In this light, almost all inferences have the potential to be complicated by unmeasured or unmeasurable transactions costs.

One may be quick to assume that transactions costs are less relevant in some exchanges than in others. In particular, it is clearly the case that the transactions costs inherent in interregional trade activities are far more significant than those associated with the purchases of a representative consumer. While this is certainly true, the important point is not the absolute magnitude of transactions costs but rather their significance relative to changes in other variables in the model. For example, in a model of consumer demand, transactions costs are small but potentially significant relative to the variability of demand function, and therefore may inhibit accurate estimation of demand parameters.

The important point is that empirical tests, by their very nature, are sensitive to factors such as transactions costs and other unobserved variables that may influence the responses of agents and thus may bias empirical estimates. This point is not meant to condemn or call into question the utility of empirical analyses. Rather, the implication is that the weaknesses and limitations associated with empirical assessments of economic conditions should always be recognized and kept in mind when making use of empirical estimates.

A specific problem with interpreting rejections of so-called market integration tests is that the null hypothesis is that the markets are both efficient and perfectly integrated. Without explicit information about transactions costs, rejections of the tests could be caused by either inefficiencies or lack of perfect integration (including, in the extreme case, market isolation). Rejections of the tests are inherently incapable of determining which. Furthermore, if test rejections are caused by lack of perfect integration, the regression model is misspecified. It is not clear how lack of integration would affect parameter estimates in a dynamic regression model and therefore whether any conclusions can be drawn about why the market fails to be integrated. One focus of future research should be the examination of the behavior of markets subject to specific kinds of market imperfections.

Preceding discussions pointed out that, because of these types of limitations, empirical tests supporting integration could be consistent with a complete lack of integration, and tests rejecting integration could occur in markets that are completely linked. These indeterminate results follow from a number of weaknesses inherent in the empirical tests, including a lack of information about transactions costs, model misspecifications, and weaknesses in the inferential procedures.

What, then, is to be learned from empirical tests? The essential ingredient necessary to properly interpret the results of empirical evaluations of market conditions is knowledge of the institutions and conditions pertinent to the markets in question. For example, knowledge that a continuous flow of goods existed between two markets greatly enhances the interpretation of tests of integration based upon prices alone. Likewise, one is often sure of a direction of commodity flow (i.e., from exporting to importing regions). Such knowledge is useful in interpreting the results of tests necessarily dependent upon strong simplifying assumptions. Recognition of patterns of seasonality or movements in aggregate prices may also enhance the interpretation of empirical tests of market integration.

Empirical tests of integration that are consistent with opposing views of market linkages may nevertheless be useful in terms of allowing one to rule out other conditions that do not support integration of markets. For example, tests which indicate a close correspondence of price changes in regional markets may be sensitive to spurious relationships inherent in cases where aggregate influences are affecting prices in all markets. However, such tests do allow one to rule out market conditions which would imply a divergence of prices over a long run. In this manner, empirical tests should be considered as diagnostic instruments in the empirical tool-kit used to assess market conditions. Diagnostic tests may not allow one to reach a definite conclusion regarding one aspect

of market relationships, but may allow other conditions to be ruled out.²⁹ In this way, the tests may provide useful inferences in spite of their significant limitations.

Having noted such points, the key question remains: What can be learned about spatial market behavior from empirical tests based upon prices alone? These tests clearly provide information about spatial relationships among prices. However, the tests should be interpreted within the context of institutional and factual characteristics of the markets in question as well as the shortcomings associated with each test. The significant limitations associated with individual tests suggest that inferences should not be based upon a single test but rather, when possible, on a variety of inferential techniques.

An approach to evaluating spatial market integration on the basis of price data alone might include an examination of correlation coefficients and simple bivariate regression models as initial descriptive devices. Of course, the factors likely to cause misleading spurious correlation should also be given careful consideration. One might then examine the time series properties of the price data, including an evaluation of the stationarity of the price data. Inferential techniques such as Granger causality, dynamic multipliers, cointegration tests, and impulse responses might then be considered to further describe the nature of price relationships. As we have noted above, techniques such as Granger causality and cointegration tests might be of limited usefulness in terms of actually testing spatial market integration. Such tests may, however, be essential for suggesting the appropriate specification for use in further evaluation of price linkages. For example, Granger causality results may be useful in suggesting identifying restrictions for use in generating impulse responses. Likewise, cointegration test results are essential for determining the appropriate specification of vector autoregressive models.

In general, then, it is incumbent upon the analyst to be aware of the significant limitations associated with empirical tests of market integration and to temper inferences accordingly. A universal truth essential to interpreting empirical research is that knowledge of the institutions and facts regarding market conditions is essential. Empirical results must be interpreted within the institutional context and framework underlying the economic system being considered. Misleading inferences are always a hazard, and careful attention to such institutional details will minimize the potential for making them.

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²⁹ The analog to diagnostic medical tests is clear. Medical diagnoses often proceed by ruling out certain conditions rather than unambiguously proceeding straight to a test for a particular condition.

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DUALITY FOR THE HOUSEHOLD: THEORY AND APPLICATIONS

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Abstract

This chapter presents the theory of consumer choice as applied to household behavior. An internally consistent, self-contained framework is developed for the analysis of consumer preferences, household production, quality attributes, and produced nonmarket commodities in static and dynamic environments. Consumer expectations and naive and rational habit formation are considered in detail. The emphasis is on developing an internally consistent duality for consumer choice theory in each of these contexts. The chapter develops a general, logically consistent modeling framework for the applied economic analysis of consumption choices by the household.

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0. Introduction

Many questions confront every economist who analyzes consumer behavior, including the theoretical structure and the econometric methodology at a basic level. A comprehensive discussion of neoclassical consumer choice is contained in [Barten and Böhm (1982)]. Deaton (1986) addresses econometric issues for analyzing the relatively naive, neoclassical demand model. Nadiri (1982) presents a comprehensive survey of neoclassical production theory. Jorgenson (1986) addresses the econometric modeling for producer behavior. These form an essential background for the material that appears in this chapter, and are highly recommended to all readers of this chapter. I hope to build upon, rather than repeat or translate, all of these works, and others, in this chapter.

The purpose of this chapter is to present a clear statement of the current status of the theory of consumer choice as applied to household behavior. The focus is on developing an internally consistent, self-contained framework for the theoretical and empirical analysis of consumer preferences, household production activities, quality attributes, produced nonmarket commodities, and both static and dynamic environments for consumer demand analysis. Outlines of the underlying individual components essential for this framework are presented first. Then a synthesized model of consumer choice in a static environment is developed to the level and extent possible given the current state of knowledge in this field. This static framework is extended to consumer choice problems in an intertemporal environment. Within the dynamic context, consumer's expectations for future prices, incomes, asset returns, durable goods in household consumption, and naive and rational habit formation become essential to the analysis at each stage of the discussion.

The chapter is organized in the following way. Section 1 outlines the main concepts and results of the neoclassical theory of consumer choice that forms the underlying framework, or skeleton, for the generalizations of the subsequent sections. Section 2 develops the theory of household production and connects this modeling framework to the neoclassical model, illustrating important special cases, including hedonic price functions, Becker's model of household production, Gorman's and Lancaster's characteristics model of quality, and the Fisher–Shell repackaging model. Section 3 discusses dynamic versions of neoclassical consumer choice theory, with an emphasis on the ways that consumers form expectations about their future economic environment. This section analyzes models of myopic, adaptive, quasi-rational, and rational expectations, as well as perfect foresight. Section 4 presents the economic theory of intertemporal choice in a household production framework with durable stocks. In empirical applications, durable goods can be interpreted variously as stocks of unobservable consumption habits, holdings of durable goods such as housing, automobiles, and/or household appliances, or the current state of knowledge of the time path of the quality attributes of consumer goods. When consumption habits are part of the empirical model, naive versus rational habit formation becomes a relevant topic of analysis. The final section summarizes the main results and briefly discusses some potential avenues for future theoretical and empirical research in this area.

The emphasis throughout the chapter is on the development and analysis of an internally consistent and valid duality for each version of consumer choice theory. The goal is to develop and motivate a general, logically consistent modeling framework that provides applied economic and econometric analysts with a deeper understanding of the relationships among primary concepts of interest – *consumers' utility and ordinary market demand functions* – and what can be reasonably described as secondary functions – *indirect utility, expenditure, and compensated demand functions* – in each of their numerous forms and applications.

1. Neoclassical demand theory

Neoclassical consumer choice theory begins with the set of bundles of consumer goods that can be selected by a consuming household, X , a subset of a separable topological space. In this and the next section, we take X to be a subset of a finite dimensional Euclidean space. However, later in the chapter, X is best described in terms of (Lebesgue) measurable functions from the interval $[0, T]$ onto a finite dimensional Euclidean space.

Associated with the set X is a binary preference relation, $\succsim$. The notation “ $x \succsim y$ ” means the consumption bundle x is at least as preferred as y . The relation $\succsim$ is endowed with properties that ensure that consumer choices are logically consistent. The following is a standard representation:

- (i) *reflexivity*; $\forall x \in X, x \succsim x$;
- (ii) *transitivity*; $\forall x, y, z \in X, x \succsim y \text{ and } y \succsim z \Rightarrow x \succsim z$;
- (iii) *completeness*; $\forall x, y \in X, \text{ either } x \succsim y \text{ or } y \succsim x$;
- (iv) *closure*; $\forall x \in X, \text{ the sets } \{x^1 \in X: x^1 \succsim x\} \text{ and } \{x^1 \in X: x \succsim x^1\} \text{ are closed.}$

These properties imply that $\succsim$ is a complete ordering on X and that there exists a continuous utility function, $u: X \rightarrow \mathbb{R}$, such that $\forall x, x^1 \in X, u(x) \geq u(x^1)$ if and only if $x \succsim x^1$ [Bowen (1968); Debreu (1954, 1959, 1964); Eilenberg (1941); Rader (1963)]. Letting $\succ$ denote the binary relation “strictly preferred to”, so that $x \succ y$ means $x \succsim y$ and not $y \succsim x$, the following assumptions usually are added to (i)–(iv):

- (v) *nonsatiation*; $\nexists x \in X \ni x \succ x^1 \forall x^1 \in X$;
- (vi) *strict convexity*; $x \succsim x^1 \text{ and } t \in (0, 1) \Rightarrow (tx + (1-t)x^1) \succ x^1$;
- (vii) *survival*; $\inf\{p'x: x \in X\} < m$; and
- (viii) X is convex and bounded from below by $\mathbf{0}$, i.e., $x \in X \Rightarrow x_i \geq 0 \forall i$.

In addition to continuity, properties (i)–(viii) imply that the utility function is strictly quasiconcave [Arrow and Enthoven (1961)].

The consumer's decision problem is to choose a bundle of market goods from the set X that is maximal for $\succsim$, given market prices, $p \in \mathbb{R}_+^n$, and income, $m \in \mathbb{R}_+$. Given properties (i)–(viii), this can be represented as $\sup\{u(x): x \in X, p'x \leq m\}$.¹ Under

¹ The notation “sup” denotes the supremum, or least upper bound, of the objective function on the associated

these conditions, the utility-maximizing demand set is nonempty and a singleton and the budget constraint is satisfied with equality at the optimal choice for the consumption bundle. The utility-maximizing quantities demanded, $x = h(p, m)$, are known as the *Marshallian ordinary demand functions*. Marshallian demands are positive-valued and have the following properties:

- (M.1) 0° homogeneity in (p, m) ; $h(p, m) \equiv h(tp, tm) \forall t \geq 0$;
- (M.2) adding up; $p'h(p, m) \equiv m$; and
- (M.3) symmetry and negativity; the matrix of substitution effects,

$$S \equiv \left[\frac{\partial h(p, m)}{\partial p'} + \frac{\partial h(p, m)}{\partial m} h(p, m)' \right],$$

is symmetric and negative semidefinite, provided that S exists and is continuous.

The maximum level of utility given prices p and income m , $v(p, m) \equiv u[h(p, m)]$, is the *indirect utility function*. Under (i)–(viii), the indirect utility function has the following properties:

- (V.1) continuous and quasiconvex in (p, m) ;
- (V.2) decreasing and strictly quasiconvex in p ;
- (V.3) increasing in m ;
- (V.4) 0° homogeneous in (p, m) ;
- (V.5) Roy's identity,

$$h(p, m) \equiv - \left(\frac{\partial v(p, m) / \partial p}{\partial v(p, m) / \partial m} \right),$$

provided the right-hand side is well-defined.

The problem of maximizing utility subject to a budget constraint is associated with the converse problem of minimizing the total expenditure that is necessary to obtain a fixed level of utility, u , given market prices p , $\inf\{p'x : x \in X, u(x) \geq u\}$. The expenditure-minimizing demands, $g(p, u)$, are known as the *Hicksian compensated demand functions*. Hicksian demands are positive valued and have the following properties:

- (H.1) 0° homogeneous in p ;
- (H.2) the Slutsky equations;

$$\left[\frac{\partial g(p, u)}{\partial p'} \right] \equiv \left[\frac{\partial h(p, e(p, u))}{\partial p'} + \frac{\partial h(p, e(p, u))}{\partial m} h(p, e(p, u))' \right]$$

set. Since the utility function is continuous, if the set X is closed and bounded from below and $p \gg 0$, then we can replace “sup” with “max”. Similarly, the notation “inf” denotes the infimum, or greatest lower bound, of the objective function on the choice set. If the choice set is compact (closed and bounded) and the objective function is continuous, then we can replace “inf” with “min”.

is symmetric and negative semidefinite, provided the derivatives exist and are continuous.

The expenditure function, $e(p, u) \equiv p'g(p, u)$, has the following properties:

- (E.1) continuous in (p, u) ;
- (E.2) increasing, 1° homogeneous, and concave in p ;
- (E.3) increasing in u ; and
- (E.4) Shephard's Lemma,

$$g(p, u) \equiv \frac{\partial e(p, u)}{\partial p},$$

provided the derivatives on the right exist.

A large body of theoretical and empirical literature exists for the neoclassical model of consumer choice. Much of this literature is based on the observation that $e(p, u)$ and $v(p, m)$ are inverse functions with respect to their $(n + 1)$ st arguments, yielding, *inter alia*, the following set of identities:

$$e[p, v(p, m)] \equiv m; \quad (1.1)$$

$$v[p, e(p, u)] \equiv u; \quad (1.2)$$

$$g(p, u) \equiv h[p, e(p, u)]; \quad \text{and} \quad (1.3)$$

$$h(p, m) \equiv g[p, v(p, m)]. \quad (1.4)$$

However, the neoclassical model has few empirical implications, embodied in the sign and symmetry of the substitution effects due to changes in the market prices of the goods x , and leaves all variances in consumption behavior not explained by prices and income to differences in tastes and preferences. The neoclassical model also is entirely static. Finally, the neoclassical model does not readily accommodate technological change, the introduction of new goods in the market, or changes in the quality or characteristics of the goods that are available.

These considerations led to extensions of the neoclassical model of consumer choice. Among these extensions, the most widely employed is the theory of household production. The seminal references are Becker (1965), Gorman (1980), and Lancaster (1966, 1971). Household production theory integrates the neoclassical theory of the consumer with that of the firm. The theory of the firm relates to that part of household decision making that is concerned with the efficient use of market goods, household time, and capital as inputs in the production of utility-yielding non-market commodities. The model posits that market goods and household time are combined via production processes analogous to the production functions of the theory of the firm to produce various commodities from which utility is obtained directly. Household production theory advances the neoclassical model by admitting analyses of issues like the number of family members in the work force, time as a constraining factor in consumption choices, quality changes among goods, durable goods in consumption, and consumer responses to the introduction of new goods.

2. The theory of household production

In this section, we present a model of consumer choice that is sufficiently general and rich to account for many of the concerns summarized above. We first need some preliminary definitions and notation. Let $x \in \mathbb{R}_+^n$ denote market goods and time used by the household, let $b \in \mathbb{R}^s$ be a vector of parameters associated with the market goods, objectively measured and quantifiable by all economic agents, and let $z \in \mathbb{R}^m$ be a vector of utility-bearing commodities or service flows desired by the household and produced from x . We assume that there is a joint production relationship for each household relating x to z , and this relationship depends explicitly on the parameters, b . For given b , let $T(b) \subset \mathbb{R}^{m+n}$ denote the household's joint production possibilities set and let $y = [x' z']' \in T(b)$ denote a feasible vector of goods and commodities. For each possible b , the properties of $T(b)$ associated with a well-defined joint production function are [Rockafellar (1970); Jorgenson and Lau (1974)]:

- (i) *origin*; $\mathbf{0} \in T(b)$;
 - (ii) *bounded*; $\forall i, y \in T(b)$ and $|y_j| < \infty \forall j \neq i \Rightarrow |y_i| < \infty$;
 - (iii) *closure*; $y^n \in T(b) \forall n$ and $y^n \rightarrow y \Rightarrow y \in T(b)$;
 - (iv) *convexity*; $y, y^1 \in T(b)$ and $t \in [0, 1] \Rightarrow ty + (1-t)y^1 \in T(b)$;
 - (v) *monotonicity*; $\exists i \ni y \in T(b)$, $y'_j = y_j \forall j \neq i$, and $y'_i \leq y_i \Rightarrow y' \in T(b)$.
- Given (i)–(v), we define the production function by

$$-F(y_{\sim i}, b) = \sup\{y_i: y \in T(b)\}, \quad (2.1)$$

where $y_{\sim i}$ is the subvector of elements excluding the i th with i chosen to satisfy (v). Then $\forall y \in T(b)$, we have $y_i + F(y_{\sim i}, b) \leq 0$. For a given value of b , the function $F(\cdot, b)$ is closed (lower semicontinuous), proper ($F(y_{\sim i}, b) < +\infty$ for at least one $y_{\sim i}$ and $F(y_{\sim i}, b) > -\infty \forall y_{\sim i}$), and convex. Monotonicity in at least one element of y (i.e., free disposal of y_i) is equivalent to applicability of the implicit function theorem to the transformation $G(y, b) = 0$, which defines the boundary of $T(b)$, to obtain the form (2.1). Free disposal of all elements of y implies monotonicity of $G(\cdot, b)$ in y .

Defining the *epigraph* of $F(\cdot, b)$ to be the set

$$T^*(b) = \{y \in \mathbb{R}^{m+n}: -y_i \geq F(y_{\sim i}, b)\}, \quad (2.2)$$

it follows immediately from the definition of $F(\cdot, b)$ that $T^*(b) \equiv T(b)$. Therefore, since a convex function is defined by its epigraph – equivalently, a closed convex function is the pointwise supremum of all affine functions that are majorized by it [Rockafellar (1970), Theorem 12.1], while a closed convex set is the intersection of all of the closed half spaces defined by its supporting hyperplanes – the properties of $F(\cdot, b)$ imply the properties of $T(b)$, and conversely.

Hence, let the goods/commodities/qualities efficient transformation frontier be defined by the implicit function $G(x, z, b) = 0$. We interpret $G(\cdot)$ to be a joint household production function with inputs x , outputs z , and parameters b . $G(\cdot, b)$ is convex in

(x, z) , increasing in z , decreasing in x , and without loss in generality, strictly increasing in z_1 . For given b , the feasible goods/commodities production possibilities set is defined in terms of $G(\cdot, b)$ by

$$T(b) = \{(x, z) \in \mathbb{R}^n \times \mathbb{R}^m: G(x, z, b) \leq 0\}. \quad (2.3)$$

For fixed b , $T(b)$ is non-empty, closed, and convex; $G(\mathbf{0}, \mathbf{0}, b) = 0$; and $G(x, z, b) = 0$ and $z \gg \mathbf{0}$ imply that $x \geq \mathbf{0}$, where $x \geq \mathbf{0}$ means $x_j \geq 0 \forall j$ and $x \neq \mathbf{0}$.

We assume that the correspondence $T(b)$ is continuous over the set of parameter vectors, $B \subset \mathbb{R}^s$, and that boundedness and closure of $T(b)$ hold throughout B . These conditions ensure that $G(x, z, \cdot)$ is continuous in $b \in B$, which can be demonstrated in the following way. Define $F(x, z, b)$ by

$$-F(x, z, b) = \sup\{z_1: (x, z) \in T(b)\}. \quad (2.4)$$

Let

$$G(x, z, b) = z_1 + F(x, z, b).$$

If $(x^n, z^n) \in T(b^n) \forall n$ and $(x^n, z^n, b^n) \rightarrow (x, z, b)$, then $(x, z) \in T(b)$ by the continuity of $T(\cdot)$ in b . Uniqueness of the supremum implies $z_1 \leq -F(x, z, b)$. On the other hand, $z_1^n = -F(x^n, z^n, b^n) \forall n$ implies that $z_1 \geq -F(x, z, b)$. Continuity of $G(x, z, \cdot)$ follows immediately. This means simply that the boundary of the feasible set $T(b)$ is connected and contained in $T(b)$, and that small changes in b do not induce large changes in the boundary of $T(b)$. Therefore the greatest possible output of z_1 does not change much either.

The above conditions on the set $T(b)$ are standard in the general theory of the firm and do not exclude cases where the commodity vector z includes some or all of the market goods. For example, if $m = n$ and $z_i \equiv x_i \forall i$, then the model reduces to the neoclassical framework where market goods are the desired commodities from which utility is derived directly. More generally, for any pair i and j such that $z_i \equiv x_j$, we can incorporate the function $z_i - x_j$ into the definition of the transformation function $G(\cdot)$.

An important aspect of the manner in which we have set up this model is the way in which time allocation tacitly enters the decision problem. If t_0 is the vector of labor times supplied to the market and w the vector of market wage rates received for this labor, then the budget constraint has the form $p'_x x_{\sim t} \leq y + w't_0$, where y is non-labor income. Let t denote the vector of household time used in the production of nonmarket commodities. Then $x = [x'_{\sim t}, t']'$ and the household's joint production function tacitly depends upon t . Finally, if T is the vector of time endowments, then $T - t - t_0$ is a vector of leisure times and is tacitly included as part of the vector z . The vector of time constraints takes the form $t + t_0 = T$ [Becker (1965); Deaton and Muellbauer (1980); Pollak and Wachter (1975)]. Substituting $t_0 = T - t$ into the budget constraint gives $p'_x x_{\sim t} \leq w'(T - t)$, or equivalently, $p'_x x_{\sim t} + w't \leq y + w'T \equiv m$, where m is the household's full income [Becker (1965)].

2.1. Static consumer choice theory with household production

In addition to the joint transformation function relating goods, commodities, and qualities, we assume that there exists a continuous, quasiconcave utility function defined over the space of commodities, $u(z)$, such that $u(z) \geq u(z^1)$ if and only if $z \succsim z^1$, where $\succsim$ is the binary preference relation defined over commodities. The consumer's decision problem is taken to be to seek a combination of market goods and household time, x , that will produce the vector of commodities, z , that maximizes utility, $u(z)$, subject to a budget constraint, $p'x \leq m$. Here p is an n -vector of market prices, defined by $p = (p'_{x-i}, w')'$, and $m = y + w'T$ is the household's full income. In addition to the standard budget constraint, the choice problem is subject to the constraint that the vector of commodities produced from the market goods and household time is feasible, $G(x, z, b) \leq 0$. This problem is related to the neoclassical consumer choice problem by the following theorem, which permits the translation of the utility function defined over produced nonmarket commodities to an induced utility function defined over market goods and time.

THEOREM 1. *For each $(x, z) \in T(b)^\circ$, the interior of $T(b)$, suppose that the set of feasible commodity bundles, $W(x, b) = \{z \in \mathbb{R}^m: G(x, z, b) \leq 0\}$, has a non-empty interior. Then the induced utility function on the space of market goods, $u^*: \mathbb{R}^n \times \mathbb{R}^s \rightarrow \mathbb{R}$, defined by*

$$u^*(x, b) \equiv \sup\{u(z): z \in W(x, b)\},$$

is strictly quasiconcave in x .

PROOF. Fix two feasible goods vectors, x and x^1 , such that $u^*(x, b) = k$ and $u^*(x^1, b) \geq k$ for some real number k . Define $x^2 = tx + (1-t)x^1$ for some $t \in (0, 1)$. Pick vectors z, z^1 and z^2 to satisfy $G(z, x, b) \leq 0$, $G(z^1, x^1, b) \leq 0$, $G(z^2, x^2, b) \leq 0$, $u(z) = u^*(x, b)$, $u(z^1) = u^*(x^1, b)$, and $u(z^2) = u^*(x^2, b)$. The strict convexity of $G(\cdot, b)$ implies that $G[tz + (1-t)z^1, x^1, b] < 0$; hence $tz + (1-t)z^1$ is a feasible commodity bundle. On the other hand, strict quasiconcavity of $u(\cdot)$ implies that $u[tz + (1-t)z^1] > u(z)$. Consequently, $u^*(x^2, b) = u(z^2) \geq u[tz + (1-t)z^1] > u(z) = k$. $\square$

This result permits the household production model to be translated into the standard neoclassical model of consumer choice. The consumer choice problem of maximizing $u(z)$ subject to the constraints $p'x \leq m$ and $G(x, z, b) \leq 0$ thus can be represented in terms of the simpler problem of choosing x to maximize $u^*(x, b)$ subject to $p'x \leq m$. Quasiconcavity of $u^*(\cdot, b)$ implies that the resulting demands for the goods x have the standard properties of neoclassical demand functions. However, these demands also relay information regarding both preferences and consumption technology [Pollak and Wachter (1975); Barnett (1977)].

Under some general regularity conditions on u and G , the following theorem describes the basic properties of the function $u^*(x, b)$ and the nature of the dual information on preferences and household consumption technology relayed by it. With little loss in generality, we restrict our attention to the case of strictly positive commodity consumption bundles.

THEOREM 2. *Suppose that $u(\cdot)$ is strictly quasiconcave and continuously differentiable, $G(\cdot)$ is strictly convex in z and continuously differentiable in (x, z, b) , $W(x, b)$ has a non-empty interior, $u(\cdot)$ is nonsatiated on $T(b)$, and the optimal commodity vector satisfies $z(x, b) \gg \mathbf{0}$. Then $u^*(\cdot)$ has the following properties:*

$$u^*(\cdot, b) \text{ is increasing in } x; \quad (2.a)$$

$$u^*(\cdot) \text{ is continuously differentiable in } (x, b); \quad (2.b)$$

$$\partial u^*/\partial x = -(\partial u/\partial z_1) \cdot (\partial G/\partial x)/(\partial G/\partial z_1); \quad (2.c)$$

$$\partial u^*/\partial b = -(\partial u/\partial z_1) \cdot (\partial G/\partial b)(\partial G/\partial z_1); \quad (2.d)$$

$$\text{sgn}(\partial u^*/\partial b_k) = -\text{sgn}(\partial G/\partial b_k) \forall k; \quad (2.e)$$

$$\text{The preference map defined by } u^*(\cdot) \text{ is invariant to increasing transformations of } u(\cdot) \text{ and } G(\cdot). \quad (2.f)$$

PROOF. Let the Lagrangean for the constrained maximization problem be

$$L = u(z) - \mu G(x, z, b),$$

where $\mu \geq 0$ is a Lagrange multiplier. Strict quasiconcavity of $u(\cdot)$ and strict convexity of $G(\cdot)$ in z imply that the necessary and sufficient conditions for a constrained maximum, with $z \gg \mathbf{0}$, are

$$\partial L/\partial z = \partial u/\partial z - \mu \partial G/\partial z = \mathbf{0},$$

$$\partial L/\partial \mu = -G(x, z, b) = 0,$$

where the second condition follows from nonsatiation of u throughout $T(b)$.

Substituting the solution functions, $z(x, b)$, into the first-order conditions generates identities in a neighborhood of the point (x, b) . Define the indirect objective function by $u^*(x, b) \equiv u[z(x, b)]$ and the constraint identity by $G[x, z(x, b), b] \equiv 0$. Substituting these and the optimal solution function for the Lagrange multiplier, $\mu(x, b)$, into the Lagrangean gives $u^*(x, b) \equiv L(x, b)$. Differentiating with respect to x then gives

$$\partial u^*/\partial x = (\partial u/\partial z - \mu \partial G/\partial z) \partial z/\partial x - (\partial \mu/\partial x) G - \mu (\partial G/\partial x).$$

The first two terms on the right-hand side vanish and the Lagrange multiplier can be written as

$$\mu = (\partial u/\partial z_1)/(\partial G/\partial z_1) > 0.$$

Combining the right-hand side expressions gives,

$$\partial u^*/\partial x = -(\partial u/\partial z_1) \cdot (\partial G/\partial x)/(\partial G/\partial z_1).$$

A completely analogous argument applies to $\partial u^*/\partial b$, verifying (2.a)–(2.e).

To demonstrate (2.f), let $w: \mathbb{R} \rightarrow \mathbb{R}$ and $v: \mathbb{R} \rightarrow \mathbb{R}$ be arbitrary strictly increasing, continuously differentiable functions. Define the set

$$W^*(x, b) \equiv \{z \in \mathbb{R}^m: v[G(x, z, b)] \leq v(0)\}.$$

Then $W^*(x, b) \equiv W(x, b)$; that is, $z \in W(x, b)$ if and only if $z \in W^*(x, b)$ and $u(z)$ achieves a maximum in $W^*(x, b)$ at the same point as it does in $W(x, b)$. Similarly, $w[u(z)]$ achieves a maximum on either $W(x, b)$ or $W^*(x, b)$ if and only if $u(z)$ does. Finally, let

$$L^* = w[u(z)] + \mu^* \{v(0) - v[G(x, z, b)]\}.$$

The first-order conditions for a constrained maximum at an interior point now are

$$\begin{aligned} \partial L^*/\partial z &= w' \partial u/\partial z - \mu^* v' \partial G/\partial z = 0, \\ \partial L^*/\partial \mu^* &= v(0) - v[G(x, z, b)] = 0. \end{aligned}$$

Since $v^{-1}[v(0)] = 0$, the latter is equivalent to $G(x, z, b) = 0$. The former can be written as

$$(w' \partial u/\partial z_i)/(w' \partial u/\partial z_1) = (\mu^* v' \partial G/\partial z_i)/(\mu^* v' \partial G/\partial z_1) \quad \forall i,$$

which after canceling (w'/w') and $(\mu^* v'/\mu^* v')$ is equivalent to the conditions implied by

$$\partial u/\partial z - \mu \partial G/\partial z = 0. \quad \square$$

Several additional properties of the consumer choice model that uses $u^*(x, b)$ as its starting point can be derived from the duality theory of the neoclassical model. Consider the problem,

$$v^*(p, m, b) \equiv \sup \{u^*(x, b): p'x \leq m, x \in \mathbb{R}_+^n\}. \quad (2.1.1)$$

This generates a vector of ordinary market demands, $x^* = h^*(p, m, b)$, a Lagrange multiplier, $\lambda^*(p, m, b)$, and an indirect utility function, $v^*(p, m, b) \equiv u^*[h^*(p, m, b), b]$. Then consider an artificial two-stage formulation of the problem,

$$\begin{aligned} v(p, m, b) &\equiv \sup \{u(z): p'x \leq m, G(x, z, b) \leq 0\} \\ &\equiv \sup \{\sup \{u(z): G(x, z, b) \leq 0\}: p'x \leq m\}. \end{aligned} \quad (2.1.2)$$

This yields a vector of ordinary market demands, $x = h(p, m, b)$, a vector of nonmarket commodity demands, $z = f(p, m, b)$, a Lagrange multiplier, $\lambda(p, m, b)$, and an indirect utility function, $v(p, m, b) \equiv u[f(p, m, b)]$. By the uniqueness of the supremum, we have

$$v(p, m, b) \equiv v^*(p, m, b). \quad (2.1.3)$$

This simple observation leads directly to the following result, which for brevity is stated in terms of $v(\cdot)$.

THEOREM 3. *Under the conditions of Theorem 2, $v(p, m, b)$ is continuously differentiable, homogeneous of degree zero in (p, m) , increasing in m , quasiconvex and decreasing in p , and*

$$\partial v / \partial m = \lambda(p, m, b); \quad (3.a)$$

$$h(p, m, b) \equiv -(\partial v / \partial p)(\partial v / \partial m) \text{ so long as the right-hand side is well-defined}; \quad (3.b)$$

$$\partial v / \partial b \equiv -\lambda \partial G / \partial b \equiv \partial u^* / \partial b; \quad (3.c)$$

$$G[h(p, m, b), f(p, m, b), b] \equiv 0; \quad \text{and} \quad (3.d)$$

$$p'h(p, m, b) \equiv m. \quad (3.e)$$

PROOF. Continuous differentiability of $v(\cdot)$ follows from the continuous differentiability of $u(\cdot)$ and $G(\cdot)$, strict quasiconcavity of $u(\cdot)$, and strict convexity of $G(\cdot, b)$. Zero degree homogeneity follows from the fact that the budget set does not change if we multiply both sides by a positive constant, $p'x \leq m$ if and only if $tp'x \leq tm \forall t > 0$. For monotonicity, if $p \geq p^\circ$, then $B = \{x: p'x \leq m\} \subset B^\circ = \{x: (p^\circ)'x \leq m\}$, and the maximum of $u^*(x, b)$ over B° can be no less than the maximum over B . Hence $v(\cdot, m, b)$ is decreasing in p . The proof of monotonicity in m is of the same nature.

For quasiconvexity in p , fix p and p^1 such that $v(p, m, b) \leq k$ and $v(p^1, m, b) \leq k$ for some real number k . Define $p^2 = tp + (1 - t)p^1$ for $t \in [0, 1]$. If $tp'x + (1 - t)(p^1)'x \leq m$ then $p'x \leq m$, $(p^1)'x \leq m$, or both. Otherwise, $p'x > m \Rightarrow tp'x > tm$ and $(p^1)'x > m \Rightarrow (1 - t)(p^1)'x > (1 - t)m$. Summing the last inequalities in each case implies $tp'x + (1 - t)(p^1)'x > m$, which is a contradiction. Therefore,

$$v(p^2, m, b) = \sup\{u^*(x, b): (p^2)'x \leq m\} \leq \max\{v(p, m, b), v(p^1, m, b)\} \leq k.$$

Properties (3.a)–(3.c) are the result of the envelope theorem, (3.d) and (3.e) follow from the nonsatiation of $u(\cdot)$. $\square$

This theorem simply states that there will be one and only one maximum level of utility, and the associated choice functions are invariant to the manner in which we choose to view the consumer choice problem, provided of course that the problem is

well-behaved. In addition, it shows how the joint preference and household production technology information contained in $u^*(\cdot)$ is transmitted to the indirect utility function $v(\cdot)$ and hence the demand functions $h(\cdot)$.

Analogous to the neoclassical consumer choice model, the converse to the utility maximization problem is the expenditure minimization problem,

$$e(p, u, b) \equiv \inf\{p'x: u^*(x, b) \geq u, x \in \mathbb{R}_+^n\}. \quad (2.1.4)$$

This generates a vector of Hicksian compensated demands, $x = g(p, u, b)$, a Lagrange multiplier, $\mu(p, u, b)$, and an expenditure function, $e(p, u, b) \equiv p'g(p, u, b)$. Our next result relates the indirect utility function to the expenditure function.

THEOREM 4. *Under the conditions of Theorem 2, the expenditure function is increasing, 1° homogeneous, and concave in p ; increasing in u ; continuously differentiable in (p, u, b) ; and,*

$$\partial e(p, u, b)/\partial p \equiv g(p, u, b); \quad (4.a)$$

$$\partial e(p, u, b)/\partial u \equiv \mu(p, u, b); \quad (4.b)$$

$$\partial e(p, u, b)/\partial b \equiv -\mu(p, u, b) \cdot \partial u^*(g(p, u, b), b)/\partial b; \quad (4.c)$$

$$e[p, v(p, m, b), b] \equiv m; \quad (4.d)$$

$$v[p, e(p, u, b), b] \equiv u; \quad (4.e)$$

$$g[p, v(p, m, b), b] \equiv h(p, m, b); \quad (4.f)$$

$$h[p, e(p, u, b), b] \equiv g(p, u, b); \quad (4.g)$$

$$\mu(p, u, b) \equiv \lambda[p, e(p, u, b), b]^{-1}; \quad (4.h)$$

$$\lambda(p, m, b) \equiv \mu[p, v(p, m, b), b]^{-1}. \quad (4.i)$$

PROOF. With the exception of (4.c), these are all straightforward duality results proved in the same manner as in the neoclassical utility theory model. Property (4.c) follows from the envelope theorem. $\square$

Thus, the static consumer choice model with household production inherits all of the properties of the indirect utility function and expenditure function from the neoclassical model. The relationship between the Marshallian ordinary demands and Hicksian compensated demands with respect to the parameters b is summarized in the next theorem.

THEOREM 5. *The Marshallian demand functions are positive-valued, continuous and 0° homogeneous in (p, m) , and so long as the associated derivatives exist and are continuous,*

$$\frac{\partial g(p, u, b)}{\partial b'} \equiv \frac{\partial h(p, e(p, u, b), b)}{\partial b'} + \frac{\partial h(p, e(p, u, b), b)}{\partial m} \cdot \frac{\partial e(p, u, b)}{\partial b'}, \quad (5.a)$$

and

$$p' \partial h(p, m, b) / \partial b' \equiv 0'. \quad (5.b)$$

PROOF. These results follow directly from differentiating (4.g) and (3.e) with respect to b . $\square$

2.2. Hedonic price functions

An alternative approach to the consumer choice problem with a household production function as an added constraint is obtained by focusing on the cost of obtaining a given vector of commodities from market goods and household time given market prices. This perspective is called the method of *hedonic price functions* [Lucas (1975); Muellbauer (1974); Rosen (1974)]. To develop this approach in the current framework, we require a version of the Shephard–Uzawa–McFadden duality theorem for cost functions.

THEOREM 6. *For a feasible commodity vector z , the cost function,*

$$c(p, z, b) \equiv \inf \{ p'x : G(x, z, b) \leq 0, x \in \mathbb{R}_+^n \},$$

is continuous in (p, z, b) , 1° homogeneous, increasing and concave in p , increasing and convex in z . When the inputs requirements set

$$X(z, b) = \{ x \in \mathbb{R}_+^n : G(x, z, b) \leq 0 \}$$

is strictly convex and $\partial c(p, z, b) / \partial p$ exists, $c(p, z, b)$ obeys Shephard's Lemma [Shephard (1953)],

$$G[\partial c(p, z, b) / \partial p, z, b] \equiv 0.$$

When G is differentiable in z the ratio of marginal costs of two commodities is equal to the marginal rate of transformation between them,

$$(\partial c / \partial z_i) / (\partial c / \partial z_{i'}) = (\partial G / \partial z_i) / (\partial G / \partial z_{i'}) \quad \forall i, i'.$$

PROOF. Convexity of $T(b)$ implies convexity of $X(z, b)$. To see this, let x^0 and x^1 be any two points such that $G(x^0, z, b) \leq 0$ and $G(x^1, z, b) \leq 0$. Define $x^2 = tx^0 + (1-t)x^1$ for $t \in [0, 1]$. Then $G(x^2, z, b) \leq 0$, since $z = tz + (1-t)z$. Similarly, closure of $T(b)$ implies closure of $X(z, b)$. To see this, let $\{z^k\}$ and $\{x^k\}$ be any two sequences such that $z^k = z \forall k$, $x^k \rightarrow x$, and $G(x^k, z^k, b) \leq 0 \forall k$. Then closure of $T(b)$ implies that $G(x, z, b) \leq 0$; hence $X(z, b)$ is closed. Decreasing monotonicity of G in x implies free disposal, since $x \geq x^0$ and $G(x^0, z, b) = 0 \Rightarrow G(x, z, b) \leq 0$. The nonemptiness of $T(b)$ and the feasibility of z imply $X(z, b) \neq \emptyset$. Theorems 1 and 2 of Uzawa (1964) and

Lemma 1 of McFadden (1973) follow from this set of hypotheses, proving continuity, monotonicity, 1° homogeneity, and concavity in p .

To prove convexity in z , fix two feasible outputs z^0 and z^1 , and define $z^2 = tz^0 + (1-t)z^1$ for $t \in [0, 1]$. Let $p'x^0 = c(p, z^0, b)$ and $p'x^1 = c(p, z^1, b)$. Then $p'x^2 \equiv c(p, z^2, b) \leq p'x \ \forall x \in X(z^2, b)$. In particular, let $x = tx^0 + (1-t)x^1$. Convexity of $T(b) \Rightarrow (x, z^2) \in T(b)$. Therefore, since x is feasible but not necessarily optimal for z^2 ,

$$c(p, z^2, b) \leq p'x = tp'x^0 + (1-t)p'x^1 = tc(p, z^0, b) + (1-t)c(p, z^1, b).$$

When $G(\cdot, z, b)$ is strictly convex in x , so that the input requirements sets are strictly convex, Shephard's Lemma is obtained from the *primal-dual* function

$$\phi(p, x, z, b) \equiv p'x - c(p, z, b).$$

$\phi(\cdot)$ is non-negative for all $x \in X(z, b)$ and attains a minimum at $x = x(p, z, b)$, the cost-minimizing bundle of market goods. If $\partial c / \partial p$ exists, minimizing $\phi(\cdot)$ with respect to p requires

$$\partial \phi(p, x, z, b) / \partial p \equiv x - \partial c(p, z, b) / \partial p \equiv 0. \quad \square$$

An additional property of the cost function is that if $G(\cdot, b)$ exhibits constant returns to scale with respect to x and z , so that $G(x, z, b) = 0 \Rightarrow G(tx, tz, b) = 0 \ \forall t \geq 0$, then $c(p, z, b)$ is 1° homogeneous in z [Hall (1973)]. By Euler's theorem we then have

$$c(p, z, b) \equiv \frac{\partial c(p, z, b)}{\partial z'} z. \quad (2.2.1)$$

The *hedonic price* for the i th commodity is the marginal cost of its production, $\rho_i(p, z, b) \equiv \partial c(p, z, b) / \partial z_i$. Under constant returns to scale, then, we can represent the consumer's choice problem as

$$\sup \{u(z): \rho'z \leq m, \ z \in \mathbb{R}_+^m\}. \quad (2.2.2)$$

Now, suppose that we define the implicit commodity prices conditionally on the optimal level of commodity consumption, $z^* = f(p, m, b)$, and then solve the household's choice problem given $\rho^* = \rho(p, z^*, b)$. These conditional shadow prices define the hyperplane that separates the projection of the production possibility set onto the m -dimensional commodity subspace from the upper contour set of the utility function. Under constant returns to scale, the commodity demand vector, $z^* = z(\rho^*, m, b)$, possesses all of the properties of neoclassical demand functions with respect to (ρ^*, m) [Barnett (1977)]. That is, taking ρ^* as a vector of constants associated only with the separating hyperplane, the functions $z(\rho^*, m, b)$ are 0° homogeneous in (ρ^*, m) , satisfy the

adding up condition, $\rho^* z(\rho^*, m, b) \equiv m$, and obey the Slutsky sign and symmetry conditions with respect to ρ^* and income m , i.e., the non-market commodity Slutsky matrix, $\partial z / \partial \rho^* + (\partial z / \partial m) z'$, is symmetric and negative semidefinite.

But the unconditional commodity shadow prices are defined by

$$\rho(p, m, b) \equiv \rho^*(p, f(p, m, b), b), \quad (2.2.3)$$

so that we have the identity

$$z(\rho(p, m, b), m, b) \equiv f(p, m, b). \quad (2.2.4)$$

Therefore, the hedonic prices for the non-market commodities and the commodity demands are necessarily simultaneously determined. Consequently, simply estimating either $\rho^* = \rho(p, z^*, b)$ or $z^* = z(\rho^*, m, b)$ with standard techniques leads to biased and inconsistent empirical results [Pollak and Wachter (1975)]. Moreover, without constant returns to scale,

$$m \equiv p' h(p, m, b) \equiv c[p, f(p, m, b), b] \neq \rho(p, m, b)' f(p, m, b), \quad (2.2.5)$$

and the above results for $z(\rho^*, m, b)$ no longer hold. Even with constant returns to scale, the hedonic price functions relay information regarding both consumer preferences and the household production function.

The simultaneity between the hedonic price functions and the commodity demand functions is overcome when the household production function displays both constant returns to scale and nonjoint production. When both of these conditions are satisfied, the joint cost function takes the additively separable form [Hall (1973); Muellbauer (1974); Samuelson (1966)],

$$c(p, z, b) = \tilde{c}(p, b)' z, \quad (2.2.6)$$

where $\tilde{c}_i(p, b)$ is the cost of producing a unit of the i th commodity. In this case, $\rho(p, z, b) \equiv \tilde{c}(p, b)$ is independent of z , so that constant returns to scale and nonjoint production imply a linear budget constraint in commodity space. As long as the Jacobian matrix for the hedonic price functions is of full rank, that is, $\min(m, n) = \text{rank}[\partial \tilde{c} / \partial p']$, the shadow price functions can be locally inverted to give price functions of the form $p = \varphi(\rho, b)$. This is the form in which nearly all empirical analyses of hedonic price functions have been undertaken, with the commodity shadow prices ρ estimated as constants in a linear or log-linear regression equation.

However, Pollak and Wachter point out that nonjointness is a restrictive assumption since it implies that the time spent in household production activities cannot yield utility except in terms of the amount of leisure time that is reduced by these activities. Moreover, we expect *a priori* that different households have different consumption technologies, and hence, different implicit price equations even if we are willing to impose

constant returns to scale and nonjoint production. This leads to different unit cost functions for the commodity outputs and different hedonic price relationships for different households.

Additionally, in any model of equilibrium price relationships, demand and supply conditions combine in the marketplace to create market clearing prices [Rosen (1974); Lucas (1975)]. The implicit prices for quality calculated from an hedonic price equation therefore represent the marginal conditions equating supply and demand, mapping observed market quantities, prices, and qualities into a single point in the space of producer costs and consumer preferences. Consequently, these relationships yield information about consumer preferences only in the sense of market equilibrium conditions. They do not contain any information regarding the direction or size of quantity or price changes that are likely to result from changes in the quality levels contained in market goods.

2.3. Special cases

The Gorman–Lancaster model of product characteristics arises when the household production function can be decomposed into the linear system

$$z_i = \sum_{j=1}^n b_{ij}x_j, \quad i = 1, \dots, m, \quad (2.3.1)$$

where $s = m \cdot n$. The utility function over goods and qualities is then of the form

$$u^*(x, b) = u\left(\sum_{j=1}^n b_{1j}x_j, \sum_{j=1}^n b_{2j}x_j, \dots, \sum_{j=1}^n b_{mj}x_j\right). \quad (2.3.2)$$

The Muth–Becker–Michael model results when $G(x, z, b) = 0$ is nonjoint, so that each commodity is produced by an individual production function of the form

$$z_i = f_i(x_{(i)}, b_{(i)}), \quad i = 1, \dots, m, \quad (2.3.3)$$

where $x = \sum_{i=1}^m x_{(i)}$ and $b = [b'_{(1)} b'_{(2)} \dots b'_{(m)}]'$. In this case, the utility function for goods has the form

$$u^*(x, b) = u(f_1(x_{(1)}, b_{(1)}), \dots, f_m(x_{(m)}, b_{(m)})). \quad (2.3.4)$$

The additional property of constant returns to scale, advocated by Muth as merely a question of definitions, generates demand side hedonic price equations discussed above.

Many applications of the hedonic price function model of quality employ translation and scaling methods [Pollak and Wales (1981)] to produce a utility function defined over goods and qualities in the scaled form

$$u^*(x, b) = u(\varphi_1(b_{(1)})x_1, \dots, \varphi_n(b_{(n)})x_n), \quad (2.3.5)$$

or in the translated form

$$u^*(x, b) = u(x_1 + \varphi_1(b_{(1)}), \dots, x_n + \varphi_n(b_{(n)})), \quad (2.3.6)$$

or a combination of the two. In the former case, the ordinary demand functions take the form

$$x_i = h^i(p_1/\varphi_1(b_{(1)}), \dots, p_n/\varphi_n(b_{(n)}), m)/\varphi_i(b_{(i)}), \quad (2.3.7)$$

which is commonly called the Fisher–Shell repackaging model [Fisher and Shell (1971)]. In the latter case, the ordinary demand functions take the form

$$x_i = h^i\left(p, m + \sum_{i=1}^m p_i \varphi_i(b_{(i)})\right) - \varphi_i(b_{(i)}), \quad (2.3.8)$$

[Hannemann (1980); Pollak and Wales (1981)]. In both cases, one implication is that preferences are weakly separable in the partition $\{(x_1, b_{(1)}), \dots, (x_n, b_{(n)})\}$. However, this will not be the case if goods are scaled by an $n \times n$ matrix, say $\mathbf{A}(b) = [\varphi_{ij}(b)]$, that is nonsingular and has nonzero off-diagonal elements. Then the Marshallian ordinary demands take the form [Samuelson (1947, p. 137)],

$$x = \mathbf{A}(b)^{-1} h(\mathbf{A}(b)^{-1} p, m). \quad (2.3.9)$$

The Gorman–Lancaster characteristics model is simply a special case of (2.3.9).

3. Intertemporal models of consumer choice

Many studies of food consumption use time series data. The static neoclassical model of consumer choice has been extended to accommodate the analysis of household decisions over time. In this section, we discuss models of intertemporal consumer choice that combine the models of the previous sections with the dynamic nature of household decision problems. Initially, we consider a model that mirrors the static neoclassical theory of consumer choice through additively separable preferences across points in time. The processes that consumers use to form expectations about the future values of economic factors such as prices and incomes are important aspects of dynamic models. Intertemporal models of household production are considered next, including the purchase, use, depreciation, maintenance, and replacement of durable household goods. Since some of these durable stocks can be interpreted as consumption habits, naive versus rational models of habit formation is an important issue in this framework.

In continuous time, the simplest form of the neoclassical intertemporal consumer choice model considers a consuming household which chooses the time path of consumption for the vector of goods, $x(t) \geq 0$, to²

$$\text{maximize } U = \int_0^T u(x(t)) e^{-\rho t} dt \quad (3.1)$$

subject to the intertemporal budget constraint,

$$dM(t)/dt = -p(t)'x(t)e^{-rt}, \quad M(0) = M_0, \quad M(t) \geq 0 \quad \forall t \in [0, T], \quad (3.2)$$

where $u(\cdot)$ is the instantaneous flow of utility from consumption, ρ is the consuming household's rate of time discount, or impatience, r is the real market discount rate, at which the consumer can freely borrow or lend, M_0 is the household's initial wealth plus the discounted present value of its full income stream, and $p(t)$ is the vector of market prices for the goods $x(t)$ in period t .³ We assume throughout that $u(\cdot)$ is twice continuously differentiable, strictly increasing ($\partial u(x)/\partial x \gg 0$) and strongly concave ($\partial^2 u(x)/\partial x \partial x'$ is negative definite) $\forall x \in \mathbb{R}_+^n$.⁴

3.1. Perfect foresight

In this subsection, we assume that the consuming household has complete information regarding all past, present, and future prices, incomes, and other relevant economic variables. The Hamiltonian for this problem can be written as

$$H = u(x(t)) e^{-\rho t} - \lambda(t) p(t)'x(t) e^{-rt}, \quad (3.1.1)$$

where $\lambda(t)$ is the shadow price, or costate variable for the equation of motion for household wealth. The first-order necessary and sufficient conditions for the maximum principle are

$$\partial H/\partial x = e^{-\rho t} \partial u/\partial x - e^{-rt} \lambda p \leq 0, \quad x \geq 0, \quad x' \partial H/\partial x = 0 \quad \forall t \in [0, T], \quad (3.1.2)$$

² A constant discount rate for consumers over the life cycle simplifies matters and plays only a minor role in the results of this section. A fixed and finite planning horizon is a strong hypothesis, but time and space preclude a more detailed analysis of the issues presented by it here.

³ We use the continuous time maximum principle to study solutions to this problem. The solution applied throughout this section is known in the operations research and economic dynamics literature as *open loop with feedback*. Although this concept differs from the *closed loop*, or *dynamic programming*, solution concept, it permits a much sharper focus on the role that expectations play in consumption models.

⁴ Additive separability, twice continuous differentiability, and quasiconcavity of U imply that $u(\cdot)$ is concave. This can be proven for discrete time with a finite planning horizon by a simple extension of the arguments in [Gorman (1995)]. This argument then can be extended to continuous time by passing to the limit via increasingly small time increments and then appealing to the continuity of the Hessian matrix. It also can be shown that concavity of $u(\cdot)$ is necessary for the existence of an optimal consumption path. Strong concavity, in turn, implies that the optimal path is unique.

$$\partial H / \partial M = 0 = -\dot{\lambda}, \quad (3.1.3)$$

$$\partial H / \partial \lambda = -p'x e^{-rt} = \dot{M}, \quad M(0) = M_0, \quad M \geq 0 \quad \forall t \in [0, T]. \quad (3.1.4)$$

Consider an interior solution for $x \forall t \in [0, T]$. Then first-order condition (3.1.2) implies

$$x = u_x^{-1}(e^{(\rho-r)t} \lambda p), \quad (3.1.5)$$

where $u_x^{-1}(\cdot)$ is the n -vector inverse of $u_x(\cdot)$. The strict monotonicity of $u(\cdot)$ combined with strictly positive prices p requires that $\lambda(t) > 0 \forall t \in [0, T]$. Because the Hamiltonian does not depend on current wealth, $M(t)$, Equation (3.1.3) implies $\lambda(t)$ is constant over the entire planning horizon, $\lambda(t) \equiv \lambda_0 \forall t \in [0, T]$. Therefore, multiplying by $e^{-rt} p(t)$ and integrating with respect to t produces a defining relationship for the wealth shadow price, $\lambda_0(M_0 - M_T, \rho, r, T)$,

$$M_0 - M_T \equiv \int_0^T e^{-rt} p(t)' u_x^{-1}(e^{(\rho-r)t} \lambda_0(M_0 - M_T, \rho, r, T) \cdot p(t)) dt. \quad (3.1.6)$$

The integral form of (3.1.6) implies that the optimal solution for λ_0 depends on all prices at all points in time, but that for given t and any finite change in $p(t)$, with prices remaining unchanged at all other times, $\partial \lambda_0 / \partial p(t) \equiv 0$.⁵

Substituting $\lambda_0(M_0 - M_T, \rho, r, T)$ into (3.1.5) gives the optimal demands at time t ,

$$x^*(t) \equiv u_x^{-1}(e^{(\rho-r)t} \lambda_0(M_0 - M_T, \rho, r, T) \cdot p(t)). \quad (3.1.7)$$

In contrast to the static model of the previous section, the neoclassical dynamic model with perfect foresight has a matrix of instantaneous uncompensated price slopes that is symmetric and negative definite,

$$\partial x^* / \partial p' = e^{(\rho-r)t} \lambda_0 u_{xx}^{-1}. \quad (3.1.8)$$

This difference in the symmetry properties of static and dynamic consumer choice models is the result of the intertemporal allocation of expenditure and is not due to perfect foresight or income smoothing *per se*. The difference is due to the integral form of the budget constraint on total household wealth in the dynamic framework. The additive structure of intertemporal preferences implies that the flow of utility in any given instant is perfectly substitutable for utility flows at every other instant. Consequently, a change in market prices at a single point in time generates substitution effects which

⁵ More generally, $\lambda(\cdot)$ does not vary with any absolutely bounded changes in prices on any subset of $[0, T]$ that has Lebesgue measure zero.

are perceptible at the given instant but are imperceptibly spread across the consumption bundles in all other times. Even in the simplest of dynamic contexts, therefore, the ubiquitously applied and tested Slutsky symmetry and negativity conditions of static consumer choice theory do not transcend to models in which wealth, rather than current income, is the constraint on consumption choices.

Continuing this line of inquiry, the marginal wealth effects on the demands at each $t \in [0, T]$ satisfy

$$\partial x^* / \partial M_0 = e^{(\rho-r)t} u_{xx}^{-1} p \cdot \partial \lambda_0 / \partial M_0. \quad (3.1.9)$$

By differentiating both sides of (3.1.6) with respect to M_0 , combining the result obtained on the right-hand side with (3.1.8), regrouping, canceling common terms, and distributing the integral, we have

$$\partial \lambda_0 / \partial M_0 = 1 / \int_0^T e^{(\rho-2r)t} p' u_{xx}^{-1} p \, dt < 0, \quad (3.1.10)$$

where the inequality on the far right follows from the (strong) concavity of $u(\cdot)$ and $p(t) \gg 0 \, \forall t \in [0, T]$.

The maximal level of cumulative discounted utility is defined by

$$V(M_0 - M_T, \rho, r, T) \equiv \int_0^T u(x^*) e^{-\rho t} \, dt. \quad (3.1.11)$$

Differentiating V with respect to M_0 gives

$$\begin{aligned} \frac{\partial V}{\partial M_0} &\equiv \int_0^T \frac{\partial u}{\partial x'} \frac{\partial x^*}{\partial M_0} e^{-\rho t} \, dt \\ &\equiv \int_0^T \underbrace{e^{-\rho t} \frac{\partial u}{\partial x'}}_{e^{-rt} \lambda_0 p'} \underbrace{\frac{\partial x^*}{\partial M_0}}_{u_{xx}^{-1} p \cdot \partial \lambda_0 / \partial M_0} \, dt \\ &\equiv \lambda_0 \int_0^T e^{-rt} p' u_{xx}^{-1} p \, dt / \int_0^T e^{-rt} p' u_{xx}^{-1} p \, dt \equiv \lambda_0 > 0, \end{aligned} \quad (3.1.12)$$

which is a direct intertemporal analogue to the envelope theorem [LaFrance and Barney (1991)]. Following the same steps, but applied to M_T implies

$$\partial \lambda_0 / \partial M_T = -1 / \int_0^T e^{(\rho-2r)t} p' u_{xx}^{-1} p \, dt > 0, \quad (3.1.13)$$

and

$$\frac{\partial V}{\partial M_T} \equiv -\lambda_0 < 0. \quad (3.1.14)$$

As a consequence, in the absence of any bequest motive, the optimal terminal wealth vanishes. This is the intertemporal analogue to the static budget identity when preferences are nonsatiable. Note, however, that $V(\cdot)$ is (strongly) concave in the household's initial wealth as a direct consequence of the (strong) concavity of $u(\cdot)$ in x . This contrasts with the static model where the marginal utility of money may be constant, increasing or decreasing due to the ordinality of preferences.

To relate the intertemporal model more closely to the static framework, define total consumption expenditures at time t by $m(t) \equiv p(t)'x(t)$ and consider the static optimization problem of maximizing $u(x)$ subject to $x \geq 0$ and $p'x \leq m$. Let $\tilde{\lambda}$ denote the shadow price for the static budget constraint. The first-order conditions for an interior solution are $u_x = \tilde{\lambda}p$ and $p'x = m$, which produce the static neoclassical demand functions, $x = h(p, m)$. In the static problem, we take m as given, and calculate the comparative statics for x and $\tilde{\lambda}$ from

$$\begin{bmatrix} \frac{\partial x}{\partial p'} & \frac{\partial x}{\partial m} \\ \frac{\partial \tilde{\lambda}}{\partial p'} & \frac{\partial \tilde{\lambda}}{\partial m} \end{bmatrix} = \begin{bmatrix} \tilde{\lambda} \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p p' u_{xx}^{-1}}{p' u_{xx}^{-1} p} \right] - \frac{u_{xx}^{-1} p x'}{p' u_{xx}^{-1} p} & \frac{u_{xx}^{-1} p}{p' u_{xx}^{-1} p} \\ -\frac{(\tilde{\lambda} p' u_{xx}^{-1} + x')}{p' u_{xx}^{-1} p} & \frac{1}{p' u_{xx}^{-1} p} \end{bmatrix}. \quad (3.1.15)$$

These in turn give the static Slutsky matrix,

$$S = \frac{\partial x}{\partial p'} + \frac{\partial x}{\partial m} x' = \tilde{\lambda} \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p p' u_{xx}^{-1}}{p' u_{xx}^{-1} p} \right], \quad (3.1.16)$$

a symmetric, negative semidefinite, rank $n - 1$ matrix.

Now, let $v(p, m) \equiv u(h(p, m))$ be the indirect utility function for the static problem, which defines the instantaneous flow of maximal utility subject to the static instantaneous budget constraint. Then, because of the additively separable structure of intertemporal preferences, the dynamic consumption problem can be represented equivalently as

$$\begin{aligned} & \text{maximize } \int_0^T v(p, m) e^{-\rho t} dt \\ & \text{subject to } \int_0^T m e^{-rt} dt \leq M_0, \quad m \geq 0 \quad \forall t \in [0, T]. \end{aligned} \quad (3.1.17)$$

The first-order conditions for an optimal (interior) solution are

$$\partial v / \partial m \equiv \tilde{\lambda} = e^{(\rho-r)t} \lambda, \quad (3.1.18)$$

$$\dot{\lambda} = 0, \quad (3.1.19)$$

$$\int_0^T m e^{-rt} dt = M_0, \quad (3.1.20)$$

where the identity in the center of (3.1.18) is due to the (static) envelope theorem. Total expenditure therefore is not predetermined in each period, but rather is jointly determined with quantities and is smoothed over time to equate the present value of the marginal utility of money across all points in time,

$$\partial v(p, m^*) / \partial m \equiv e^{(\rho-r)t} \lambda_0, \quad (3.1.21)$$

where $m^*(t)$ denotes the optimal level of total consumption expenditures $\forall t \in [0, T]$.⁶

Applying Roy's identity to the static problem then gives

$$x^*(t) \equiv h(p(t), m^*(t)) \equiv - \frac{\partial v(p(t), m^*(t)) / \partial p}{\partial v(p(t), m^*(t)) / \partial m} \quad \forall t \in [0, T]. \quad (3.1.22)$$

Taking the vector product of (3.1.22) with p , multiplying by e^{-rt} and integrating with respect to t , and utilizing (3.1.18) and (3.1.19) generates two alternative defining relationships for λ_0 ,

$$\begin{aligned} \lambda_0 &\equiv - \int_0^T e^{-\rho t} p(t)' v_p(p(t), m^*(t)) dt / M_0 \\ &\equiv \int_0^T e^{-\rho t} m^*(t) v_m(p(t), m^*(t)) dt / M_0 > 0, \end{aligned} \quad (3.1.23)$$

where the second identity follows from zero degree homogeneity of $v(\cdot)$ in (p, m) and the inequality follows from the fact that $v(\cdot)$ is strictly increasing in m . As before, we conclude that λ_0 is invariant to all absolutely bounded changes in prices on subsets of $[0, T]$ with Lebesgue measure zero. Hence, differentiating (3.1.21) with respect to p implies

$$\partial m^* / \partial p = - \frac{\partial^2 v(p, m^*) / \partial m \partial p}{\partial^2 v(p, m^*) / \partial m^2}. \quad (3.1.24)$$

Instantaneous symmetry is obtained by differentiating (3.1.22) with respect to p , substituting (3.1.24) into the result, and canceling vanishing terms due to (3.1.21)

⁶ In other words, the optimal flow of consumption expenditures generally depends on the parameters of the utility function and market prices at time t , as well as initial wealth, individual and market discount rates, and the optimal value of the shadow price for the wealth constraint. Thus, except for models with myopic expectations and with $\rho = r$, total consumption expenditures cannot be treated as exogenous [Engle et al. (1983)] in empirical models of intertemporal consumer choice.

and (3.1.22),

$$\begin{aligned}\frac{\partial x^*}{\partial p'} &= -\frac{\frac{\partial^2 v}{\partial p \partial p'}}{\frac{\partial v}{\partial m}} - \frac{\frac{\partial^2 v}{\partial m \partial p}}{\frac{\partial v}{\partial m}} \left(\frac{\partial m^*}{\partial p'} \right) + \frac{\frac{\partial v}{\partial p}}{\left(\frac{\partial v}{\partial m} \right)^2} \overbrace{\left[\frac{\partial^2 v}{\partial m \partial p} + \frac{\partial^2 v}{\partial m^2} \cdot \frac{\partial m^*}{\partial p} \right]}^{\equiv 0} \\ &= -\frac{1}{\frac{\partial v}{\partial m}} \left[\frac{\partial^2 v}{\partial p \partial p'} - \frac{\frac{\partial^2 v}{\partial m \partial p} \cdot \frac{\partial^2 v}{\partial m \partial p'}}{\frac{\partial^2 v}{\partial m^2}} \right],\end{aligned}\quad (3.1.25)$$

a symmetric matrix. It is also worthwhile to contrast (3.1.25) with its static neoclassical counterpart, which has the asymmetric form

$$\frac{\partial x^*}{\partial p'} = -\frac{1}{\frac{\partial v}{\partial m}} \left[\frac{\partial^2 v}{\partial p \partial p'} - \frac{\frac{\partial v}{\partial p} \cdot \frac{\partial^2 v}{\partial m \partial p'}}{\frac{\partial v}{\partial m}} \right]. \quad (3.1.26)$$

3.2. Myopic expectations

The opposite of full information regarding all future economic values on the part of consuming households is myopic expectations. In this case, the household is modeled as if it expects no change in relative prices of goods or services throughout its planning horizon, i.e., $p(t) = p_0 \forall t \geq 0$. This assumption plays an important part in many dynamic economic models [e.g., Cooper and McLaren (1980); McLaren and Cooper (1980); Epstein (1981, 1982); Epstein and Denny (1983)]. One drawback is the apparent contradiction between the level of sophistication that individuals are presumed to use to formulate their economic plans versus the manner in which they formulate and update their expectations about future events. As pointed out by Epstein and Denny (1983, pp. 649–650), “Current prices are . . . expected to persist indefinitely. As the base period changes and new prices . . . are observed, the [decision maker] revises its expectations and its previous plans. Thus only the $t = 0$ portion of the plan . . . is carried out in general”.

One unfortunate implication of the myopic expectations hypothesis is that economic decision makers are infinitely forward looking when they design their optimal consumption plans, but are totally myopic when they formulate their expectations about their future economic environment. Nevertheless, prior to moving on to more general and robust models of household expectations formation, it will prove useful to identify the economic structure and duality of the intertemporal consumer choice problem with myopic expectations. The primary reason for this is that several properties of the myopic expectations framework generalize in straightforward ways to the more general situations that we shall consider later.

Under myopic expectations, the model and solution approach of the previous section continues to apply, with the caveat that $p(t)$ is replaced by p_0 at all points in time. This

apparently minor change significantly alters many of the conclusions drawn for the case of perfect foresight.

We begin with the question of Slutsky symmetry in this context. Specifically, the goal of the following developments is to demonstrate that there is no short-run, instantaneous analogue for the static Slutsky symmetry condition in dynamic models. However, we will also show that a dynamic analogue to static Slutsky symmetry exists, but takes the form of an $n \times n$ matrix of integral terms.

The first step is to note that the shadow price for the budget constraint now satisfies the condition

$$M_0 \equiv \int_0^T e^{-rt} p'_0 u_x^{-1} (e^{(\rho-r)t} \lambda_0(p_0, M_0, \rho, r, T) p_0) dt, \quad (3.2.1)$$

while, since p_0 is presumed constant over the planning horizon, (3.1.8) now has the form

$$\frac{\partial x^*(t)}{\partial p'_0} = e^{(\rho-r)t} u_{xx}^{-1} \left[\lambda_0 I + p_0 \frac{\partial \lambda_0}{\partial p'_0} \right]. \quad (3.2.2)$$

Differentiating the intertemporal budget identity, $\int_0^T e^{-rt} p'_0 u_x^*(t) dt \equiv M_0$, with respect to p_0 then implies that

$$\int_0^T e^{-rt} \frac{\partial x^*(t)}{\partial p_0} p_0 dt \equiv - \int_0^T e^{-rt} x^*(t) dt. \quad (3.2.3)$$

Next, we pre-multiply (3.2.2) by $e^{-rt} p'_0$, integrate over t , combine the results with (3.2.3), and solve for $\partial \lambda_0 / \partial p_0$, all of which gives

$$\frac{\partial \lambda_0}{\partial p_0} \equiv - \frac{\int_0^T e^{-rt} (x^* + u_{xx}^{-1} u_x) dt}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}. \quad (3.2.4)$$

This completes the first step, which was to derive the response of the shadow price for initial wealth to changes in relative prices.

The second step is to proceed along similar lines of reasoning, but now with respect to changes in the initial level of wealth. In particular, the analogue to (3.1.9) now has the form,

$$\frac{\partial x^*(t)}{\partial M_0} \equiv \frac{e^{(\rho-r)t} u_{xx}^{-1} p_0}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0}. \quad (3.2.5)$$

We then combine (3.2.2) with (3.2.4) to generate the matrix of instantaneous uncompensated (ordinary demand) price derivatives as

$$\frac{\partial x^*(t)}{\partial p'_0} \equiv e^{(\rho-r)t} \left\{ \lambda_0 \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p_0 p'_0 \int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right] - \frac{u_{xx}^{-1} p_0 \int_0^T e^{-rt} x^*(\tau)' d\tau}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right\}. \quad (3.2.6)$$

Simple inspection of this matrix equation shows that, in contrast to the case of perfect foresight, $\partial x^*(t)/\partial p'_0$ is not a symmetric negative definite matrix.

Now, by combining (3.2.5) and (3.2.6), we find the instantaneous “wealth-compensated” substitution matrix,

$$\begin{aligned} & \frac{\partial x^*(t)}{\partial p'_0} + \frac{\partial x^*(t)}{\partial M_0} x^*(t)' \\ & \equiv e^{(\rho-r)t} \left\{ \lambda_0 \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p_0 p'_0 \int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right] + \frac{u_{xx}^{-1} p_0 (x^*(t)' - \int_0^T e^{-rt} x^*(\tau)' d\tau)}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right\}. \end{aligned} \quad (3.2.7)$$

Again, this matrix is neither symmetric nor negative semidefinite.

Finally, using the identity $x^*(t) \equiv h(p_0, m^*(t))$, the instantaneous “income-compensated” substitution matrix is given by

$$\begin{aligned} & \frac{\partial x^*(t)}{\partial p'_0} + \frac{\partial h(p_0, m^*(t))}{\partial m} x^*(t)' \\ & \equiv e^{(\rho-r)t} \left\{ \lambda_0 \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p_0 p'_0 \int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right] - \frac{u_{xx}^{-1} p_0 \int_0^T e^{-rt} x^*(\tau)' d\tau}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right\} \\ & \quad + \frac{u_{xx}^{-1} p_0 x^*(t)'}{p'_0 u_{xx}^{-1} p_0}, \end{aligned} \quad (3.2.8)$$

which also is neither symmetric nor negative semidefinite.

Thus, the primary mainstay of *static* consumer choice theory – the Slutsky symmetry and negativity condition – does not have *any* short-run (instantaneous) counterpart in *dynamic* contexts. As we shall see in the sequel, this important result carries over to dynamic models of consumer choice in which individuals form expectations for the values of economic factors that influence their future environments.

Nevertheless, since the solution to the consumer’s choice problem is the result of a maximization exercise subject to a linear budget constraint, we know instinctively that

there must be some kind of symmetry inherent in the problem's optimal solution. Indeed, such a symmetry condition does exist, although it has a nonstandard form relative to the static model, and in practice would be extremely difficult, if not impossible, to either empirically implement or test.

To show this, we begin heuristically and constructively by multiplying both sides of Equations (3.2.5) and (3.2.6) by e^{-rt} and integrating over $[0, T]$ to obtain

$$\int_0^T e^{-rt} \frac{\partial x^*(t)}{\partial M_0} dt \equiv \frac{(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}, \quad (3.2.9)$$

$$\begin{aligned} & \int_0^T e^{-rt} \frac{\partial x^*(t)}{\partial p'_0} dt \\ & \equiv \lambda_0 \left[\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt - \frac{(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0 p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt)}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0} \right] \\ & \quad - \frac{(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0 (\int_0^T e^{-rt} x^*(t) dt)'}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}. \end{aligned} \quad (3.2.10)$$

Next, multiplying (3.2.9) by $[\int_0^T e^{-rt} x^*(t) dt]'$ and adding the result to (3.2.10) produces an $n \times n$ matrix of integral equations, which gives us the discounted present value of wealth-compensated cross-price substitution terms,

$$\begin{aligned} & \int_0^T e^{-rt} \frac{\partial x^*(t)}{\partial p'_0} dt + \left(\int_0^T e^{-rt} \frac{\partial x^*(t)}{\partial M_0} dt \right) \left(\int_0^T e^{-rt} x^*(t) dt \right)' \\ & \equiv \lambda_0 \left[\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt - \frac{(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0 p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt)}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0} \right]. \end{aligned} \quad (3.2.11)$$

The $n \times n$ matrix on the right-hand side of (3.2.11) is clearly symmetric, negative semidefinite, and has rank $n - 1$. It turns out that this matrix of discounted present values of wealth compensated cross-price substitution terms is precisely the dynamic analogue to the static matrix of Slutsky symmetry terms. We will verify this fact directly in the course of developing the duality arguments that follow next.⁷

⁷ A simple, heuristic argument for the validity of (3.2.11) as the dynamic Slutsky substitution matrix is the following. Let $U_{xx}^{-1} \equiv \int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt$ and note that this $n \times n$ matrix is negative definite and defines, in a sense, the "inverse Hessian" matrix that determines how changes in consumption choices due to changes in relative prices are allocated over the life cycle. Direct substitution into (3.2.11) gives

$$S \equiv \lambda_0 [U_{xx}^{-1} - (p'_0 U_{xx}^{-1} p_0)^{-1} U_{xx}^{-1} p_0 p'_0 U_{xx}^{-1}],$$

which has exactly the form of the static neoclassical Slutsky substitution matrix.

First, we define the maximal level of discounted utility flows, subject to the wealth constraint, by

$$V(p_0, M_0) \equiv \sup_{\{x(t)\}} \left\{ \int_0^T e^{-\rho t} u(x) dt : \int_0^T e^{-rt} p'_0 x dt = M_0 \right\}, \quad (3.2.12)$$

where the equality constraint follows from monotonicity of $u(\cdot)$. We call $V(p_0, M_0)$ the *dynamic indirect utility function*.⁸ Under myopic expectations, the dynamic indirect utility function has properties that are intertemporal analogues to those of the static indirect utility function. That is, $V(p_0, M_0)$ is:

- (DV.1) *twice continuously differentiable in (p_0, M_0) ;*
- (DV.2) *decreasing and quasiconvex in p_0 ;*
- (DV.3) *strictly increasing and strongly concave in M_0 ; and*
- (DV.4) *0° homogeneous in (p_0, M_0) ; and*
- (DV.5) *satisfies the Dynamic Envelope Theorem,*

$$\begin{aligned} \partial V(p_0, M_0) / \partial p_0 &\equiv -\lambda_0(p_0, M_0) \int_0^T e^{-rt} h(p_0, M_0, t) dt \ll \mathbf{0}, \\ \partial V(p_0, M_0) / \partial M_0 &\equiv \lambda_0(p_0, M_0) > 0, \end{aligned}$$

and the Dynamic Roy's Identity,

$$-\left(\frac{\partial V(p_0, M_0) / \partial p_0}{\partial V(p_0, M_0) / \partial M_0} \right) \equiv \int_0^T e^{-rt} h(p_0, M_0, t) dt,$$

where $x^*(t) \equiv h(p_0, M_0, t)$ is the n -vector of dynamic ordinary Marshallian demands at time t .

Twice continuous differentiability of $V(\cdot)$ follows from strict monotonicity and twice continuous differentiability of $u(\cdot)$. Strict monotonicity, and strong concavity in M_0 follow from the adaptation, without change, of (3.1.10) and (3.1.12) to the present situation. Monotonicity in p_0 also follows from the monotonicity of $u(\cdot)$ and the fact that the intertemporal budget set contracts as prices increase. Quasiconvexity is demonstrated in precisely the same manner as for a static problem. Homogeneity follows from the fact that the wealth constraint, $p'_0 \int_0^T e^{-rt} x(t) dt = M_0$, is invariant to proportional changes in all prices and initial wealth.

In a very general context, including both equality and inequality constraints and a countable number of switch points over the planning horizon, LaFrance and Barney

⁸ The function $V(\cdot)$ also depends upon the discount rates, ρ and r , and the length of the planning horizon, T . Since these parameters are not the central focus of our discussion, they have been suppressed as arguments to reduce the notational burden.

(1991) demonstrate the dynamic envelope theorem. Their argument is complex and involved and will not be reproduced here. However, it is pedagogically useful to verify (DV.5) by direct calculation to lend heuristic support for the dynamic envelope theorem results that are presented below. This is accomplished simply by differentiating

$$V(p_0, M_0) \equiv \int_0^T e^{-\rho t} u(h(p_0, M_0, t)) dt$$

with respect to p_0 and M_0 , substituting the first-order conditions into the resulting expressions, grouping terms, and integrating over the planning horizon, to obtain

$$\begin{aligned} \frac{\partial V(p_0, M_0)}{\partial p_0} &\equiv \int_0^T e^{-\rho t} \frac{\partial h'}{\partial p_0} u_x dt \equiv \int_0^T e^{-\rho t} \left(e^{(\rho-r)t} \left\{ \lambda_0 u_{xx}^{-1} \right. \right. \\ &\quad \left. \left. - \frac{\lambda_0 u_{xx}^{-1} p_0 p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) + (\int_0^T e^{-rt} h dt) p'_0 u_{xx}^{-1}}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0} \right\} e^{(\rho-r)t} \lambda_0 p_0 \right) dt \\ &\equiv \lambda_0^2 \left(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt \right) p_0 \\ &\quad - \left[\lambda_0^2 \left(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt \right) p_0 p'_0 \left(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt \right) p_0 \right. \\ &\quad \left. + \lambda_0 \left(\int_0^T e^{-rt} h dt \right) p'_0 \left(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt \right) p_0 \right] \\ &\quad / p'_0 \left(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt \right) p_0 \\ &\equiv -\lambda_0 \int_0^T e^{-rt} h(p_0, M_0, t) dt, \end{aligned} \tag{3.2.13}$$

and

$$\begin{aligned} \frac{\partial V(p_0, M_0)}{\partial M_0} &\equiv \int_0^T e^{-\rho t} u'_x \frac{\partial h}{\partial M_0} dt \\ &\equiv \int_0^T e^{-\rho t} (e^{(\rho-r)t} \lambda_0 p'_0) \left[\frac{e^{(\rho-r)t} u_{xx}^{-1} p_0}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right] dt \equiv \lambda_0. \end{aligned} \tag{3.2.14}$$

The converse of the intertemporal utility maximization problem is the problem of minimizing the discounted present value of consumption expenditures subject to the

constraint that the discounted cumulative flow of utility is no lower than a given value, U_0 ,

$$E(p_0, U_0) \equiv \inf_{\{x(t)\}} \left\{ \int_0^T e^{-rt} p'_0 x \, dt : \int_0^T e^{-\rho t} u(x) \, dt \geq U_0 \right\}. \quad (3.2.15)$$

We call this the *dynamic expenditure function*. The dynamic expenditure function is:

(DE.1) *twice continuously differentiable, strictly increasing, 1° homogeneous, and concave in p_0 ;*

(DE.2) *twice continuously differentiable, strictly increasing and strongly convex in U_0 ; and*

(DE.3) *satisfies the Dynamic Envelope Theorem,*

$$\frac{\partial E(p_0, U_0)}{\partial p_0} \equiv \int_0^T e^{-rt} g(p_0, U_0, t) \, dt,$$

and

$$\frac{\partial E(p_0, U_0)}{\partial U_0} \equiv \mu_0(p_0, U_0) > 0,$$

where $x^*(t) = g(p_0, U_0, t)$ is the vector of wealth-compensated dynamic Hicksian demands at time t and $\mu_0(p_0, U_0)$ is the shadow price for the intertemporal utility constraint.

To lay the groundwork for our analysis of more general models in later sections, we develop these properties and the intertemporal duality between the dynamic indirect utility and expenditure functions for the present, simple case of myopic expectations. Toward this end, let $U(0) = U_0$, $dU(t)/dt = -e^{-\rho t} u(x) \, \forall t \in [0, T]$, and redefine the constraint on the discounted present value of total utility flows as an inequality restriction, $U(T) = U(0) - \int_0^T e^{-\rho t} u(x) \, dt \geq 0$.⁹ Then the Hamiltonian for the dynamic expenditure minimization problem is

$$H = e^{-rt} p'_0 x - \mu e^{-\rho t} u(x), \quad (3.2.16)$$

and the first-order necessary and sufficient conditions for an interior optimal path are:

$$\partial H / \partial x = e^{-rt} p_0 - \mu e^{-\rho t} \partial u / \partial x = 0; \quad (3.2.17)$$

$$\partial H / \partial U = 0 = -\dot{\mu}; \quad (3.2.18)$$

$$\partial H / \partial \mu = -e^{-\rho t} u = \dot{U}, \quad U(T) \equiv U_0 - \int_0^T e^{-\rho t} u \, dt \geq 0. \quad (3.2.19)$$

⁹ This transformation converts the consumer's intertemporal expenditure minimization problem from an isoperimetric calculus of variations problem into a standard optimal control problem. The latter form is convenient for generating comparative dynamics results and the properties of the optimal solution path. The former, to which we will return momentarily, is useful for analyzing dynamic duality.

It is easy to see that strict monotonicity of $u(\cdot)$ implies that $U(T) = 0$ since otherwise the discounted present value of expenditures could be lowered without violating the inequality constraint on the present value of discounted utility flows. It also follows from the properties of $u(\cdot)$ that the optimal path is unique. As in the case of dynamic utility maximization, condition (3.2.18) implies that the shadow price is constant throughout the planning horizon, $\mu(t) = \mu_0 \forall t \in [0, T]$.

Let $x^*(t) \equiv g(p_0, U_0, t)$ denote the optimal dynamic Hicksian demands at time t and let $\mu_0(p_0, U_0) > 0$ denote the optimal shadow price for the intertemporal utility constraint. We can verify (DE.1)–(DE.6) by direct calculation. We begin by first differentiating (3.2.17) with respect to p_0 , and solving for $\partial g / \partial p'_0$,

$$\frac{\partial g}{\partial p'_0} = \mu_0^{-1} u_{xx}^{-1} \left[e^{(\rho-r)t} I - u_x \frac{\partial \mu_0}{\partial p'_0} \right]. \quad (3.2.20)$$

We then can differentiate the identity $\int_0^T e^{-\rho t} u(g(p_0, U_0, t)) dt \equiv U_0$ with respect to p_0 to get $\int_0^T e^{-\rho t} (\partial g' / \partial p_0) u_x dt \equiv \mathbf{0}$, transpose both sides of (3.2.20), post-multiply by $e^{-\rho t} u_x$, integrate over the planning horizon, and solve for $\partial \mu_0 / \partial p_0$,

$$\frac{\partial \mu_0}{\partial p_0} \equiv \frac{\int_0^T e^{-rt} u_{xx}^{-1} u_x dt}{\int_0^T e^{-\rho t} u'_x u_{xx}^{-1} u_x dt} \equiv \mu_0 \frac{(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}. \quad (3.2.21)$$

Our next step is to substitute the right-hand side of (3.2.21) into (3.2.20), which gives the instantaneous wealth-compensated matrix of cross-price substitution effects as

$$\frac{\partial g}{\partial p'_0} \equiv e^{(\rho-r)t} \mu_0^{-1} \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p_0 p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau)}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right]. \quad (3.2.22)$$

We can now verify the dynamic analogue to Hotelling's/Shephard's Lemma as represented by the first identity in (DE.3). By definition of the dynamic expenditure function, $E(p_0, U_0) \equiv \int_0^T e^{-\rho t} p'_0 g(p_0, U_0, t) dt$, we have

$$\begin{aligned} \frac{\partial E(p_0, U_0)}{\partial p_0} &\equiv \int_0^T e^{-rt} \left(\frac{\partial g'}{\partial p_0} p_0 + g \right) dt \\ &\equiv \int_0^T e^{-rt} \left(\frac{\partial g'}{\partial p_0} (e^{(r-\rho)t} \mu_0 u_x) + g \right) dt \\ &\equiv \mu_0 \int_0^T e^{-\rho t} \frac{\partial g'}{\partial p_0} u_x dt + \int_0^T e^{-rt} g dt \\ &\equiv \int_0^T e^{-rt} g dt \gg \mathbf{0}. \end{aligned} \quad (3.2.23)$$

Thus, by the converse to Euler's theorem, the dynamic expenditure function is linearly homogeneous in p_0 . Moreover, since the right-hand side of (3.2.22) is continuous, $E(p_0, U_0)$ is twice continuously differentiable in p_0 .

Next, although concavity in p_0 can be demonstrated with the same arguments as are used for the static neoclassical model, it is useful to verify this directly. Differentiating (3.2.23) with respect to p_0 , using (3.2.22) for the right-hand side integrand, we have

$$\begin{aligned} & \frac{\partial^2 E(p_0, U_0)}{\partial p_0 \partial p'_0} \\ & \equiv \int_0^T e^{-rt} \frac{\partial g}{\partial p'_0} dt \\ & \equiv \int_0^T e^{(\rho-2r)t} \mu_0^{-1} \left[u_{xx}^{-1} - \frac{u_{xx}^{-1} p_0 p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau)}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} \right] dt \\ & \equiv \mu_0^{-1} \left[\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt - \frac{(\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0 p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt)}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0} \right]. \end{aligned} \quad (3.2.24)$$

Since $\mu_0 > 0$ and $U_{xx}^{-1} \equiv \int_0^T e^{(r-2r)t} u_{xx}^{-1} dt$ is symmetric, negative definite, the Hessian matrix for $E(p_0, U_0)$ is negative semidefinite with rank $n - 1$.

This completes the verification of (DE.1) and the first half of (DE.3). We shall return to (3.2.24) in a moment to verify that it is in fact the symmetric, negative semidefinite, rank $n - 1$ wealth-compensated Slutsky matrix given in (3.2.11) above.

The steps required to verify (DE.2) are similar. First, differentiating (3.2.17) with respect to U_0 implies

$$\frac{\partial g}{\partial U_0} \equiv -\mu_0^{-1} u_{xx}^{-1} u_x \frac{\partial \mu_0}{\partial U_0}. \quad (3.2.25)$$

Second, by differentiating the identity for the discounted present value of total utility flows,

$$\int_0^T e^{-\rho t} u(g(p_0, U_0, t)) dt \equiv U_0,$$

with respect to U_0 , we have $\int_0^T e^{-\rho t} u'_x \partial g / \partial U_0 dt \equiv 1$. Therefore, premultiplying (3.2.25) by $e^{-\rho t} u'_x$, integrating over t , and using the first-order condition (3.2.17) to replace u_x , we obtain

$$\frac{\partial \mu_0}{\partial U_0} \equiv \frac{-\mu_0}{\int_0^T e^{-rt} u'_x u_{xx}^{-1} u_x dt} \equiv \frac{-\mu_0^3}{p'_0 (\int_0^T e^{-rt} u_{xx}^{-1} dt) p_0} > 0, \quad (3.2.26)$$

where the inequality on the far right follows from strong concavity of $u(\cdot)$ and $p_0 \neq \mathbf{0}$. Third, substituting (3.2.26) into (3.2.25) gives

$$\frac{\partial g}{\partial U_0} \equiv \frac{u_{xx}^{-1} u_x}{\int_0^T e^{-\rho t} u'_x u_{xx}^{-1} u_x dt} \equiv \frac{e^{(\rho-r)t} \mu_0 u_{xx}^{-1} p_0}{p'_0 (\int_0^T e^{(\rho-2r)t} u_{xx}^{-1} dt) p_0}. \quad (3.2.27)$$

Finally, differentiating the dynamic expenditure function with respect to U_0 gives

$$\begin{aligned} \frac{\partial E(p_0, U_0)}{\partial U_0} &\equiv \int_0^T e^{-rt} p'_0 \frac{\partial g}{\partial U_0} dt \\ &\equiv \int_0^T e^{-rt} p'_0 \frac{e^{(\rho-r)t} \mu_0 u_{xx}^{-1} p_0}{p'_0 (\int_0^T e^{(\rho-2r)\tau} u_{xx}^{-1} d\tau) p_0} dt \equiv \mu_0 > 0. \end{aligned} \quad (3.2.28)$$

Inspection of (3.2.28) and (3.2.26) then shows us that $\partial^2 E(p_0, U_0) / \partial U_0^2 > 0$, thus completing the verification of (DE.2) and the second half of (DE.3).

The duality between the dynamic indirect utility function and the dynamic expenditure function can be established most directly by viewing them as problems in the classical theory of the calculus of variations [e.g., Clegg (1968, pp. 117–121)]. Recalling the strict monotonicity of $u(\cdot)$ and noting that $p'_0 x$ is strictly decreasing in at least one x_i if $p_0 \neq \mathbf{0}$, the utility maximization and expenditure minimization problems can be restated in the isoperimetric form

$$\begin{aligned} V(p_0, M_0) &\equiv \sup_{\{x(t)\}} \left\{ \int_0^T e^{-\rho t} u(x(t)) dt : \int_0^T e^{-\rho t} p'_0 x(t) dt = M_0 \right\}, \\ E(p_0, U_0) &\equiv \inf_{\{x(t)\}} \left\{ \int_0^T e^{-\rho t} p'_0 x(t) dt : \int_0^T e^{-\rho t} u(x(t)) dt = U_0 \right\}. \end{aligned}$$

A well-known result in the theory of the calculus of variations is that, for isoperimetric control problems, the solutions to the two problems are equivalent throughout the entire optimal path if $M_0 = E(p_0, U_0)$, or equivalently, if $U_0 = V(p_0, M_0)$. This equivalence is analogous to the duality in static models of consumer choice, $M_0 \equiv E(p_0, V(p_0, M_0))$ and $U_0 \equiv V(p_0, E(p_0, U_0))$, except that now all definitions are in terms of the discounted present values of consumption expenditures and utility flows. Several conclusions follow directly from this fact, each generating the dynamic analogue to a corresponding duality property in the static theory:

$$\lambda_0(p_0, E(p_0, U_0)) \equiv \mu_0(p_0, U_0)^{-1}; \quad (3.2.29)$$

$$\mu_0(p_0, V(p_0, M_0)) \equiv \lambda_0(p_0, M_0)^{-1}; \quad (3.2.30)$$

$$g(p_0, U_0, t) \equiv h(p_0, E(p_0, U_0), t); \quad (3.2.31)$$

$$h(p_0, M_0, t) \equiv g(p_0, V(p_0, M_0), t); \quad (3.2.32)$$

$$\begin{aligned}
\frac{\partial E(p_0, U_0)}{\partial p} &\equiv \int_0^T e^{-rt} g(p_0, U_0, t) dt \\
&\equiv \int_0^T e^{-rt} h(p_0, E(p_0, U_0), t) dt \\
&\equiv -\frac{\partial V(p_0, E(p_0, U_0))/\partial p}{\partial V(p_0, E(p_0, U_0))/\partial M};
\end{aligned} \tag{3.2.33}$$

$$\begin{aligned}
\frac{\partial g(p_0, U_0, t)}{\partial p'_0} &\equiv \frac{\partial h(p_0, E(p_0, U_0), t)}{\partial p'_0} \\
&\quad + \frac{\partial h(p_0, E(p_0, U_0), t)}{\partial M} \left(\int_0^T e^{-rt} h(p_0, E(p_0, U_0), t) dt \right)';
\end{aligned} \tag{3.2.34}$$

$$\begin{aligned}
\frac{\partial^2 E(p_0, U_0)}{\partial p \partial p'} &\equiv \int_0^T e^{-rt} \frac{\partial g(p_0, U_0, t)}{\partial p'} dt \\
&\equiv \int_0^T e^{-rt} \frac{\partial h(p_0, E(p_0, U_0), t)}{\partial p'} dt \\
&\quad + \int_0^T e^{-rt} \frac{\partial h(p_0, E(p_0, U_0), t)}{\partial M} dt \\
&\quad \times \left(\int_0^T e^{-rt} h(p_0, E(p_0, U_0), t) dt \right)'.
\end{aligned} \tag{3.2.35}$$

Equation (3.2.34) defines the *instantaneous Slutsky substitution matrix*. The first matrix on the right-hand side denotes the instantaneous price effects on the ordinary demands at each point in time and the second right-hand side matrix denotes the wealth effects. However, it is (3.2.35) and not (3.2.34) that is symmetric and negative semidefinite. Even in this simplest of possible dynamic contexts, therefore, caution is advisable when interpreting hypothesis tests for “Slutsky symmetry and negativity” and other strictures of the static theory. Also note that the identities (3.2.29) and (3.2.35) establish the validity of Equation (3.2.11) as the dynamic Slutsky substitution matrix.

Finally, if consumers look ahead with respect to their future economic environment when designing their consumption plans, the manner in which they form expectations is a critical determinant of observable behavior. This topic is the focus of the following subsection.

3.3. Other forecasting rules

In the neoclassical model of competition, market prices are invariant to the purchasing and consumption choices of the individual. However, this does not imply that consumers are incapable of learning about market price mechanisms or of forming expectations about their future economic environment. Perfect foresight and myopic expectations

are but two extreme possibilities among an uncountable number of alternative forecasting rules that may be reasonable hypotheses in a model of consumption behavior. In this subsection, therefore, we analyze models in which consuming households employ forecasting rules for predicting their future economic conditions when they formulate their dynamic consumption plans. Important members of the class of rules we consider are adaptive, rational, and quasi-rational expectations. Notwithstanding the previous subsection's detailed analysis of myopic expectations, rather than treat each of these special cases separately, we attempt to embed all of these hypotheses as special cases within a general, unifying framework.

Clearly, future incomes, rates of return on assets, and market rates of interest at which the individual can borrow or lend are important economic variables affecting future opportunity sets. However, the basic questions, arguments, and conclusions arising from expectations formation processes are most clear and simplest to present when we focus on forecasting market prices.

To motivate the models and the solution approach that we shall consider throughout this section, assume that prices follow some form of filtered diffusion, say,

$$dp(t) = \alpha(p(t), t) dt + \beta(p(t), t) dz(t), \quad (3.3.1)$$

where $\alpha(p(t), t)$ is an n -vector of conditional means, $\beta(p(t), t)$ is an $n \times n$ matrix such that

$$\begin{aligned} E[(dp(t) - \alpha(p(t), t) dt)(dp(t) - \alpha(p(t), t) dt)' | \mathcal{F}_t] \\ = \beta(p(t), t) \beta(p(t), t)' dt \equiv \Sigma(p(t), t) dt, \end{aligned}$$

with probability one $\forall t$, $dz(t) \sim \text{i.i.d. } N(\mathbf{0}_n, I_n dt)$, and $\{\mathcal{F}_t\}$ denotes an increasing sequence of σ -algebras defining a filtration for the pre-visible stochastic process $p(t)$, such that $\mathcal{F}_t \subseteq \mathcal{F}_s \forall t \leq s$. Conditional on $\mathcal{F}_0$, $\forall t \geq 0$, then, we have

$$E[dp(t) | \mathcal{F}_0] = E[\alpha(p(t), t) | \mathcal{F}_0] dt, \quad (3.3.2)$$

so that

$$\frac{d}{dt} E[p(t) | \mathcal{F}_0] = E[\alpha(p(t), t) | \mathcal{F}_0], \quad E[p(0) | \mathcal{F}_0] = p_0 \quad (3.3.3)$$

defines a system of n ordinary differential equations with initial condition p_0 .

Under standard regularity conditions (e.g., those that will be maintained throughout this section of the chapter), we can denote the unique solution to this system of differential equations as a smooth function of the initial conditions, say $\varphi(p_0, t)$. Note that the general (i.e., unspecified) dependence of $\varphi(\cdot)$ on t admits all sorts of expectations formation processes, as well as potential dependence of the expectations formation process on other economic variables and phenomena.

If (3.3.1) is the “true” data-generating process for future price movements, then the *rational expectations open loop with feedback* solution for the household’s intertemporal choice problem can be written in the form

$$\sup \left\{ \int_0^T e^{-\rho t} u(x(t)) dt : \int_0^T e^{-\rho t} \varphi(p_0, t)' x(t) dt = M_0 \right\}. \quad (3.3.4)$$

However, it is entirely possible that consumers use forecasting models, including myopic, adaptive, or quasi-rational expectations, in formulating their perceptions for how the future economic environment is expected to evolve.

Regardless of the forecasting rule, it is essential to assume that the consuming household carries out only the initial instant of the optimal consumption plan. Once additional information becomes available regarding the realization of prices (and/or other relevant economic phenomena), the household updates its information set according to its filtering mechanism and designs a new intertemporal consumption plan. This is consistent with assumptions made in previous market demand analyses, as well as the manner in which a consumer would behave if it applied the *closed loop*, or *stochastic dynamic programming*, solution concept in formulating an intertemporal consumption plan. Of course, the *open loop* solution in general is not equivalent to the *closed loop* solution. In particular, with price uncertainty, because the dynamic budget constraint is bilinear in prices (a vector of uncontrolled state variables) and consumption purchases (a vector of control variables), it is impossible for the *open loop* and *closed loop* solutions to coincide – even when the instantaneous utility function is quadratic.

The primary advantages to studying open loop with feedback solutions to this class of dynamic consumer choice problems include the following: (1) It permits a direct and clear comparison with static model results, as well as those obtained for dynamic models with myopic expectations or perfect foresight; (2) the closed loop solution does not lend itself readily to any clearly stated or universal comparative statics or dynamics results, and in particular, is highly dependent on the specific structure of the consumer’s preference function as well as the data-generating process for future economic phenomena; and (3) the open loop solution produces a well-defined, intuitively appealing, and easy to understand and interpret set of intertemporal duality results that can be readily related to those obtained for the static neoclassical model of consumer choice.

Therefore, let the system of ordinary differential equations,

$$\dot{p}(t) = \psi(p(t), t), \quad p(0) = p_0, \quad (3.3.5)$$

be the rule that the consumer is presumed to use to form expectations for future prices, where the “ $\dot{\cdot}$ ” over a variable (or vector of variables) denotes the ordinary time derivative. We assume throughout the discussion that $\psi: \mathbb{R}_+^n \times \mathbb{R}_+ \rightarrow \mathbb{R}^n$ is twice continuously differentiable and $|\partial \psi / \partial p'| \neq 0$ throughout its domain. This implies the existence of a unique, twice continuously differentiable solution to the differential equation sys-

tem which defines all future price forecasts as a function of the initial price vector, p_0 , and time, t ,

$$p(t) \equiv \varphi(p_0, t) \equiv p_0 + \int_0^t \psi(\varphi(p_0, \tau), \tau) d\tau. \quad (3.3.6)$$

In addition to the above properties for $\psi(\cdot)$, we shall assume that the solution to the forecasting rule generates strictly positive price forecasts, $\varphi: \mathbb{R}_{++}^n \times \mathbb{R}_+ \rightarrow \mathbb{R}_{++}^n$.

It is a well-accepted stylized empirical fact that observed market prices tend to have common trends. In the present context, the most general statement of such a property is that the forecasting solution, $\varphi(\cdot, t)$, is linearly homogeneous in p_0 . It turns out that this property is necessary and sufficient for the dynamic expenditure function to be linearly homogeneous in current prices in this model. This property can be stated equivalently in terms of the condition that $\psi(\cdot, t)$ is homogeneous of degree one in $p(t) \forall t \in [0, T]$.

LEMMA. $\varphi(\cdot, t)$ is 1° homogeneous in $p_0 \forall (p_0, t) \in \mathbb{R}_{++}^n \times \mathbb{R}_+$, if and only if $\psi(\cdot, t)$ is 1° homogeneous in $p \forall (p, t) \in \mathbb{R}_{++}^n \times \mathbb{R}_+$.

PROOF. Suppose that $\varphi(p, t) \equiv \frac{\partial \varphi(p, t)}{\partial p'} p \forall (p, t) \in \mathbb{R}_{++}^n \times \mathbb{R}_+$. Then

$$\begin{aligned} \frac{\partial \varphi(p_0, t)}{\partial p'_0} &\equiv I + \int_0^t \frac{\partial \psi(\varphi(p_0, \tau), \tau)}{\partial p'} \frac{\partial \varphi(p_0, \tau)}{\partial p'_0} d\tau \\ &\Rightarrow \varphi(p_0, t) \equiv \frac{\partial \varphi(p_0, t)}{\partial p'_0} p_0 \equiv p_0 + \int_0^t \frac{\partial \psi(\varphi(p_0, \tau), \tau)}{\partial p'} \varphi(p_0, \tau) d\tau \\ &\equiv p_0 + \int_0^t \psi(\varphi(p_0, \tau), \tau) d\tau, \end{aligned}$$

where the far right-hand side is the definition of the far left-hand side, while the middle identity follows from the linear homogeneity of $\varphi(\cdot, t)$ in p_0 . Subtracting p_0 from the last two expressions implies

$$\int_0^t \frac{\partial \psi(p(\tau), \tau)}{\partial p'} p(\tau) d\tau \equiv \int_0^t \psi(p(\tau), \tau) d\tau.$$

By the fundamental theorem of calculus, differentiating both sides with respect to t gives

$$\frac{\partial \psi(p(t), t)}{\partial p'} p(t) \equiv \psi(p(t), t).$$

Hence, $\psi(\cdot, t)$ is 1° homogeneous in p by the converse to Euler's theorem, proving necessity.

We verify sufficiency by employing the method of successive approximations to solve the ordinary differential equation system (3.3.5). Each iteration begins with an approximate solution that is linearly homogeneous. We then show that this property is inherited by the subsequent iteration's approximate solution. Induction, and an appeal to the contraction mapping theorem, to verify that the sequence of iterations converges to a unique solution to the ordinary differential equation system that itself must be linearly homogeneous in p_0 conclude the proof.

Let $\varphi^{(0)}(p_0, t) \equiv p_0$, which is trivially 1° homogeneous in p_0 , and define

$$\varphi^{(1)}(p_0, t) \equiv p_0 + \int_0^t \psi(p_0, \tau) d\tau \equiv p_0 + \int_0^t \psi(\varphi^{(0)}(p_0, \tau), \tau) d\tau,$$

so that

$$\begin{aligned} \frac{\partial \varphi^{(1)}(p_0, t)}{\partial p'_0} p_0 &\equiv p_0 + \int_0^t \frac{\partial \psi(p_0, \tau)}{\partial p'_0} p_0 d\tau \\ &\equiv p_0 + \int_0^t \psi(p_0, \tau) d\tau \equiv \varphi^{(1)}(p_0, t), \end{aligned}$$

which therefore also is 1° homogeneous in p_0 . Proceeding by induction, if for any $i \geq 2$, we have

$$\frac{\partial \varphi^{(i-1)}(p_0, t)}{\partial p'_0} p_0 \equiv \varphi^{(i-1)}(p_0, t)$$

and we define

$$\varphi^{(i)}(p_0, t) \equiv p_0 + \int_0^t \psi(\varphi^{(i-1)}(p_0, \tau), \tau) d\tau,$$

then

$$\begin{aligned} \frac{\partial \varphi^{(i)}(p_0, t)}{\partial p'_0} p_0 &\equiv p_0 + \int_0^t \frac{\partial \psi(\varphi^{(i-1)}(p_0, \tau), \tau)}{\partial p'} \cdot \frac{\partial \varphi^{(i-1)}(p_0, \tau)}{\partial p'} p_0 d\tau \\ &\equiv p_0 + \int_0^t \frac{\partial \psi(\varphi^{(i-1)}(p_0, \tau), \tau)}{\partial p'} \cdot \varphi^{(i-1)}(p_0, \tau) d\tau \\ &\equiv p_0 + \int_0^t \psi(\varphi^{(i-1)}(p_0, \tau), \tau) d\tau \equiv \varphi^{(i)}(p_0, t), \end{aligned}$$

and $\varphi^{(i)}(p_0, t)$ is 1° homogeneous in $p_0 \forall i \geq 1$. It follows that the unique solution to the ordinary differential equations,

$$\varphi(p_0, t) \equiv \lim_{i \rightarrow \infty} \varphi^{(i)}(p_0, t),$$

also must be linearly homogeneous in p_0 . □

For the remainder of the chapter, therefore, we assume that the forecasting rule, $\varphi(p_0, t)$, is twice continuously differentiable in (p_0, t) , and increasing, positively linearly homogeneous, and concave in p_0 . As we shall see in the course of the discussion that follows, the last condition is an essential ingredient for concavity of the dynamic expenditure function.

When relative prices change over time and consumers form expectations for future price levels according to some rule that is consistent with (3.3.6), the defining equation for the wealth constraint's shadow price takes the form

$$\int_0^T e^{-rt} u_x^{-1} (e^{-rt} \lambda_0(p_0, M_0) \varphi(p_0, t))' \varphi(p_0, t) dt \equiv M_0. \quad (3.3.7)$$

Consequently, whenever consumers form price expectations in devising their consumption plans, market prices cannot be exogenous in the empirical model.¹⁰ This can be seen most clearly in the case of rational expectations, where $\varphi(p_0, t)$ equals the conditional mean of the price vector at time t given information available at time 0, so that the parameters of the marginal distribution for prices enter the conditional distribution for quantities given prices. The implication is that if consumers form expectations about their future economic environment as they develop consumption plans, then the expectation process must be modeled jointly with demand behavior to obtain consistent and efficient empirical results.

Following the same logic as in the previous subsections, we obtain the instantaneous price and wealth effects on demands to be

$$\frac{\partial h(p_0, M_0, t)}{\partial M_0} \equiv e^{(\rho-r)t} u_{xx}^{-1} \varphi(p_0, t) \frac{\partial \lambda_0(p_0, M_0)}{\partial M_0}, \quad (3.3.8)$$

$$\begin{aligned} & \frac{\partial h(p_0, M_0, t)}{\partial p'_0} \\ & \equiv e^{(\rho-r)t} u_{xx}^{-1} \left[\lambda(p_0, M_0) \frac{\partial \varphi(p_0, t)}{\partial p'_0} + \varphi(p_0, t) \frac{\partial \lambda_0(p_0, M_0)}{\partial p'_0} \right], \end{aligned} \quad (3.3.9)$$

while the impacts of a change in initial prices and wealth on the marginal utility of wealth are

$$\frac{\partial \lambda_0(p_0, M_0)}{\partial p_0} \equiv - \frac{(\int_0^T e^{(\rho-2r)t} (\partial \varphi' / \partial p_0) u_{xx}^{-1} \varphi dt + \int_0^T e^{-rt} (\partial \varphi' / \partial p_0) h dt)}{\int_0^T e^{(\rho-2r)t} \varphi' u_{xx}^{-1} \varphi dt}, \quad (3.3.10)$$

$$\frac{\partial \lambda_0(p_0, M_0)}{\partial M_0} \equiv \frac{1}{\int_0^T e^{(\rho-2r)t} \varphi' u_{xx}^{-1} \varphi dt} < 0. \quad (3.3.11)$$

¹⁰ [Hendry (1995, Chapter 5)], contains an excellent and exhaustive treatment of exogeneity in econometric models.

It follows from the last two equations that λ_0 is -1° homogeneous in (p_0, M_0) if and only if φ is 1° homogeneous in p_0 . This implies that linear homogeneity of the price forecasting rule in current prices is necessary and sufficient for 0° homogeneity of the ordinary demand functions in current prices and wealth. In turn, this latter property is necessary and sufficient for linear homogeneity of the dynamic expenditure function in the initial price vector, p_0 .

In the price forecasting model, the intertemporal Slutsky matrix has the form

$$\begin{aligned} S &\equiv \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} \frac{\partial h}{\partial p'_0} dt + \left(\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} \frac{\partial h}{\partial M_0} dt \right) \times \left(\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h dt \right)' \\ &\equiv \lambda_0 \left[\int_0^T e^{(\rho-2r)t} \frac{\partial \varphi'}{\partial p_0} u_{xx}^{-1} \frac{\partial \varphi}{\partial p'_0} dt \right. \\ &\quad \left. - \frac{(\int_0^T e^{(\rho-2r)t} (\partial \varphi' / \partial p_0) u_{xx}^{-1} \varphi dt) (\int_0^T e^{(\rho-2r)t} (\partial \varphi' / \partial p_0) u_{xx}^{-1} \varphi dt)'}{\int_0^T e^{(\rho-2r)t} \varphi' u_{xx}^{-1} \varphi dt} \right], \end{aligned} \quad (3.3.12)$$

a symmetric, negative semidefinite matrix with rank no greater than $n - 1$.¹¹ Notwithstanding the effects of the additional terms $\partial \varphi' / \partial p_0$, the relationship between the intertemporal Marshallian and wealth-compensated (Hicksian) demands remains the same as in the previous subsection.

However, the dynamic Slutsky matrix no longer is the Hessian matrix for the dynamic expenditure function. In particular, the dynamic envelope theorem now implies

$$\frac{\partial E(p_0, U_0)}{\partial p_0} \equiv \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} g(p_0, U_0, t) dt, \quad (3.3.13)$$

where $g(p_0, U_0, t)$ is the time t vector of Hicksian demands, which solve the dynamic expenditure minimization problem

$$E(p_0, U_0) \equiv \inf_{\{x(t)\}} \left\{ \int_0^T e^{-rt} \varphi(p_0, t)' x(t) dt : \int_0^T e^{-\rho t} u(x(t)) dt = U_0 \right\}. \quad (3.3.14)$$

Differentiating (3.3.13) with respect to p_0 therefore implies

$$\begin{aligned} \frac{\partial^2 E(p_0, U_0)}{\partial p_0 \partial p'_0} &\equiv \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} \frac{\partial g(p_0, U_0, t)}{\partial p'_0} dt \\ &\quad + \sum_{i=1}^n \int_0^T e^{-rt} g_i(p_0, U_0, t) \frac{\partial^2 \varphi_i(p_0, t)}{\partial p_0 \partial p'_0} dt \end{aligned}$$

¹¹ If $\text{rank}(\partial \varphi / \partial p')$ is constant $\forall t \in [0, T]$, then $\text{rank}(S) = \min\{n - 1, \text{rank}(\partial \varphi / \partial p')\}$.

$$\equiv S + \sum_{i=1}^n \int_0^T e^{-rt} g_i(p_0, U_0, t) \frac{\partial^2 \varphi_i(p_0, t)}{\partial p_0 \partial p'_0} dt, \quad (3.3.15)$$

where $\lambda_0(p_0, E(p_0, U_0)) \equiv 1/\mu_0(p_0, U_0)$ has been used on the right-hand side. It follows that, in general, the dynamic expenditure function will be concave in p_0 only if all of the components of the price expectation rule are jointly concave in the initial price vector.

Introducing a general class of forecasting rules results in only minor changes to the duality between the dynamic indirect utility and expenditure functions. Writing the utility maximization and expenditure minimization problems in their isoperimetric forms for the present case,

$$V(p_0, M_0) \equiv \sup_{\{x(t)\}} \left\{ \int_0^T e^{-\rho t} u(x(t)) dt : \int_0^T e^{-rt} \varphi(p_0, t)' x(t) dt = M_0 \right\}, \quad (3.3.16)$$

$$E(p_0, U_0) \equiv \inf_{\{x(t)\}} \left\{ \int_0^T e^{-rt} \varphi(p_0, t)' x(t) dt : \int_0^T e^{-\rho t} u(x(t)) dt = U_0 \right\}, \quad (3.3.17)$$

it follows that

$$M_0 \equiv E(p_0, V(p_0, M_0)) \quad \text{and} \quad U_0 \equiv V(p_0, E(p_0, U_0)).$$

Consequently, (3.2.29)–(3.2.32) remain unchanged, (3.2.35) becomes (3.3.15), and (3.2.33) and (3.2.34), respectively, become:

$$\begin{aligned} \frac{\partial E(p_0, U_0)}{\partial p_0} &\equiv \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} g(p_0, U_0, t) dt \\ &\equiv \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} h(p_0, E(p_0, U_0), t) dt \\ &\equiv - \frac{\partial V(p_0, E(p_0, U_0))/\partial p_0}{\partial V(p_0, E(p_0, U_0))/\partial M_0}; \end{aligned} \quad (3.3.18)$$

and

$$\begin{aligned} \frac{\partial g(p_0, U_0, t)}{\partial p'_0} &\equiv \frac{\partial h(p_0, E(p_0, U_0), t)}{\partial p'_0} + \frac{\partial h(p_0, E(p_0, U_0), t)}{\partial M_0} \\ &\quad \times \left(\int_0^T e^{-rt} \frac{\partial \varphi(p_0, \tau)'}{\partial p_0} h(p_0, E(p_0, U_0), \tau) d\tau \right)'. \end{aligned} \quad (3.3.19)$$

Similarly, the dynamic envelope theorem for the indirect utility function previously given in (3.2.13) above now takes the form

$$\frac{\partial V(p_0, M_0)}{\partial p_0} \equiv -\lambda_0 \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} h(p_0, M_0, t) dt, \quad (3.3.20)$$

while (3.2.14) continues to be $\partial V(p_0, M_0)/\partial M_0 \equiv \lambda_0(p_0, M_0)$. Note the effect of initial prices on future price expectations. This plays a significant role in each of the above results, determining when the dynamic expenditure function is 1° homogeneous and concave in prices, as well as the functional expressions for the dynamic envelope theorem and the instantaneous and intertemporal Slutsky equations.

4. Dynamic household production theory

This section merges household production theory with the theory of consumer choice over time. In this context, it is natural to incorporate durable goods into the household's production process. The basic model structure and variable definitions are analogous to previous sections, with $x(t)$ an n -vector of flows of consumable market goods used at time t , $z(t)$ an m -vector of flows of nonmarket commodities produced by the household and which generate utility directly, and $k(t)$ an ℓ -vector of stocks of household durables, some of which may be interpreted as consumption habits. We continue to take the household's objective to be to maximize the present value of discounted lifetime utility flows, but the flow of produced nonmarket commodities is now presumed to generate the flow of consumer satisfaction,

$$U = \int_0^T e^{-\rho t} u(z(t)) dt. \quad (4.1)$$

The efficient boundary of the household production possibility set for each point in time is defined by the joint consumables/durables/commodities transformation function

$$G(x(t), k(t), z(t), \beta, t) \leq 0, \quad (4.2)$$

where β is an s -vector of quality characteristics of both the consumables and durables and the index t tacitly implies that the feasible household production possibilities set may vary over time.¹² The rates of change in the household's holdings of durable stocks are defined by the differential equations,

$$\dot{k}(t) = f(x(t), k(t), \gamma, t), \quad k(0) = k_0, \quad \text{fixed}, \quad (4.3)$$

¹² One possibility is that the characteristics of market goods vary over time with consumer expectations for these changes modeled similarly as for price expectations in Section 3.3 above. This would imply that β in Equation (4.2) tacitly represents goods characteristics at the initial date in the planning horizon, while the structure of $f(\cdot)$ reflects the consuming household's expectations for both future household production technology and goods qualities.

where γ is a vector of durable goods' characteristics that affect the rates of accumulation and/or decay. The household's life cycle budget constraint is defined by

$$M_0 = \int_0^T e^{-rt} p(t)' x(t) dt. \quad (4.4)$$

We begin with a straightforward extension of Theorem 2 to show that the derived instantaneous utility function defined over consumables, durables, qualities, and time,

$$u^*(x, k, \beta, t) \equiv \sup_{z \geq 0} \{u(z): G(x, k, z, \beta, t) \leq 0\} \quad (4.5)$$

is jointly strongly concave in (x, k) and increasing (decreasing) in x_i or k_j if and only if $f(\cdot)$ is increasing (decreasing) in the corresponding x_i or k_j . This implies that the *instantaneous myopic indirect utility function*,

$$v(p, m, k, \beta, t) \equiv \sup_{x \geq 0} \{u^*(x, k, \beta, t): p'x \leq m\}, \quad (4.6)$$

is neoclassical in (p, m) , i.e., $v(\cdot, k, \beta, t)$ is continuous and 0° homogeneous in (p, m) , increasing in m , and decreasing and quasiconvex in p . The corresponding myopic ordinary demands, $x = \tilde{h}(p, m, k, \beta, t)$, therefore also possess all of the neoclassical properties, while reflecting the structure commonly known as *naive habit formation*.

Continuity of $f(\cdot)$ and $\tilde{h}(\cdot)$ implies that there is a unique solution for the time path of household durable holdings defined by

$$\hat{k}(k_0, \beta, t) \equiv k_0 + \int_0^t f(\tilde{h}(p(\tau), m(\tau), \hat{k}(k_0, \beta, \tau), \beta, \tau), \hat{k}(k_0, \beta, \tau), \beta, \tau) d\tau. \quad (4.7)$$

Note that $\hat{k}(k_0, \beta, t)$ depends upon all past prices and consumption expenditures. This implies the following for consumption models under naive habit formation:

- (a) Current stocks of durables cannot be *weakly exogenous*.
- (b) Preferences are *intertemporally inconsistent*, i.e., current preferences depend on the entire history of past consumption choices.
- (c) Consumers are assumed to understand the effects of changes in household durables on the solution to their instantaneous utility maximization problem, but to ignore this when planning for future consumption.
- (d) If consumers are assumed to be naive regarding the influence of current consumption on future preferences and consumption possibilities, then only the assumption of myopic price expectations avoids a logical contradiction regarding household planning and foresight.

This essentially summarizes the current state of the art in empirical demand analysis, particularly with respect to foodstuffs and agricultural products. With very few exceptions, extant empirical demand analyses incorporate naive habit formation and myopic

price expectations. There are, perhaps, many reasons for this. Household holdings of durable stocks, including real capital items, are often unobservable, particularly when one is using aggregate time series data. Consequently, lagged quantities demanded of the consumable, nondurable goods are generally used to proxy these as well as other unobservable trends in the data. Even with the simplification that results when lagged quantities are used to proxy habits and other missing consumption trends, however, incorporating rational habit persistence in demand is difficult and complicated [Browning (1991); Lluch (1973); Pashardes (1986); Spinnewyn (1981)]. *Rational habit formation* also suggests *rational expectations*, or at least expectations other than myopic. This complicates the econometric analysis even further.

In this context, it is important to analyze the economics of dynamic models of household production and consumption that includes expectations processes and a dynamic accounting of the effects of changes in the level of household durables. With regard to future expectations, we will maintain our focus on prices, smooth expectation rules, and the open loop with feedback control solution concept. However, the analysis of this section could be readily extended to include future expectations for other economic factors as deemed appropriate by the analyst. Also, our main focus continues to be establishing an internally consistent duality theory of the dynamic household production model.

When the household production technology is time-dependent, e.g., as a result of technological change, the derived instantaneous utility function over consumable market goods and household stocks is a function of time, t . Hence, to reduce the notational burden, define $\tilde{u}(x, k, \beta, t) \equiv e^{-\rho t} u^*(x, k, \beta, t)$. The consumer's decision problem now is to solve

$$\begin{aligned} V(p_0, M_0, k_0, \beta, \gamma) \\ \equiv \sup \left\{ \int_0^T \tilde{u}(x, k, \beta, t) dt : M_0 = \int_0^T e^{-rt} \varphi' x dt, \dot{k} = f(x, k, \gamma, t), \right. \\ \left. k(0) = k_0, k(T) \geq 0 \right\}. \end{aligned} \quad (4.8)$$

Let ω be the ℓ -vector of co-state variables (i.e., shadow prices) for the equations of motion for household durables and let λ be the co-state variable for the equation of motion for the present value of wealth. Then the Hamiltonian can be written as

$$H = \tilde{u}(x, k, \beta, t) + \omega' f(x, k, \gamma, t) - \lambda e^{-rt} \varphi' x. \quad (4.9)$$

To simplify the discussion, we assume that (a) the Hamiltonian is jointly concave in (x, k) , (b) for each $t \in [0, T)$, $\tilde{u} + \omega' g$ is strictly increasing in x throughout an $n + \ell + 1$ -dimensional open tube in the neighborhood of the optimal path, and (c) the optimal path satisfies $(x^*(t), k^*(t)) \gg (0, 0) \forall t \in [0, T)$. Then the necessary and sufficient first-order conditions plus the transversality conditions for the optimal path are:

$$\frac{\partial H}{\partial x} = \frac{\partial \tilde{u}}{\partial x} + \frac{\partial f'}{\partial x} \omega - \lambda e^{-rt} p = 0; \quad (4.10)$$

$$\frac{\partial H}{\partial k} = \frac{\partial \bar{u}}{\partial k} + \frac{\partial f'}{\partial k} \omega = -\dot{\omega}; \quad (4.11)$$

$$\frac{\partial H}{\partial M} = 0 = -\dot{\lambda}; \quad (4.12)$$

$$\frac{\partial H}{\partial \omega} = f = \dot{k}, \quad k(0) = k_0, \quad k(T) \geq 0; \quad (4.13)$$

$$\frac{\partial H}{\partial \lambda} = -e^{-rt} \varphi' x = \dot{M}, \quad M(0) = M_0, \quad M(T) = 0; \quad \text{and} \quad (4.14)$$

$$\omega_j(T) k_j(T) = 0 \quad \forall j = 1, \dots, \ell. \quad (4.15)$$

At time t , the optimal Marshallian demands, stocks of household durable goods, and shadow prices are

$$x^*(t) \equiv h(p_0, M_0, k_0, \beta, \gamma, t), \quad (4.16)$$

$$k^*(t) \equiv \kappa(p_0, M_0, k_0, \beta, \gamma, t), \quad (4.17)$$

$$\omega^*(t) \equiv \omega(p_0, M_0, k_0, \beta, \gamma, t), \quad \text{and} \quad (4.18)$$

$$\lambda^*(t) \equiv \lambda_0(p_0, M_0, k_0, \beta, \gamma), \quad (4.19)$$

respectively. Differentiating the *intertemporal budget identity*, $\int_0^T e^{-rt} \varphi' h \, dt \equiv M_0$, with respect to p_0 and M_0 generates the *intertemporal Cournot aggregation* and the *intertemporal Engel aggregation*, respectively,

$$\int_0^T e^{-rt} \left[\frac{\partial \varphi'}{\partial p_0} h + \frac{\partial h'}{\partial p_0} \varphi \right] dt \equiv 0, \quad \text{and} \quad (4.20)$$

$$\int_0^T e^{-rt} \varphi' \frac{\partial h}{\partial M_0} dt \equiv 1. \quad (4.21)$$

Now, to minimize the notational clutter, define the following blocks of Hessian terms: $H_{xx} \equiv \bar{u}_{xx} + \sum_{i=1}^{\ell} \omega_i f_{xx}^i$; $H_{xk} \equiv \bar{u}_{xk} + \sum_{i=1}^{\ell} \omega_i f_{xk}^i$; and $H_{kk} \equiv \bar{u}_{kk} + \sum_{i=1}^{\ell} \omega_i f_{kk}^i$. Then, following exactly the same steps as in the previous section, we obtain

$$\frac{\partial h}{\partial p'_0} = H_{xx}^{-1} \left[e^{-rt} \left(\lambda_0 \frac{\partial \varphi}{\partial p'_0} + \varphi \frac{\partial \lambda_0}{\partial p'_0} \right) - H_{xk} \frac{\partial \kappa}{\partial p'_0} - \frac{\partial f'}{\partial x} \frac{\partial \omega}{\partial p'_0} \right], \quad (4.22)$$

$$\frac{\partial \lambda_0}{\partial p_0} = \frac{-\int_0^T e^{-rt} \left\{ \frac{\partial \varphi'}{\partial p_0} h + \left[e^{-rt} \lambda_0 \frac{\partial \varphi'}{\partial p_0} - \frac{\partial \kappa'}{\partial p_0} H_{kx} - \frac{\partial \omega'}{\partial p_0} \frac{\partial f'}{\partial x'} \right] H_{xx}^{-1} \varphi \right\} dt}{\int_0^T e^{-2rt} \varphi' H_{xx}^{-1} \varphi \, dt}, \quad (4.23)$$

$$\frac{\partial h}{\partial M_0} = H_{xx}^{-1} \left[e^{-rt} \varphi \frac{\partial \lambda_0}{\partial M_0} - H_{xk} \frac{\partial \kappa}{\partial M_0} - \frac{\partial f'}{\partial x} \frac{\partial \omega}{\partial M_0} \right], \quad (4.24)$$

$$\begin{aligned}
\frac{\partial \lambda_0}{\partial M_0} &= \frac{1 + \int_0^T e^{-rt} \varphi' H_{xx}^{-1} \left(H_{xk} \frac{\partial \kappa}{\partial M_0} + \frac{\partial f'}{\partial x} \frac{\partial \omega}{\partial M_0} \right) dt}{\int_0^T e^{-2rt} \varphi' H_{xx}^{-1} \varphi dt}, \quad \text{and} \\
&\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} \frac{\partial h}{\partial p'_0} dt + \left(\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} \frac{\partial h}{\partial M_0} dt \right) \left(\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h dt \right)' \\
&= \lambda_0 \left[\int_0^T e^{-2rt} \frac{\partial \varphi'}{\partial p_0} H_{xx}^{-1} \frac{\partial \varphi}{\partial p'_0} dt \right. \\
&\quad \left. - \frac{\left(\int_0^T e^{-2rt} \frac{\partial \varphi'}{\partial p_0} H_{xx}^{-1} \varphi dt \right) \left(\int_0^T e^{-2rt} \frac{\partial \varphi'}{\partial p_0} H_{xx}^{-1} \varphi dt \right)'}{\int_0^T e^{-2rt} \varphi' H_{xx}^{-1} \varphi dt} \right] \\
&\quad + \frac{\left(\int_0^T e^{-2rt} \frac{\partial \varphi'}{\partial p_0} H_{xx}^{-1} \varphi dt \right)}{\int_0^T e^{-2rt} \varphi' H_{xx}^{-1} \varphi dt} \left\{ \int_0^T e^{-2rt} \varphi' H_{xx}^{-1} \left(H_{xk} \frac{\partial \kappa}{\partial p'_0} + \frac{\partial f'}{\partial x} \frac{\partial \omega}{\partial p'_0} \right) dt \right. \\
&\quad \left. + \left[\int_0^T e^{-rt} \varphi' H_{xx}^{-1} \left(H_{xk} \frac{\partial \kappa}{\partial M_0} + \frac{\partial f'}{\partial x} \frac{\partial \omega}{\partial M_0} \right) dt \right] \left(\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h dt \right)' \right\} \\
&\quad - \left[\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} H_{xx}^{-1} \left(H_{xk} \frac{\partial \kappa}{\partial M_0} + \frac{\partial f'}{\partial x} \frac{\partial \omega}{\partial M_0} \right) dt \right] \left(\int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h dt \right)'.
\end{aligned} \tag{4.26}$$

Note, in particular, the added complexity of the intertemporal wealth-compensated price effects represented by the additional terms in the last three lines of (4.26). Even symmetry, much less negativity or homogeneity, of all but the first matrix on the right-hand side is highly complex and extremely difficult to prove using the direct methods of the previous sections. Therefore, we will pursue another approach to the intertemporal duality of the dynamic household production and consumption problem (4.8).

This alternative way of looking at problems of this type has several advantages. The approach is simple and both heuristically and pedagogically appealing. It establishes a connection between the duality of static models and both discrete and continuous dynamic models, including the envelope theorem, adding up, homogeneity, symmetry and negativity, and the relationships between utility maximization and expenditure minimization. Finally, and at least as important as the simple and clear derivations, the arguments are valid for a very large class of problems – essentially all of optimal control theory.¹³

¹³ In other words, once the necessary and sufficient conditions for an optimal solution path have been identified, the arguments of this section remain valid for: (a) absolutely bounded Lebesgue measurable controls; (b) nondifferential inequality and equality constraints; and (c) a countable number of switch points along the optimal path. The interested reader is referred to [LaFrance and Barney (1991)] for a discussion of a set of conditions and derivations for the special case in which (c) is tightened to a finite number of switch points.

We proceed by defining the “Lagrangian” function for (4.8) by

$$\begin{aligned}\ell_1 &\equiv \int_0^T \tilde{u} \, dt + \lambda \left(M_0 - \int_0^T e^{-rt} \varphi' x \, dt \right) + \int_0^T \omega' (f - \dot{k}) \, dt \\ &\equiv \int_0^T (\tilde{u} - \lambda e^{-rt} \varphi' x + \omega' f + \dot{\omega}' k) \, dt + \lambda M_0 + \omega(0)' k_0 - \omega(T)' k(T),\end{aligned}\quad (4.27)$$

where the second line follows from integrating the term $-\omega' \dot{k}$ by parts. Finding the pointwise maximum with respect to x of either the first or second lines of (4.27) reproduces first-order condition (4.10). Similarly, minimizing either expression for ℓ_1 with respect to λ reproduces (4.14) and also motivates the constant marginal utility of money condition given in (4.12). On the other hand, pointwise minimization of the first line of (4.27) with respect to ω gives (4.13), while pointwise maximization of the second line with respect to k generates (4.11). Also note that when the first-order conditions are satisfied $\forall t \in [0, T]$, the integrals of the constraints multiplied by their associated shadow prices vanish. This, in turn, implies that $\ell_1^*(p_0, M_0, k_0, \beta, \gamma) \equiv V(p_0, M_0, k_0, \beta, \gamma)$. From the second line of (4.27), this simple observation immediately generates the following pair of dynamic envelope theorem results:

$$\frac{\partial V}{\partial M_0} \equiv \lambda_0 > 0; \quad \text{and} \quad (4.28)$$

$$\frac{\partial V}{\partial k_0} \equiv \omega(p_0, M_0, k_0, \beta, \gamma, 0). \quad (4.29)$$

Several other dynamic envelope theorem results, as well as symmetry, curvature, and homogeneity properties also can be derived from the Lagrangian in (4.27). We do so in detail here for $\partial V / \partial p_0$ to illustrate the basic logic. We follow this with a statement of the properties of the dynamic indirect utility function for this problem. We then proceed with a brief development of the properties of the dynamic expenditure function. We conclude this section with a statement of the intertemporal duality for this problem.

We first proceed by substituting (4.16)–(4.19) into (4.27) to generate $\ell_1^*(p_0, M_0, k_0, \beta, \gamma)$. Then we differentiate the resulting expression term-by-term with respect to p_0 , which gives

$$\begin{aligned}\frac{\partial \ell_1^*}{\partial p_0} &\equiv \int_0^T \frac{\partial h'}{\partial p_0} \overbrace{\left(\frac{\partial \tilde{u}}{\partial x} - \lambda e^{-rt} \varphi + \frac{\partial f'}{\partial x} \omega \right)}^{\equiv 0} \, dt + \int_0^T \frac{\partial \kappa'}{\partial p_0} \overbrace{\left(\frac{\partial \tilde{u}}{\partial k} + \frac{\partial f'}{\partial k} \omega + \dot{\omega} \right)}^{\equiv 0} \, dt \\ &\quad + \frac{\partial \lambda_0}{\partial p_0} \overbrace{\left(M_0 - \int_0^T e^{-rt} \varphi' h \, dt \right)}^{\equiv 0} - \lambda_0 \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h \, dt\end{aligned}$$

$$\begin{aligned}
& + \int_0^T \frac{\partial \omega'}{\partial p_0} f \, dt + \int_0^T \frac{\partial^2 \omega'}{\partial t \partial p_0} \kappa \, dt + \frac{\partial \omega(\cdot, 0)'}{\partial p_0} k_0 \\
& - \frac{\partial \omega(\cdot, T)'}{\partial p_0} \kappa(\cdot, T) - \overbrace{\frac{\partial \kappa(\cdot, T)'}{\partial p_0} \omega(\cdot, T)}^{\equiv 0},
\end{aligned} \tag{4.30}$$

where the first three terms vanish by the first-order conditions (4.10)–(4.14) and the final term vanishes by the transversality conditions (4.15). Given the properties hypothesized for $\tilde{u}(\cdot)$, $f(\cdot)$, and $\varphi(\cdot)$, the Marshallian demands and the marginal utility of money are continuously differentiable, while the household durables and their shadow prices are twice continuously differentiable. Hence, by Young's theorem, we can integrate the terms $(\partial^2 \omega / \partial t \partial p_0) \kappa \equiv (\partial^2 \omega / \partial p_0 \partial t) \kappa$ by parts, which gives

$$\int_0^T \frac{\partial^2 \omega}{\partial p_0 \partial t} \kappa \, dt \equiv \frac{\partial \omega(\cdot, T)'}{\partial p_0} \kappa(\cdot, T) - \frac{\partial \omega(\cdot, 0)'}{\partial p_0} k_0 - \int_0^T \frac{\partial \omega}{\partial p_0} \frac{\partial \kappa}{\partial t} \, dt. \tag{4.31}$$

Canceling the terms that vanish on the right-hand side of (4.30) and substituting the right-hand side of (4.31) into (4.30) gives

$$\begin{aligned}
\frac{\partial \ell_1}{\partial p_0} & \equiv -\lambda_0 \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h \, dt + \int_0^T \frac{\partial \omega'}{\partial p_0} \overbrace{\left(f - \frac{\partial \kappa}{\partial t} \right)}^{\equiv 0} \, dt \\
& \equiv -\lambda_0 \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h \, dt.
\end{aligned} \tag{4.32}$$

Applying the identity $\ell_1^*(p_0, M_0, k_0, \beta, \gamma) \equiv V(p_0, M_0, k_0, \beta, \gamma)$ we therefore can state the dynamic envelope theorem with respect to the initial price vector as

$$\frac{\partial V}{\partial p_0} \equiv \int_0^T \left(\frac{\partial h'}{\partial p_0} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \kappa'}{\partial p_0} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv -\lambda_0 \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h \, dt. \tag{4.33}$$

We follow essentially the same steps for each of the other sets of parameters to obtain the following list of properties for the dynamic indirect utility function.

THEOREM 6. *The dynamic indirect utility function in (4.8) is twice continuously differentiable in $(p_0, M_0, k_0, \beta, \gamma)$ and satisfies*

$$\frac{\partial V}{\partial p_0} \equiv \int_0^T \left(\frac{\partial h'}{\partial p_0} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \kappa'}{\partial p_0} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv -\lambda_0 \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} h \, dt; \tag{6.a}$$

$$\frac{\partial V}{\partial M_0} \equiv \int_0^T \left(\frac{\partial h'}{\partial M_0} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \kappa'}{\partial M_0} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv \lambda_0 > 0; \tag{6.b}$$

$$\frac{\partial V}{\partial k_0} \equiv \int_0^T \left(\frac{\partial h'}{\partial k_0} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \kappa'}{\partial k_0} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv \omega(\cdot, 0); \quad (6.c)$$

$$\frac{\partial V}{\partial \beta} \equiv \int_0^T \left(\frac{\partial h'}{\partial \beta} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \kappa'}{\partial \beta} \frac{\partial \tilde{u}}{\partial k} + \frac{\partial \tilde{u}}{\partial \beta} \right) dt \equiv \int_0^T \frac{\partial \tilde{u}}{\partial \beta} dt; \quad \text{and} \quad (6.d)$$

$$\frac{\partial V}{\partial \gamma} \equiv \int_0^T \left(\frac{\partial h'}{\partial \gamma} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \kappa'}{\partial \gamma} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv \int_0^T \frac{\partial f'}{\partial \beta} \omega dt; \quad (6.e)$$

If $\varphi(\cdot, t)$ is 1° homogeneous in p_0 , then $V(\cdot, k_0, \beta, \gamma)$ is

$$0^\circ \text{ homogeneous in } (p_0, M_0); \quad (6.f)$$

If $\varphi(\cdot, t)$ is increasing and concave in p_0 , then $V(\cdot, k_0, \beta, \gamma)$

$$\text{is decreasing and quasiconvex in } p_0. \quad (6.g)$$

In addition, the dynamic Marshallian demand functions satisfy the intertemporal budget identity, Cournot aggregation, Engel aggregation, and Roy's identity,

$$\int_0^T e^{-rt} \varphi' h dt \equiv M_0, \quad (6.h)$$

$$\int_0^T e^{-rt} \left[\frac{\partial \varphi'}{\partial p_0} h + \frac{\partial h'}{\partial p_0} \varphi \right] dt \equiv 0, \quad (6.i)$$

$$\int_0^T e^{-rt} \varphi' \frac{\partial h}{\partial M_0} dt \equiv 1, \quad \text{and} \quad (6.j)$$

$$-\frac{\partial V / \partial p_0}{\partial V / \partial M_0} \equiv \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} dt, \quad \text{respectively.} \quad (6.k)$$

The properties of the dynamic expenditure function,

$$\begin{aligned} E(p_0, U_0, k_0, \beta, \gamma) \\ \equiv \inf \left\{ \int_0^T e^{-rt} \varphi' x dt : u_0 = \int_0^T \tilde{u}(x, k, \beta, t) dt, \dot{k} = f(x, k, \gamma, t), \right. \\ \left. k(0) = k_0, k(T) \geq 0 \right\}, \end{aligned} \quad (4.34)$$

are derived in a similar way. We first define the Lagrangean function for the consumer's intertemporal cost minimization problem as

$$\begin{aligned} \ell_2 &\equiv \int_0^T e^{-rt} \varphi' x dt + \mu \left(U_0 - \int_0^T \tilde{u} dt \right) + \int_0^T \psi' (\dot{k} - f) dt \\ &\equiv \int_0^T (e^{-rt} \varphi' x dt - \mu \tilde{u} - \psi' f - \dot{\psi} k) dt + \mu U_0 + \psi(T)' k(T) - \psi(0)' k_0, \end{aligned} \quad (4.35)$$

where μ is the shadow price on the discounted utility constraint, ψ is the vector of shadow prices for the equations of motion for household durable goods, and as before, the second line of (4.35) is obtained by integrating the terms $\psi' \dot{k}$ by parts. We continue to assume that $(x^*(t), k^*(t)) \gg (\mathbf{0}, \mathbf{0}) \forall t \in [0, T]$, as well as the previous regularity conditions for $\tilde{u}(\cdot)$ and $f(\cdot)$.

The necessary and sufficient first-order conditions for the unique optimal path now are:

$$e^{-rt} \varphi - \mu \frac{\partial \tilde{u}}{\partial x} - \frac{\partial f'}{\partial x} \psi = \mathbf{0}; \quad (4.36)$$

$$\mu \frac{\partial \tilde{u}}{\partial k} + \frac{\partial f'}{\partial k} \psi + \dot{\psi} = \mathbf{0}; \quad (4.37)$$

$$\dot{\mu} = 0; \quad (4.38)$$

$$f = \dot{k}, \quad k(0) = k_0, \quad k(T) \geq \mathbf{0}; \quad \text{and} \quad (4.39)$$

$$U_0 = \int_0^T \tilde{u} \, dt; \quad (4.40)$$

together with the transversality conditions

$$\psi_j(T) k_j(T) = 0 \quad \forall j = 1, \dots, \ell. \quad (4.41)$$

At time t , the optimal Hicksian demands, stocks of household durable goods, and shadow prices are

$$x^*(t) \equiv g(p_0, U_0, k_0, \beta, \gamma, t), \quad (4.42)$$

$$k^*(t) \equiv \xi(p_0, U_0, k_0, \beta, \gamma, t), \quad (4.43)$$

$$\psi^*(t) \equiv \psi(p_0, U_0, k_0, \beta, \gamma, t), \quad \text{and} \quad (4.44)$$

$$\mu^*(t) \equiv \mu_0(p_0, U_0, k_0, \beta, \gamma), \quad (4.45)$$

respectively.

The first-order conditions imply that the optimal Lagrangean function and the dynamic expenditure function satisfy

$$\begin{aligned} \ell_2^*(p_0, U_0, k_0, \beta, \gamma) &\equiv E(p_0, U_0, k_0, \beta, \gamma) \\ &\equiv \int_0^T e^{-rt} \varphi(p_0, t)' g(p_0, U_0, k_0, \beta, \gamma, t) \, dt. \end{aligned} \quad (4.46)$$

This, in turn, when combined with the discounted utility constraint, $U_0 \equiv \int_0^T \tilde{u} \, dt$, implies the following set of properties for $E(p_0, U_0, k_0, \beta, \gamma)$:

THEOREM 7. *The dynamic expenditure function in (4.35) is twice continuously differentiable in $(p_0, U_0, k_0, \beta, \gamma)$ and satisfies:*

$$\frac{\partial E}{\partial p_0} \equiv \int_0^T e^{-rt} \frac{\partial \varphi'}{\partial p_0} g \, dt; \quad (7.a)$$

$$\frac{\partial E}{\partial U_0} \equiv \mu_0 > 0; \quad (7.b)$$

$$\frac{\partial E}{\partial k_0} \equiv -\psi(\cdot, 0); \quad (7.c)$$

$$\frac{\partial E}{\partial \beta} \equiv \int_0^T e^{-rt} \frac{\partial g'}{\partial \beta} \varphi \, dt = -\mu_0 \int_0^T \frac{\partial \tilde{u}}{\partial \beta} \, dt; \quad \text{and} \quad (7.d)$$

$$\frac{\partial E}{\partial \gamma} \equiv \int_0^T e^{-rt} \frac{\partial g'}{\partial \gamma} \varphi \, dt = -\int_0^T \frac{\partial f'}{\partial \gamma} \varphi \, dt; \quad (7.e)$$

$$E(\cdot, U_0, k_0, \beta, \gamma) \text{ is } 1^\circ \text{ homogeneous in } p_0 \text{ if and only if } \varphi(\cdot, t) \\ \text{is } 1^\circ \text{ homogeneous in } p_0; \quad (7.f)$$

If $\varphi(\cdot, t)$ is increasing and concave in p_0 , then $E(\cdot, U_0, k_0, \beta, \gamma)$ is increasing and concave in p_0 , with Hessian matrix defined by

$$\frac{\partial^2 E}{\partial p_0 \partial p'_0} \equiv \int_0^T e^{-rt} \left(\sum_{i=1}^n g^i \frac{\partial^2 \varphi'_i}{\partial p_0 \partial p'_0} + \frac{\partial \varphi'}{\partial p_0} \frac{\partial g}{\partial p'_0} \right) dt. \quad (7.g)$$

In addition, the dynamic Hicksian demand functions and the expenditure minimizing demands for household durables satisfy:

$$\int_0^T \tilde{u}(g, \xi, \beta, t) \, dt \equiv U_0; \quad (7.h)$$

$$\int_0^T \left(\frac{\partial g'}{\partial p_0} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \xi'}{\partial p_0} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv \mathbf{0}; \quad (7.i)$$

$$\int_0^T \left(\frac{\partial g'}{\partial U_0} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \xi'}{\partial U_0} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv 1; \quad (7.j)$$

$$\int_0^T \left(\frac{\partial g'}{\partial \beta} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \xi'}{\partial \beta} \frac{\partial \tilde{u}}{\partial k} + \frac{\partial \tilde{u}}{\partial \beta} \right) dt \equiv \mathbf{0}; \quad \text{and} \quad (7.k)$$

$$\int_0^T \left(\frac{\partial g'}{\partial \gamma} \frac{\partial \tilde{u}}{\partial x} + \frac{\partial \xi'}{\partial \gamma} \frac{\partial \tilde{u}}{\partial k} \right) dt \equiv \mathbf{0}. \quad (7.l)$$

The final piece of the puzzle is to establish the dual relationship between the dynamic expenditure and indirect utility functions as inverses to each another with respect to their $(n+1)$ st arguments. We now will show that if $U_0 = V(p_0, M_0, k_0, \beta, \gamma)$, then $E(p_0, V(p_0, M_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \equiv M_0$; equivalently, if $M_0 = E(p_0, U_0, k_0, \beta, \gamma)$, then $V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \equiv U_0$. Intuitively, this seems obvious. The

minimum present value of discounted consumption expenditures necessary to obtain the maximum present value of discounted utility flows that can be afforded with initial wealth M_0 must be M_0 . Utilizing the Lagrangeans in (4.27) and (4.35) makes the proofs nearly as obvious.

The intuition actually is quite simple. From Theorem 4, recall that in the static case, $\mu(p, u, b) \equiv 1/\lambda(p, e(p, u, b), b)$, and similarly, $\lambda(p, m, b) \equiv 1/\mu(p, v(p, m), b)$, where λ is the marginal utility of money, μ is the marginal cost of utility, and the first-order conditions for expenditure minimization and utility maximization are identical when income is set equal to expenditure. In the dynamic case, we will show that analogous properties hold, although the argument is slightly more involved.

Let $M_0 = E(p_0, U_0, k_0, \beta, \gamma)$, and note that

$$\begin{aligned} \ell_1^*(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \\ &\equiv \int_0^T \tilde{u}(h(p_0, E(p_0, U_0, k_0, \beta, \gamma, t), k_0, \beta, \gamma, t), \\ &\quad \kappa(p_0, E(p_0, U_0, k_0, \beta, \gamma, t), \beta, \gamma, t), \beta, t) dt \\ &\equiv V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \geq U_0, \end{aligned} \quad (4.47)$$

where the inequality follows from maximization and the fact that U_0 is affordable. Writing out ℓ_1^* explicitly, we have

$$\begin{aligned} 0 \leq \ell_1^* - U_0 &= \int_0^T \tilde{u} dt + \lambda_0 \left(M_0 - \int_0^T e^{-rt} \varphi' h dt \right) + \int_0^T \omega' (f - \dot{k}) dt - U_0 \\ &= \lambda_0 \left\{ M_0 - \left[\int_0^T e^{-rt} \varphi' h dt + (1/\lambda_0) \left(U_0 - \int_0^T \tilde{u} dt \right) + \int_0^T (\omega/\lambda_0)' (\dot{k} - f) dt \right] \right\} \\ &= \lambda_0 (M_0 - \hat{\ell}_2) \leq 0, \end{aligned} \quad (4.48)$$

where $\hat{\ell}_2$ is the Lagrangean for the expenditure minimization problem evaluated along the utility-maximizing path for x and k with $\mu_0 = 1/\lambda_0$ and $\xi \equiv \omega/\lambda_0$.

The second inequality follows from the fact that this path is feasible, so that $M_0 = \int_0^T e^{-rt} \varphi' g dt \equiv \ell_2^*(p_0, U_0, k_0, \beta, \gamma) \leq \hat{\ell}_2 \equiv \int_0^T e^{-rt} \varphi' h dt$. It follows immediately that $V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \equiv U_0$.

The argument for $E(p_0, V(p_0, M_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \equiv M_0$ is identical, with the roles of the dynamic expenditure and indirect utility functions interchanged.

We therefore have the following rather remarkable result. Only parts (8.i) and (8.j) of the next theorem are not immediately obvious from the previous developments. However, this pair of conclusions follows from: (a) the uniqueness of the optimal paths for the two problems; (b) the above relationships among the shadow prices; and (c) the fact that the first-order conditions for the two problems are equivalent $\forall t \in [0, T]$. Hence, no further proof is necessary to establish the following.

THEOREM 8. *The dynamic indirect utility and expenditure functions for the intertemporal consumer choice problem with household production and non-static price expectations satisfy:*

$$V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \equiv U_0; \quad (8.a)$$

$$E(p_0, V(p_0, M_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \equiv M_0; \quad (8.b)$$

$$\begin{aligned} & \frac{\partial V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma)}{\partial M_0} \\ & \equiv \lambda_0(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \\ & \equiv \frac{1}{\mu_0(p_0, U_0, k_0, \beta, \gamma)} \equiv \frac{1}{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial U_0}; \end{aligned} \quad (8.c)$$

$$\begin{aligned} & \frac{\partial E(p_0, V(p_0, M_0, k_0, \beta, \gamma), k_0, \beta, \gamma)}{\partial U_0} \\ & \equiv \mu_0(p_0, V(p_0, M_0, k_0, \beta, \gamma), k_0, \beta, \gamma) \\ & \equiv \frac{1}{\lambda_0(p_0, M_0, k_0, \beta, \gamma)} \equiv \frac{1}{\partial V(p_0, M_0, k_0, \beta, \gamma)/\partial M_0}; \end{aligned} \quad (8.d)$$

$$\begin{aligned} & \frac{\partial V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma)}{\partial k_0} \\ & \equiv \omega(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, 0) \\ & \equiv \frac{\psi(p_0, U_0, k_0, \beta, \gamma, 0)}{\mu_0(p_0, U_0, k_0, \beta, \gamma)} \equiv -\frac{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial k_0}{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial U_0}; \end{aligned} \quad (8.e)$$

$$\frac{\partial V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma)}{\partial \beta} \equiv -\frac{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial \beta}{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial U_0}; \quad (8.f)$$

$$\frac{\partial V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma)}{\partial \gamma} \equiv -\frac{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial \gamma}{\partial E(p_0, U_0, k_0, \beta, \gamma)/\partial U_0}; \quad (8.g)$$

$$\begin{aligned} & \frac{\partial V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma)/\partial p_0}{\partial V(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma)/\partial M_0} \\ & \equiv \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} h(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t) dt \\ & \equiv \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} g(p_0, U_0, k_0, \beta, \gamma, t) dt \equiv \frac{\partial E(p_0, U_0, k_0, \beta, \gamma)}{\partial p_0}; \end{aligned} \quad (8.h)$$

$$h(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t) \equiv g(p_0, U_0, k_0, \beta, \gamma, t) \quad \forall t \in [0, T]; \quad (8.i)$$

$$g(p_0, V(p_0, M_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t) \equiv h(p_0, M_0, k_0, \beta, \gamma, t) \quad \forall t \in [0, T]; \quad (8.j)$$

and

$$\begin{aligned}
 & \frac{\partial^2 E(p_0, U_0, k_0, \beta, \gamma)}{\partial p_0 \partial p'_0} \\
 & \equiv \int_0^T e^{-rt} \sum_{i=1}^n g^i(p_0, U_0, k_0, \beta, \gamma, t) \frac{\partial^2 \varphi_i(p_0, t)}{\partial p_0 \partial p'_0} dt \\
 & \quad + \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} \frac{\partial g(p_0, U_0, k_0, \beta, \gamma, t)}{\partial p'_0} dt \\
 & \equiv \int_0^T e^{-rt} \sum_{i=1}^n h^i(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t) \frac{\partial^2 \varphi_i(p_0, t)}{\partial p_0 \partial p'_0} dt \\
 & \quad + \int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} \frac{\partial h(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t)}{\partial p'_0} dt \\
 & \quad + \left(\int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} \frac{\partial h(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t)}{\partial M_0} dt \right) \\
 & \quad \times \left(\int_0^T e^{-rt} \frac{\partial \varphi(p_0, t)'}{\partial p_0} h(p_0, E(p_0, U_0, k_0, \beta, \gamma), k_0, \beta, \gamma, t) dt \right)' \quad (8.k)
 \end{aligned}$$

is a symmetric $n \times n$ matrix with rank no greater than $n - 1$ and is negative semidefinite if $\varphi(\cdot, t)$ is concave in p_0 .

5. Discussion

The static neoclassical model provides a solid foundation for the host of generalizations to consumer choice theory considered in this chapter. The central core of the duality theory of the neoclassical model transcends the theory of household production, characteristics theory, and intertemporal consumer choice, models of consumer expectations for future values of important economic variables, durable goods, consumption habits, and changing household production technologies and/or goods qualities and characteristics.

This illustrates a robust theoretical framework. But the way that the duality theory manifests itself varies substantially across specifications. When intertemporal considerations are added, there no longer is any short-run, or instantaneous, counterpart to the static neoclassical model's Slutsky symmetry and negativity conditions. Once the proper concept of substitution has been taken into account in a dynamic setting, however, the precise nature of the symmetry condition becomes self-evident. In addition, the standard homogeneity and curvature conditions of the static model are not necessarily satisfied in a dynamic framework. Again, however, once the influences of households' expectations about future economic variables on their optimal plans have been identified, the conditions in which homogeneity and curvature are satisfied become apparent.

The analysis in this chapter shows that the naive way that consumption habits and durable goods have traditionally been treated in empirical demand analysis suffers from several weaknesses, particularly when myopic expectations are not assumed. On the other hand, myopic expectations in dynamic consumption models is fraught with logical inconsistencies in its own right.

This raises several questions for future research in empirical demand analysis. How do we estimate rational consumption habits? Can we distinguish between changes in household durables and changes in consumption habits? Does habit formation exist? What other economic trends do consumption habits proxy for – e.g., changing demographics, changes in the distribution of income over time, nonlinearities in the income responses of goods' demand, and/or structural change in the demand for foods and other goods? Can expectations be modeled successfully in empirical demand studies? In a dynamic setting with rational consumers, how do we correctly measure the consumer welfare effects of policy changes? If consumers use rational forecasting models and are intertemporal utility maximizers, do they respond to future uncertainty with *open loop* or *closed loop* consumption plans? Can these solution types be distinguished empirically?

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ECONOMIC ANALYSIS OF FOOD SAFETY

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Abstract

This chapter addresses the analysis of markets for food products that are differentiated by safety characteristics. The first part of the paper surveys the broad array of issues that are involved in food safety and the regulations that have been devised to address them. The next sections of the paper consider the analysis of the demand and supply of safety-differentiated products and the implications of alternative information regimes for market equilibrium. The final section of the paper considers the measurement of benefits and costs of food safety regulations in the context of recent efforts at regulatory impact assessment.

JEL classification: Q18

1. Introduction

The food processing industry in the United States is a \$100 billion industry, with food processing representing about 10 percent of the value of the U.S. manufacturing sector, the largest of any single industry group [Connor (1988)]. It is also an increasingly regulated industry. Both the Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) announced sweeping new regulations of the food processing and meat packing industries in 1995 and 1996. With the recent movement in federal policy towards the use of benefit-cost analysis in regulatory impact assessments, economists have begun to play a significant role in food safety policy. The growth in demand for high-quality food products also is stimulating an interest by industry in assessing the potential demand for quality-differentiated products, including taste, nutritional, and safety characteristics. The food processing sector provides an important and relatively little studied case for academic research on both consumer demand and product supply in markets in which technology structure, imperfect information, heterogeneity, imperfect competition, and international trade all play important roles. This chapter provides an overview of the way that economic theory and data can be used for economic analysis of food safety, drawing upon literature in economics both within and outside the food safety arena.

When product quality information is readily available, safety is no different from other quality attributes of foods. Just as one can buy food products with varying taste, cosmetic, and nutritional characteristics, so one can buy foods with varying safety characteristics. To the extent that safety is just another product characteristic, the economics literature on quality-differentiated products [e.g., Eaton and Lipsey (1989)] could be used to model and analyze the demand, supply, and market equilibrium issues associated with food safety. These models could in turn be used to address the various policy issues associated with food safety.

Yet because product safety information is often imperfect, safety is different from other food quality attributes. Consumers do not willingly accept unwanted risks, but consumers do sometimes unknowingly buy unsafe products because they may have difficulty knowing the safety attributes of the foods and other products they buy. In some cases, the seller of a product may know more about product safety than consumers, e.g., a vegetable producer knows what pesticides were applied to a crop, and may know something about the health risks of those pesticides. In such cases, a food market is characterized by asymmetric information, and the relevant economic analysis can be used to understand the properties of demand, supply, and market equilibrium. These properties can then be used to analyze policy questions.

In many cases, however, sellers may not have better information about the safety attribute of a product than a consumer. For example, even though a vegetable producer knows what pesticides were applied to a crop, the producer may not know whether any pesticide residues contaminate the product. Another example is when a pathogen such as *E. coli* O157:H7 is inadvertently introduced into ground beef in a meat processing plant. Unless a reliable test is applied to each meat product from the plant, the plant operator

does not know any better than a distributor or consumer whether a product from the plant is free from this pathogen. Thus, even though the food producer, processor, or marketer may often know more about the production *process* than the consumer, their knowledge of the production process does not necessarily imply that they know the actual safety attributes of their food products. Even if the producer has this information, it is costly for this information to be carried with the product throughout the remainder of the food system from processing to distribution and retail marketing. Consequently, both buyers and sellers are likely to face imperfect information about food safety.

The food safety regulation problem is thus closely related to the food safety technologies and their implications for information about product safety. The preceding examples illustrate that, while the market for food safety generally is characterized by imperfect information about product quality, there is not necessarily an asymmetry in information favoring producers. Indeed, in many cases consumers, producers, and regulators all may have imperfect information about the safety of food products. This situation of *symmetric* imperfect information means that the market for food safety is likely to function differently than the market for other quality characteristics where information is asymmetric. As Antle (1996) and Caswell and Mojduszka (1996) observe, a key challenge in food safety policy design is to learn how, and whether, markets characterized by these types of information regimes can be made to function efficiently through any of the policy options that are available, ranging from market mechanisms such as development of private product reputations through advertising, product quality certification and labeling, liability laws, or statutory regulation of either the process or performance standard variety.

The analysis of food safety is complicated by several other important features of food markets. It may be necessary to account for differences in demand associated with the vulnerability of some segments of the population – such as young children, the elderly, and individuals with impaired immune systems – to chemical contaminants and food-borne pathogens. On the supply side, the safety attributes of products, the structure of production, and the economic organization of the industry all may play a role in the production of quality- and safety-differentiated products. The analytical challenge in the economic analysis of markets in which food safety is an issue, therefore, is to represent the behavior of both consumers and firms under the appropriate production technology, information regimes, and market structures, and to analyze the properties of market equilibria under these regimes.

2. Food safety, the food system, and policy

Food safety is a significant factor in public health. Food safety is particularly important to vulnerable segments of the population such as the elderly, pregnant women, young children, and the immuno-compromised [National Research Council (1993); Steahr (1996a, 1996b)]. The Centers for Disease Control estimate that as many as 9,000 deaths per year are associated with food-borne disease. According to the U.S. Department of

Agriculture data, there are millions of cases of illness associated with major food-borne pathogens, which result in thousands of deaths and billions of dollars of annual medical and productivity costs [Crutchfield et al. (1997)]. However, it is important to note that these figures are estimates based on available data. For example, the number of cases reported annually averaged about 18,000 over the 1983–87 period [Council for Agricultural Science and Technology (1994)]. The number of estimated cases is so much greater than the number of reported cases because it is believed that many food-related illnesses are not reported, are misdiagnosed by physicians, or are not recognized as being related to food-borne pathogens.

Food safety encompasses a wide array of issues affecting the food system, ranging from basic commodity production and processing to retail marketing and international trade. At the most basic level, the quality of soil and water used in crop and animal production can give rise to food safety concerns, as when water-borne diseases are transmitted through irrigation water or when chemical contaminants in soil or water accumulate in crops or livestock. Another important class of food safety issues is associated with the use of purchased inputs such as fertilizers and pesticides for crop production, and feed and drugs for animal agriculture. Pesticides, because they are often acutely toxic to humans at high doses or may have adverse long-term consequences such as causing cancer, have been the focus of a great deal of public concern and regulatory activity [National Research Council (1987b, 1993)]. Likewise, certain feed additives and drugs used in livestock production, notably hormones and antibiotics, have raised concerns about the impacts that these chemicals could have on human health. Genetically altered plants could produce toxins or induce allergic reactions in some people [Olempska-Beer et al. (1993); Barefoot et al. (1994)]. A major food safety concern at the production level is the control of human pathogens such as *Salmonella* and *E. coli* O157:H7, which can become serious health risks if they are carried on animal carcasses and introduced into the meat slaughter and processing stage of production.

The use of chemical preservatives and fumigants also is a food safety issue [Forsythe and Evangelou (1994)]. The presence of pathogens, chemical residues, or the use of hormones and drugs in production has raised a variety of international trade policy issues [Patterson (1989); von Witzke and Hanf (1992)]. A particular concern is the use of non-tariff barriers to trade in agricultural commodities. Many such non-tariff barriers are rationalized by provisions in trade agreements, such as the General Agreement on Tariffs and Trade (GATT), that allow countries to prevent the importation of products that would pose a human health risk [Powell (1997); Liefert (1998)].

Food processing may create food safety risks. Chemical residues may be found at higher levels in processed foods; pathogens in animal feces may be introduced into ground meat so that they present a greater hazard to consumers than they would if the meat were consumed in larger cuts such as steaks. Preservatives that may pose a health risk are added to many foods. Physical hazards such as glass or metal shards may be introduced in processing. Spoilage and botulism are risks when foods are canned. Finally, certain processes, such as food irradiation, may reduce risks associated with

food pathogens but are considered hazardous by some consumers [Loaharanu (1994); Misra et al. (1995)].

In the distribution of raw and processed product to the restaurant and hotel industry and to retail markets for home consumption, the principal issue is the handling and cooking of foods. Many of the risks associated with food-borne pathogens can be eliminated through safe handling and adequate cooking of foods. Poor hygiene can also introduce contaminants and pathogens into food at this stage.

2.1. Food safety policies

The federal government regulated food quality and safety long before most other consumer safety regulations were enacted. The first federal food safety regulations, the Pure Food and Drugs Act and the Meat Inspection Act, became law in 1906. Under the Federal Food, Drug and Cosmetic Act (FFDCA) of 1938, the Food and Drug Administration (FDA) has responsibility for many aspects of food safety regulation. The Food Additives Amendment to FFDCA in 1958 and the Federal Insecticide, Fungicide and Rodenticide Act of 1972 and its subsequent amendments led to the regulation of agricultural pesticides by the Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA). USDA is responsible for meat, poultry, and egg inspection, and inspection of imported foods. In the meat inspection area, important changes were made in 1967 and 1968 with the Wholesome Meat Act and the Wholesome Poultry Act. These laws required standardized meat and poultry inspection across states and required states to match federal inspection standards. Several important additional changes were made in laws affecting food safety regulation in the 1990s, as noted below.

Pesticide regulation. One important development in food safety regulation in the United States concerned the so-called Delaney clause of Section 409 of FFDCA. The 1958 amendments to FFDCA established the authority to set tolerances (maximum allowable levels) for pesticide residues in foods. Section 409 treats pesticide residues in processed foods as food additives, and in the section known as the Delaney clause, provided "that no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animals". Consequently, section 409 was interpreted as applying a zero-risk standard for pesticides that concentrate in processed foods, without provision for cancer risks to be balanced against potential benefits of the pesticide.

The zero cancer risk standard of the Delaney clause became increasingly unrealistic as science's ability to detect chemical residues increased from one part per million in the 1950s to one part per trillion and less by the 1980s. Nevertheless, until the mid-1980s, the EPA used a strict zero-risk interpretation of the Delaney clause. Due to criticism of this policy [National Research Council (1987a); Archibald and Winter (1990)], the EPA provided an exemption to the Delaney clause and began applying a negligible risk standard of one cancer per million persons exposed to a pesticide through food consumption

during a seventy-year lifetime. In 1992 the court ruled that EPA was required to apply the zero-risk interpretation of the Delaney clause. This decision finally forced Congress to take action to revoke the Delaney clause. The Food Quality Protection Act of 1996 replaced the Delaney clause with a “reasonable certainty of no harm” standard, i.e., a health-based standard. The new law also has provisions to implement the recommendations of the National Research Council’s (1993) study of the vulnerability of infants and children to pesticide residues.

Mandatory HACCP and pathogen reduction. A recent development in food safety regulation is the decision by both the FDA and the Food Safety and Inspection Service (FSIS) of USDA to require firms to implement a quality control system in meat slaughter and in food processing plants known as HACCP (Hazard Analysis Critical Control Points) [Food and Drug Administration (1994b); Food Safety and Inspection Service (1995, 1996)]. HACCP involves the identification of hazards and critical control points in the production process where the hazards can be reliably monitored and controlled, and a system of verification and record keeping to ensure that the controls are working effectively.

In meat and poultry inspection, the 1906 Act and its amendments require that all carcasses and all meat products be inspected. The Food Safety and Inspection Service (FSIS) employs some 7,400 inspectors in over 6,000 slaughter and processing plants, at a cost of over \$500 million annually, to conduct inspections of every carcass slaughtered using so-called organoleptic surveillance methods, i.e., sight, smell, and touch, and to monitor sanitary conditions in processing plants. These methods have been criticized as inadequate to identify and control food-borne pathogens, chemical contaminants, and other hazards that cannot be detected through visual examination [National Research Council (1985, 1987a)]. In the early 1990s, FSIS began pilot efforts to improve the scientific basis for meat and poultry inspection, and in 1996 it finalized rules that mandate that all federally inspected meat and poultry plants adopt HACCP procedures, develop written sanitation standard operating procedures, and test for generic *E. coli* bacteria on carcasses to verify that their process is preventing and removing fecal contamination. In addition, FSIS planned to begin testing for *Salmonella* on raw meat and poultry products to verify pathogen reduction standards [Food Safety and Inspection Service (1996)].

Consumer education, food labeling and food safety. Consumers and workers in the food preparation industry can take many actions that effectively prevent food-borne pathogens from being introduced into foods, including safe handling that can prevent food contamination and thorough cooking that can destroy harmful pathogens contained in foods. In 1994, USDA required that all fresh meat and poultry products sold in retail outlets or handled by food service workers carry labels with safe handling and cooking information. The Nutrition Labeling and Education Act of 1990 overhauled food label laws and tightened the regulation of health claims allowed on labels. Traditionally, food labeling has been oriented toward the provision of consumer information. An update of food labeling regulations completed in 1994 was driven by the growing evidence that

major diseases, notably heart disease and cancer, are diet-related [National Research Council (1989)]. Increasingly, food labeling is regarded as a way to convey information regarding all relevant quality attributes, including safety [Caswell and Padberg (1992); Caswell and Mojduszka (1996); Magat and Viscusi (1992)]. Both consumer education and labeling are considered to be important alternatives to statutory regulation such as the mandatory HACCP regulations. However, current FDA and USDA policies limit the use of safety labeling to identify risks, rather than to indicate that products are demonstrably safe.

The issue of labeling also arises in the regulation of new food production and processing technologies. Labeling of genetically engineered foods and foods produced with biogenetic drugs is currently part of the public debate, as is the labeling of irradiated products. Such labeling raises a variety of issues, including the provision of scientifically accurate information to consumers, industry concern that labeling only for hazards will create a consumer perception biased against certain processes or products, and the costs associated with determining whether components of products are produced with a particular bioengineered product. The debate over the labeling of milk from animals treated with recombinant bovine somatotropin illustrates these issues [Hallberg (1992)].

Trade policy and food safety. Quality and safety standards can be used not only for legitimate health and safety regulation but also as non-tariff barriers to restrict trade and international competition [Powell (1997); Liefert (1998)]. The Codex Alimentarius Commission was founded in 1962 by a joint commission of the Food and Agriculture Organization (FAO) and World Health Organization (WHO) to provide a forum for resolution of trade disputes that arise because of food industry regulation. Codex pursues the application of the principle of national treatment and the harmonization of minimum standards across countries, allowing countries to adopt higher standards if they so choose. Codex has standards for commodity quality, food additives, pesticide residues, and processes (primarily sanitation standards for slaughter and processing of animal products) [Skully (1994)].

The Uruguay Round of GATT and the North American Free Trade Agreement (NAFTA) have adopted the principle that science-based standards should be the basis of international safety standards. However, the harmonization of health and safety standards through international trade agreements is a controversial issue. Despite the principle of national treatment that allows countries to set their own standards as long as they apply the same standards to traded goods as to domestically produced goods, environmental and consumer groups in the United States argue that harmonization according to Codex standards would lead to a lowering of U.S. standards. Evidence suggesting that contamination of foods with harmful bacteria and other pathogens is increasing with the increased food trade brought about by the GATT and NAFTA agreements led the Clinton Administration to announce in 1997 a new initiative to monitor the safety of imported foods.

2.2. The regulatory debate

Recent developments in regulatory review, combined with the announcement of new food safety regulations, have spurred a literature on whether such regulations are economically justified, and what form regulation should take.

In terms of federal regulatory policy, several events have moved the U.S. government to use benefit-cost criteria to assess new regulations. In 1982 President Reagan issued an Executive Order requiring that major new regulations pass a benefit-cost test [Smith (1984)]. This Executive Order was renewed by both Presidents Bush and Clinton with some modifications. Congress also passed the Government Performance and Results Act in 1993, which requires federal agencies to review and justify their programs in terms of quantifiable performance indicators, which could include benefit-cost assessments. Until these actions were taken, most federal agencies were not required to demonstrate that health and safety regulations produced benefits in excess of costs. Responding to increased demands for assessment of its programs, USDA instituted an Office of Regulatory Assessment and Cost-Benefit Analysis in 1995. Many other countries have implemented some form of regulatory review, and governments in all OECD countries have agreed to use some form of regulatory impact assessment, but most do not yet require benefit-cost analysis [Jacobs (1997)].

Following this trend towards application of benefit-cost criteria to federal regulations, economists such as Arrow et al. (1996) have advocated principles for benefit-cost analysis of environmental, health and safety regulation; Antle (1995) presented principles for efficient food safety regulation. Arrow et al. and Antle observe that the existence of purported market failures *per se* is not a justification for regulation, unless it can be demonstrated that it is possible to design a regulation that yields benefits that exceed its costs. This argument echoes the arguments made by earlier critics of government regulation, such as Demsetz (1969). Following the literature on environmental regulations such as clean air legislation [Council of Economic Advisers (1990)], Antle also argues that as a general principle, performance standards are to be preferred to process standards on efficiency grounds. Interestingly, the mandatory HACCP regulations being implemented by USDA appear to have elements of both process standards and performance standards, although how they are actually implemented remains to be seen.

The recent movement towards the implementation of mandatory HACCP regulations by FDA and USDA has spawned an emerging literature on the benefits and costs of such regulations [Antle (1996); McDonald and Crutchfield (1996); Roberts et al. (1996); Unnevehr and Jensen (1996); Crutchfield et al. (1997); Klein and Brester (1997); Antle (1998); Unnevehr (1999)]. These studies indicate that because the costs of designing and implementing a HACCP plan are lower on a per unit basis for larger food processors, increased demand for food safety and food safety regulation requiring HACCP may have impacts on the competitiveness of smaller firms in the industry. Another finding is that the costs of HACCP include a substantial human capital component in plan development, training of personnel, on-going monitoring activities, and management of the HACCP system. HACCP costs also may include investments in specific processes

that require new physical capital and result in additional operating expenses, but these will only be effective when managed within a larger system of prevention and monitoring. Studies also indicate that there are private market incentives to adopt HACCP or to improve food safety. However, these are often difficult to quantify, as they arise from product or firm reputation rather than specific price premia. These private incentives influence the need for regulation to mandate HACCP or other measures to improve food safety.

3. Markets for food safety

3.1. Demand

Consumers derive value from food safety because it means they are exposed to a lower degree of health risk. Health risk can be usefully classified into two categories, risk of illness (morbidity) and risk of death (mortality). To simplify the initial discussion of demand, we consider the case of morbidity first, and then briefly describe how the analysis would need to be extended to incorporate mortality. As in the literature on hedonic prices [Rosen (1974); Palmquist (1991)], the market for quality attributes of products is an implicit one wherein the demand for products with differentiated quality attributes is equated to the supply. The literature on the demand for quality-differentiated products [as surveyed by Hannemann (1982); also see Smallwood and Blaylock (1991), and LaFrance (1999)], together with the literature on the analysis of environmental health effects [e.g., Graham (1981); Smith (1991); Cropper and Freeman III (1991)], provide the basis for this analysis. Van Ravenswaay (1995) provides a review of the food safety-related literature. Carriquiry, Jensen and Nusser (1991), Choi and Jensen (1991), Falconi and Roe (1991), Eom (1995), Weaver (1995), and van Ravenswaay and Hoehn (1996) provide related theoretical models designed specifically for analysis of food safety.

Consider a static model in which the household is defined as an individual decision making unit that maximizes expected utility by choosing the quantity of food y_f , a non-food good y_n , a health-risk averting activity a , and medical expenditures m . To keep the model simple we abstract from the household's allocation of time. Also to simplify the presentation, we assume that all decisions are made *ex ante*, including medical expenditures. In a more realistic model of health care decisions, one would distinguish between *ex ante* preventative health care and *ex post* recuperative health care expenditures that would be made after health outcomes were realized. For this type of analysis, a multi-period model would be required [Kolstad and Braden (1991); van Ravenswaay and Hoehn (1996)].

Assume that a health risk is associated with the consumption of y_f but not with y_n (note the latter can also be interpreted as a riskless food). Utility is a function $U(y_f, y_n, h)$ where h is a scalar index of the household's health status, and it is assumed that $h \leq 0$ indicates death, i.e., $U(y_f, y_n, 0) = 0$. Health is a function $h(e, m, \varepsilon)$ decreasing in exposure to risk $e(r, a, \rho)$ and increasing in health care expenditures m .

The household selects an activity a to mitigate or avert health risk $r(y_f, \delta)$, where health risk associated with food is assumed a non-decreasing, non-negative function of food consumption, and δ is a parameter indicating the degree of risk. Note that risk could also be a function of cumulative consumption (and hence exposure) over time, in which case a dynamic model would be implied. Consuming perfectly safe foods leads to a value of $r = 0$, whereas consuming foods with some positive health risk results in $r > 0$.

Both health and exposure to health risks are randomly and independently distributed in the population. The household's beliefs about health variation are embodied in the random variable, which is distributed according to the cumulative distribution function $H(\varepsilon | \chi)$, where χ is a parameter representing the household's health-related human capital. ρ is the stochastic element in exposure to food-related health risks. The household is assumed to hold subjective beliefs regarding the risks of exposure represented by the cumulative distribution function $R(\rho | \kappa)$ where κ represents the household's knowledge of health risks.

Given money income I and prices p_f , p_n , and p_a , the household's choice problem is:

$$\max_{y_f, y_n, a, m} \mathcal{L} = \iint U(y_f, y_n, h(e(r(y_f, \delta)a, \rho), m, \varepsilon)) dR(\rho | \kappa) dH(\varepsilon | \chi) + \lambda(I - p_f y_f - p_n y_n - p_a a - p_m m). \quad (1)$$

Assume the utility, health, and risk exposure functions are continuous and twice differentiable so that differentiation under the integral is permissible, and assume that their convexity is sufficient to generate a globally concave expected utility function. In addition to the budget constraint, the first-order conditions for the above problem can be expressed as

$$\partial \mathcal{L} / \partial y_f = \lambda^{-1} \iint \{U_f + U_h h_e e_r r_f\} dR(\rho | \kappa) dH(\varepsilon | \chi) - p_f = 0, \quad (2)$$

$$\partial \mathcal{L} / \partial y_n = \lambda^{-1} \iint U_n dR(\rho | \kappa) dH(\varepsilon | \chi) - p_n = 0, \quad (3)$$

$$\partial \mathcal{L} / \partial a = \lambda^{-1} \iint U_h h_e e_a dR(\rho | \kappa) dH(\varepsilon | \chi) - p_a = 0, \quad (4)$$

$$\partial \mathcal{L} / \partial m = \lambda^{-1} \iint U_h h_m dR(\rho | \kappa) dH(\varepsilon | \chi) - p_m = 0. \quad (5)$$

Equation (3) states the standard result that the expected marginal utility of non-food consumption per dollar is equated to the price of the non-food good (note 8 is the marginal utility of income). Likewise, Equations (4) and (5) state that the expected marginal utility of averting activity and medical care per dollar is equated to the respective prices. Note that the marginal utility of each health factor depends on a chain of linked effects. For example, the marginal utility of averting activities a depends on the marginal utility of health U_h , the marginal effect of exposure on health, h_e , and the

marginal effect of averting activity on exposure, e_a . Each of these pieces of the link from averting activity to health is important in understanding the various aspects of the demand for food safety.

To interpret Equation (2), define the expected marginal health risk per dollar (EMHR) as

$$\text{EMHR} \equiv -\lambda^{-1} \iint U_h h_e e_r r_f dR(\rho | \kappa) dH(\varepsilon | \chi) > 0.$$

The expression within the integrals is the product of the marginal utility of health $U_h > 0$, the marginal health effect of exposure $h_e < 0$, the marginal effect of risk on exposure $e_r > 0$, and the marginal effect of food consumption on health risk $r_f > 0$. The household's perception of this complex chain of factors determines its behavioral response to health risk, as conditioned by its human capital in the form of its health characteristics χ and its knowledge of health risks κ . Also define the expected marginal utility of food as:

$$\text{EMUF} \equiv \lambda^{-1} \iint U_f dR(\rho | \kappa) dH(\varepsilon | \chi) > 0.$$

The first-order condition (2) can then be interpreted as stating that

$$\text{EMUF} = p_f + \text{EMHR}. \quad (6)$$

This relationship is illustrated in Figure 1 for given values of non-food consumption, averting activity, and medical expenditures, assuming that expected utility is concave in y_f and that EMHR is increasing in y_f . In the conventional model of consumer demand, the quantity of food demanded is found by equating the price of food to the expected marginal utility of food per dollar (EMUF), as at point A. But when a food poses a health risk recognized by the consumer, the quantity of food demanded is at point B, and is less than in the no-risk solution at point A. Typically, the greater is the perceived marginal health risk, the lower is the demand for the risky food, hence the curves in Figure 1 shift according to the values of χ and κ .

In the simple one-food model above, food safety risk is a function of how much food is consumed. Generalizing the model to more than one food shows that the demand for each food is a function of the EMUF, the EMHR and the price of each food. To illustrate, consider the choice between a fruit grown with pesticides and thus posing a possible health risk due to pesticide residues, and the same fruit grown without pesticides and thus without health risk. Equating the first-order conditions (6) for the two fruits, and noting that the EMUF for each fruit is equal, shows that the consumer would choose the fruit grown without pesticides if

$$\text{EMHR}_{\text{pesticide}} > p_{\text{no pesticide}} - p_{\text{pesticide}}.$$

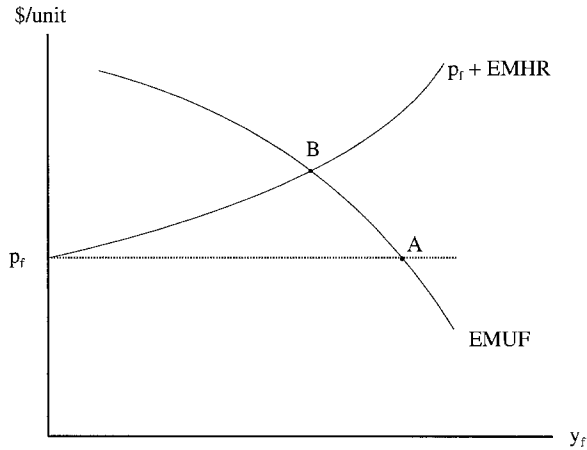


Figure 1. Expected marginal disutility of health risk per dollar (EMHR) and expected marginal utility of food consumption (EMUF).

i.e., if the expected marginal disutility of health risk per dollar of the pesticide is greater than the price premium associated with the pesticide-free food. Holding constant the other food attributes, the household's choice between more and less risky foods, therefore, is a function of the relative prices of the foods and the household's perceived susceptibility to the risk. The household's susceptibility to risk is in turn a function of the household's human capital (both its health capital χ and its health-related knowledge κ).

Solving the first-order conditions (2)–(5) gives the household demand functions $y_f(\mathbf{p}, \delta, I, \kappa, \chi)$, $y_n(\mathbf{p}, \delta, I, \kappa, \chi)$, $a(\mathbf{p}, \delta, I, \kappa, \chi)$, and $m(\mathbf{p}, \delta, I, \kappa, \chi)$, where $\mathbf{p}$ is the price vector. These household demand functions depend on prices, income, and the household's health capital χ , health-related knowledge κ , and food risk parameter δ . χ determines the household's perceived vulnerability to health risks through the household's subjective distribution of health $H(\varepsilon | \chi)$. E.g., a young child or an elderly person's health capital is such that they are more likely to be susceptible to infectious diseases. The household's health-related knowledge κ affects its demand through its perceived exposure to health risk as embodied in the distribution $R(\rho | \kappa)$. Note that the demand function $a(\mathbf{p}, I, \kappa, \chi, \delta)$ represents the household's efforts to produce safe food through safe handling and cooking of foods and other safety practices, and this behavior depends on prices, income, the household's health capital, and its health-related knowledge.

Comparative static analysis of these household demand functions is typically ambiguous regarding the signs of derivatives with respect to the parameters. Typically, y_f would be decreasing in the food risk parameter δ , whereas y_n , a and m would be increasing in δ .

3.1.1. Market demand

Viewed now from the perspective of the population of households, the various characteristics of the households (income, health characteristics, and knowledge of health risks) are assumed to be jointly distributed in the population according to the cumulative distribution function $G(I, \chi, \kappa \mid \Delta, \Psi)$. Here I represents the moments of the income distribution, Δ represents demographic characteristics of the population such as age and education, and Ψ represents policy parameters affecting the distribution of knowledge such as consumer education programs and product labeling regulations. Letting the number of persons in the population be N , market demand functions for food, non-food, and averting activities are given by

$$Y_f(\mathbf{p}, \delta, I, \Delta, \Psi, N) = N \int y_f(\mathbf{p}, \delta, I, \kappa, \chi) dG(I, \chi, \kappa \mid I, \Delta, \Psi). \quad (7)$$

Similarly, the demand functions for the non-food good, averting activities, and medical care can be derived from the household demand functions. By the assumption that $\partial y_f / \partial \delta < 0$, it follows that $\partial Y_f / \partial \delta < 0$, with similar properties applying to the other market demand functions. In addition, note that these derivative properties of the market demand functions do not require that the same properties hold for all households; the household functions only need exhibit these properties on average in the population. These market demand functions have several important implications for the analysis of market demand and food safety.

First, observe that the market demands for food, averting activities, and medical care are functions of income and prices as in conventional demand models, plus demographic and policy variables. The latter variables enter the market demand functions because household demand depends on perceived food risks, and the market demand for these foods depends on population characteristics that condition household perception of risks. Thus, for given prices, income, and demographic and policy parameters, the demand for a food will vary inversely with the degree of perceived health risk in the population. Second, the parameter δ represents the degree of actual risk associated with a food, showing that demand also depends on the objective food risk. Third, the market demand functions depend on the underlying distribution of income, consumer characteristics, and knowledge in the population represented by $G(I, \chi, \kappa \mid I, \Delta, \Psi)$. The market demand functions are well-defined, stable functions as long as this underlying distribution is stable in the population, a fact demonstrated in the analysis of statistical aggregation [Stoker (1982)].

3.1.2. Valuing risk reduction for policy analysis

The most often used approach to value reduced risk of morbidity is to estimate the cost of illness (COI) [Kenkel (1994)]. COI is based on the measurement of the medical costs of an illness plus the foregone market income due to lost work time. The COI approach

has several advantages: it is intuitively appealing to non-economists; it can be used to account for important medical details, such as the various consequences and severities of disease [Cropper (1995)]; and it is empirically tractable with available medical and economic data. However, the COI approach has fundamental theoretical shortcomings. The COI approach is not equivalent to willingness to pay (WTP), and although it can be shown to be a lower bound on WTP for reduced morbidity under certain conditions [Harrington and Portney (1987)], it is not necessarily a lower bound in general when both morbidity and mortality are considered [Berger et al. (1987)]. Nor is COI necessarily a good approximation to WTP, and one can identify a number of situations in which the use of COI could seriously bias a benefit-cost analysis [Kenkel (1994)]. Empirical evidence shows that mean WTP in a sample does typically exceed mean COI for certain health symptoms [Kenkel et al. (1994)]. COI data may nevertheless be useful because of the medical detail that can be taken into account, and because they can supplement willingness-to-pay data when respondents in contingent valuation surveys do not bear all medical costs [Cropper (1995)]. Moreover, data from hypothetical and experimental methods, such as contingent valuation studies, may not be acceptable to regulatory agencies, and these agencies may continue to rely on COI data [Belzer and Theroux (1995)].

The model developed above can be used to explore the relationship between cost of illness and willingness to pay. An increase in health risk δ , all else equal, reduces expected utility in dollar terms by

$$\text{WTP}_{\text{morb}} \equiv -\lambda^{-1} \iint U_h h_e e_r r_\delta dR(\rho | \kappa) dH(\varepsilon | \chi) > 0.$$

This is the amount that an individual would be willing to pay to avoid an increase in health risk. Based on the solution to the choice problem defined in Equation (1), let the indirect expected utility function be $\text{EU}(\mathbf{p}, \delta, I, \kappa, \chi)$. Totally differentiating the indirect expected utility function with respect to δ and equating to zero shows that

$$\text{WTP}_{\text{morb}} = p_a a_\delta + p_m m_\delta + p_f y_{f\delta} + p_n y_{n\delta} = \text{COI}_\delta + \text{CON}_\delta, \quad (8)$$

where $y_{f\delta}$, $y_{n\delta}$, a_δ , and m_δ are partial derivatives of the household demand functions with respect to δ , the degree of health risk. Here $\text{COI}_\delta = p_a a_\delta + p_m m_\delta$ is the marginal cost of illness and $\text{CON}_\delta = p_f y_{f\delta} + p_n y_{n\delta}$ is the marginal effect of health risk on consumption, representing the overall impact of health risk on the individual's utility. It can be shown that $\text{CON}_\delta > 0$, thus demonstrating that the cost of illness is an underestimate of total willingness to pay. In a model with household time allocation represented explicitly, there would be an additional term for the reduction in labor time lost due to illness.

Policy analysis can utilize data on health risk in several ways, either through health-risk standards or through benefit-cost criteria. In some cases, such as in water quality standards set by the EPA, a maximum contaminant level is set based on estimates of

health risk posed by chemical contaminants such as pesticides. Also, the 1996 Food Quality Protection Act modified the pesticide regulatory process by imposing a health risk standard rather than benefit-cost criteria. In these cases, regulations are designed to achieve a safety-first standard that can be defined in terms of health outcomes. For example, suppose the health standard desired by EPA is h_g . Letting $\Gamma = \{\varepsilon, \rho \mid h \leq h_g\}$, then the goal of the regulations could be defined as ensuring that the probability of health falling below h_g in the population is less than or equal to some negligible value ν , i.e., that

$$\Pr(h \leq h_g \mid p, \delta, I, \Delta, \Psi) \\ = \int_{\Gamma} h(e(r(y_f, \delta), a, \rho), m, \varepsilon) dR(\rho \mid \kappa) dH(\varepsilon \mid \chi) dG(I, \chi, \kappa \mid I, \Delta, \Psi) \leq \nu,$$

where y_f , a , and m are the solutions to the utility maximization problem in (1). Observe that this probability is a function of prices, health risk δ , and the distribution of income and other population characteristics. Thus, in order to assess health risk-based regulations, analysts need to know the same behavioral factors that they need to know in order to assess market demand for the foods that give rise to the risk.

Risk of death can be valued using the value of a statistical life through a human capital approach that measures foregone income or earnings over an individual's lifetime [Landefeld and Seskin (1982)]. Various other methods have been used to infer willingness to pay to avoid risk of death, such as using wage differences between occupations with different risks [Cropper and Freeman III (1991); Viscusi (1993)]. The different methods produce a wide range of values of a statistical life, from less than \$1 million to tens of millions of dollars. None of the studies in the literature has utilized avoidance of death caused by food-borne illness. An unexplored issue is whether the values derived from a non-food context necessarily transfer to the food risk case.

A static version of the willingness to pay model was developed by Jones-Lee (1974). Adapting this type of analysis, the decision problem (1) is interpreted as applying to an individual rather than a household. In this static model, the individual faces a risk of death associated with food-borne disease. The individual dies if the health production function takes on a non-positive value, in which case utility equals zero. Thus, recalling that health is given by the function $h(e(r(y_f, \delta), a, \rho), m, \varepsilon)$, with death represented as $h \leq 0$, define $L = \{\varepsilon, \rho \mid h > 0\}$. The probability of living is then given by

$$P_L(y_f, \delta, a, m, \chi, \kappa) = \iint_L dR(\rho \mid \kappa) dH(\varepsilon \mid \chi),$$

where it is assumed that $\partial P_L / \partial \delta < 0$. Given a consumption bundle, the willingness to pay to avoid mortality risk is then $WTP_{\text{mort}} = -\lambda^{-1}(\partial P_L / \partial \delta) U(y_f, y_n, h)$, and total willingness to pay to avoid an increase in health risk is

$$WTP = WTP_{\text{mort}} + P_L WTP_{\text{morb}}, \quad (9)$$

where the willingness to pay to avoid morbidity risk is from Equation (8). Note that the WTP defined in (9) is a function of income, household characteristics χ , and knowledge κ , and therefore distributed in the population according to these variables.

Ceteris paribus, those who are more vulnerable to health risks should be willing to pay more to avoid risks. However, if income were negatively correlated with vulnerability, the most vulnerable members of the population might be willing to pay less than wealthier, less vulnerable members of society. As always, the use of willingness to pay measures of value in benefit-cost analysis is predicated on the existing distribution of income as the standard by which social valuations are made. If the values implied by the existing distribution of income are not an acceptable basis for health risk valuation, then other weighting procedures are needed, as has been discussed in the benefit-cost analysis literature.

It is also possible to extend the static model to a dynamic one in which the time dimension is accounted for explicitly. Here we briefly sketch the setup for a dynamic analysis. The static model discussed above is now viewed as the household's decision problem in each time period t . Expected utility is $u_{jt} = P_{Ljt}U(y_{ft}, y_{nt}, h_t)$, where P_{Ljt} is defined as the probability of being alive in year $t > j$ given that one is alive in year j . Letting α be the individual's discount factor, expected lifetime utility at time j is $V_j = \sum_t \alpha^t u_{jt}$. Note that the individual's utility function is assumed to be additively separable over time, as is typical in the literature. As a generalization of the static case, this dynamic model indicates that a change in health risk in the present would be valued because of the increased probability of surviving into future years, and because of the increased utility associated with reduced morbidity.

3.1.3. The empirical literature

The empirical literature includes studies of the cost of illness and death, studies using survey and experimental methods for measurement of willingness to pay, and studies that assess the impacts of food safety on consumer demand. Cost of illness and death studies are reviewed in Council for Agricultural Science and Technology (1994). Most studies put the total annual cost of illness associated with food-borne disease in the United States in the range of \$5 to \$10 billion, although some studies obtain values in the range of \$20 to \$30 billion annually by using higher values for a statistical life or by assuming larger numbers of illnesses and deaths.

A number of studies that estimate the willingness to pay for food safety use contingent valuation surveys [e.g., Lin and Milon (1995); Wessells and Anderson (1995); Buzby et al. (1995); van Ravenswaay and Wohl (1995)]. Several of these studies use socioeconomic variables to attempt to explain variation in valuations (income, age, gender, attitudinal characteristics, education, etc.), although results are mixed. Due to the problems encountered with responses to hypothetical questions [Hausman (1993)], contingent valuation methods have been combined with experimental methods [Fox et al. (1995, 1998)].

While the literature should in principle provide the basis for benefit valuation in regulatory analysis (as discussed in Section 5 below), it is difficult to make use of these

studies because they cover different consumer populations and measure willingness to pay for specific risks that are difficult to generalize beyond the context of the study. For example, Buzby, Ready and Skees (1995) find that consumers from a national survey would be willing to pay from 31 percent to 138 percent more for grapefruit that have lower health risks associated with certain pesticides used in their production. Fox et al. (1995) find that willingness to pay for a pork sandwich that has lower risk of contamination with *Salmonella* to be between \$.50 and \$1.40 from experiments and questions posed to undergraduate students in four regions of the United States. Whether these findings can be reliably generalized to other risks or to larger populations is not known. Shin et al. (1992) attempt to extrapolate experimental values to the U.S. population and find that aggregate willingness to pay could be several times larger than cost of illness estimates.

Various empirical studies have investigated how consumer demand for food products responds to nutrition and safety information [e.g., see the studies in Caswell (1991)]. A relatively new approach being utilized by researchers in this area is conjoint analysis [Halbrendt et al. (1995); Holland and Wessells (1998)]. Evidence from population-level studies, as well as evidence from experimental studies, supports the general structure of the theoretical model outlined above in the sense that consumer characteristics, including the information available about nutritional and safety characteristics of foods, are found to have predictable effects on individual and market demand.

3.2. Supply

In a competitive, perfect information equilibrium, firms supply a product with particular safety characteristics that are demanded by consumers. But in markets for quality-differentiated products, information may not be perfect because of asymmetries and uncertainties, firms may possess market power, and industries may be organized in ways that affect the supply of quality-differentiated products. Thus, analysis of the supply of products with safety characteristics cuts across the fields of production economics, productivity analysis, and industrial organization. This section discusses some of the ways that these literatures could be usefully applied in the economic analysis of food safety.

3.2.1. Production structure and quality control

Many different types of firms are responsible for food quality and safety, ranging from the producer of the basic commodity (the farm or ranch), to distributors, processors, and retail marketing. These entities may differ substantially in economic organization. On one end of the spectrum is the individual proprietorship typical of the family farm, the small-scale meat processing plant, or the family grocery operating a single production process (plant). These firms are most likely to be price-takers and to sell in a local market. On the other end of the spectrum is the large national or multinational corporation that is likely to operate many plants and trade in regional, national or international markets, and may exert monopoly or monopsony power.

These differences in firm size, organization, and behavior may have several important implications for the analysis of food safety. First, in terms of the structure of production, we must be clear whether we are referring to the structure of an individual production process, i.e., a farm or plant operated at a specific site, or whether we are referring to a firm that operates one or more plants. This distinction is important for the analysis of multi-product firms because the structure of production and cost is different for a single plant producing a single output, a plant producing many outputs, and a firm producing many outputs with a set of plants each of which produces one or more outputs [Panzar (1989)]. Moreover, the ability of the firm to manage the quality of its product at the plant, its ability to differentiate its product from competing products, and its ability to exert monopoly or monopsony power, are likely to depend on its size and organization. Firms' decisions about the supply of safety characteristics of products are likely to be affected by liability laws, and a firm's incentive to supply safe products may be affected by its size, organization, and the structure of its market [Shavell (1987)].

The analysis of the supply of food safety begins with the characterization of firms producing quality-differentiated products. Consider a firm operating a single plant and producing a single product, y , with quality q . Define the firm's production inputs as the vector x and capital stock k . The general form of the firm's production function is $f(y, q, x, k) = 0$, where f satisfies the standard properties of multiple output technologies [Chambers (1989)]. In this form, quality is interpreted as a second output of the production process, and the literature on multiple output technologies can be utilized. Two important properties of multi-product technologies are input-output separability and nonjointness in inputs. Input-output separability holds if and only if the production function can be written $f^1(y, q) = f^2(x, k)$. In effect, this property implies that the quantity of output y and output quality q can be aggregated using the function $f^1(y, q)$. This term f^1 could be interpreted as a quality-adjusted output, and for some purposes could be useful for production analysis. However, such aggregation would not be useful in an analysis where the objective is to explicitly account for product quality.

Nonjointness of inputs implies that separate production functions of the form $y = f^y(x^y, k^y)$ and $q = f^q(x^q, k^q)$ can be defined. This condition, if true, would be useful for the analysis of product quality, as it implies that a distinct production function for quality exists. The function f^q could be interpreted as a distinct process related to quality control. Several examples that are discussed in greater detail in Section 5.2 illustrate the importance of nonjointness. Perrin (1997) assumes that the processing of meat and the irradiation of meat are nonjoint processes. This is a reasonable assumption because irradiation is an operation that is applied to the meat products after all other processing is completed. Klein and Brester (1997) treat quality control as a part of the slaughter process that involves slowing or stopping the production line to remove fecal contamination from meat carcasses. In this case, quality is clearly a part of the overall production process and nonjointness would be an inappropriate assumption.

Firms may also produce many outputs with many quality attributes. This situation can create additional complexities not normally associated with multiple-output technologies. Suppose, for example, that a firm produces two outputs. The first output y_1

has quality attribute q_1 and the second output y_2 has a corresponding quality attribute q_2 . The general production function would be represented as $f(y_1, y_2, q_1, q_2, \mathbf{x}, k) = 0$. In some cases it could make sense to simplify the model by constructing an aggregate output $y = g^y(y_1, y_2)$ and an aggregate quality index $q = g^q(q_1, q_2)$, thus reducing the problem to the form described above with one output and one quality attribute. This approach requires the assumption that quality attributes are separable from other outputs and inputs.

The upshot of this discussion is that the representation of production technologies with one or more quality attributes is likely to take the form of a multi-output process that is neither input-output separable nor nonjoint in inputs, with outputs and their corresponding quality attributes disaggregated. While such multi-output production technologies can be utilized in the primal form, for both analysis and estimation purposes it is typically more convenient to use dual cost or profit representations of multiple-output technologies. The general nonseparable, joint representation of the dual cost function takes the form $c(y, q, \mathbf{w}, k)$ where $\mathbf{w}$ is a vector of prices corresponding to the input vector $\mathbf{x}$, where y and q may be interpreted as either scalar or as vectors. In the case where production is nonjoint in inputs and there are distinct production functions, it then follows that dual cost functions exist of the form $C^y(y, \mathbf{w}, k)$ and $C^q(q, \mathbf{w}, k)$ [Hall (1973)].

A variety of specific quality control technologies are used in producing quality-differentiated products. Following Antle (1998), we consider here process control, inspection, testing, and identity preservation. While not an exhaustive list, these types illustrate a number of key properties of quality control technologies.

Process Control, such as the installation of thermometers to monitor temperature in cooking or chilling, maintains quality by providing the means to control key aspects of the production process. HACCP is nothing more than a systematic approach to the identification of hazards and their systematic control and monitoring. Note that process controls may involve activities that affect the operation and productivity of the production process, and thus affect the variable cost of production. Process control may also involve activities that are independent of the rate of output, but that involve both variable and fixed inputs. Thus the cost function takes the form

$$cc(y, q, \mathbf{w}, \mathbf{w}_c, k, k_c) = vc(y, q, \mathbf{w}, k) + qc(q, \mathbf{w}_c, k_c) + fc(k), \quad (10)$$

where total cost $cc(\cdot)$ is composed of variable cost $vc(\cdot)$ that is jointly determined by the rate of output and quality, the nonjoint component of the quality control process $qc(\cdot)$ that is independent of output, and fixed cost $fc(k)$. The non-joint component of process control may involve both variable and fixed costs, thus,

$$qc(q, \mathbf{w}_c, k_c) = vcc(q, \mathbf{w}_c, k_c) + fcc(k_c), \quad (11)$$

where $\mathbf{w}_c$ is the vector of factor prices specific to quality control and k_c is capital-specific to the quality control process. To illustrate, consider process controls in a meat

slaughter plant. The impact of process controls on slaughter-line design and operation is represented by the presence of q in $vc(\cdot)$, whereas $qc(\cdot)$ represents the costs of designing and monitoring the quality control process that are independent of the rate of plant output.

Inspection involves the physical examination of the product for defects, such as the USDA inspection of animal carcasses for evidence of disease or fecal contamination. Inspection may affect the efficiency of the production process, e.g., as when slaughter-line speed must be reduced to accommodate inspection and removal of defective carcasses. Inspection of the product for defects requires more labor as the rate of output increases, so the cost of inspection is a function of the rate of output as well as product quality. Food safety inspections also may involve inspection of the plant for sanitary conditions, in which case the cost is a function of plant size but not a function of the rate of output. However, inspections do not require additional capital. Thus, the technology takes the form

$$ci(y, q, \mathbf{w}, \mathbf{w}_i, k) = vc(y, q, \mathbf{w}, k) + qi(y, q, \mathbf{w}_i, k) + fc(k), \quad (12)$$

$$qi(y, q, \mathbf{w}_i, k) = cvi(y, q, \mathbf{w}_i) + fci(k), \quad (13)$$

where $\mathbf{w}_i$ is the wage rate for inspector labor.

Testing involves subjecting inputs or outputs to tests that verify inputs or outputs meet quality standards. Testing for food safety is costly because it involves the use of sophisticated laboratory equipment and skilled labor, and because it destroys product. Testing may be exhaustive, in which every unit of output is tested, but typically involves sampling a small proportion of output. In either case, the number of tests, the amount of rejected output, and hence the total cost of testing are necessarily a function of the rate of output. However, testing does not require modifications of or interference with the production process. In addition, the cost of testing per unit time will also depend on the number of different products being produced, since each type of product will have to be tested. Letting the number of products be m , the cost function with testing is

$$ct(y, q, \mathbf{w}, \mathbf{w}_t, k, m) = vc(y, \mathbf{w}, k) + qt(y, q, \mathbf{w}_t, k_t, m) + fc(k), \quad (14)$$

$$qt(y, q, \mathbf{w}_t, k_t, m) = vct(y, q, \mathbf{w}_t, k_t, m) + fct(k_t). \quad (15)$$

Thus, in the case of a pure testing system with no process controls to maintain quality, the variable cost of production is independent of quality, whereas the quality control process depends on both the rate of output and the level of quality being attained.

Identity preservation involves maintaining the identity of each unit of material as it moves through the production process. The purpose of identity preservation may be to know the identity of the process used to produce inputs (e.g., organic crops), or to be able to trace contaminated products to their source. Identity preservation may involve costs associated with segregating output, such as process modifications necessary to maintain identity (e.g., limitations on product mixing). Identity preservation also will involve additional management effort that is independent of the rate of output, and these

costs should increase with the number of input sources, n . The cost function thus takes the form

$$cp(y, q, \mathbf{w}, \mathbf{w}_p, k, k_p, n) = vc(y, q, \mathbf{w}, k) + qp(q, \mathbf{w}_p, k_p, n) + fc(k), \quad (16)$$

$$qp(q, \mathbf{w}_p, k_p, n) = vcp(q, \mathbf{w}_p, k_p, n) + fcp(k_p). \quad (17)$$

Functionally, identity preservation and process control are similar in that they both involve a non-joint component of quality control. In both process control and identity preservation, if quality control does not affect productivity, quality control is independent of the rate of output.

Implications for firm size. The neoclassical theory of the firm determines firm size by taking technology as exogenously given and associating firm size with the capital stock that corresponds to minimum long-run average total cost. Following the neoclassical approach, a number of observations can be made about the potential impacts of quality control technology on firm size. A basic question is whether the effects of quality control on the efficiency of the production process will differ across small and large firms. This question has begun to be addressed in empirical studies of the meat packing industry, as described in Section 5.

Following the neoclassical approach to firm size based on minimum average total cost, the four types of quality control introduced above give rise to a number of different possible results on optimal firm size. Define y_v as the value of output where variable cost attains its minimum and y_a as the output where average total cost (including both production and quality control costs) attains its minimum. The case of process controls generates a quality control cost function $qc(q, \mathbf{w}, k_c)$ (Equation (11)) that is independent of output y , hence average quality control cost qc/y is monotonically declining with y . The value of output y_a , that minimizes average total cost (atc), satisfies the familiar condition $vc_y - atc = 0$. Differentiation with respect to q shows that $\partial y_a / \partial q > 0$. Viewed from the short-run perspective of a given capital stock, the firm's long-run equilibrium output is increasing in quality, all else equal. From the long-run perspective of a firm with decreasing returns to scale, the same logic implies that the optimal firm size is increasing in quality. In the case of constant returns to scale in production, the addition of declining average quality-control costs transforms the firm to increasing returns to scale.

Inspection technology makes quality control cost a function of output and capital stock (Equation (13)). Typically, inspection that is designed to achieve a particular safety standard involves a certain number of inspectors per unit of output. However, the minimum number of inspectors is one, so increasing returns to scale may be experienced at low rates of output in small plants. Beyond that minimum level, however, it is reasonable to assume that inspection costs are proportional to output, so average inspection costs are constant and have no effect on y_a . If plant inspection is also involved, average plant inspection costs will decline with output and cause average total inspection costs to decline with output. But unlike process control costs, plant inspection costs

vary with plant size and thus are similar to conventional fixed costs. It does not follow that average plant inspection costs are necessarily higher for small plants than large.

In the case of testing (Equation (15)), variable production cost is independent of quality, but quality control depends on both output and quality. The cost of testing for chemical contaminants or pathogens is likely to exhibit increasing returns to scale for firms that operate their own testing laboratories. Smaller firms are more likely to obtain testing services from independent testing laboratories at a constant cost per test. Large firms also may outsource testing but may be able to negotiate quantity discounts. Thus, small firms are likely to face a constant, but relatively high, average cost of testing, whereas large firms may experience a decreasing average cost of testing. However, the effect of testing costs on y_a depends on the relationship between y_v and y_q (the value of output at which quality control cost is minimum). If $y_v < y_q$, then y_a is increased by testing costs, with the converse true if $y_v > y_q$.

Product variety, denoted by the number of products m , also affects the cost of testing. An increase in m shifts the cost function upward. In food processing industries, small firms sometimes produce a larger variety of products, in which case they would face a cost disadvantage in terms of testing. This aspect of testing costs was a major issue in the design of the USDA's HACCP and pathogen-reduction regulations [Food Safety and Inspection Service (1996)]. Complaints by small firms led the USDA to redesign the regulations to mitigate the adverse impacts on small firms.

Identity preservation technology (Equation (17)) has the same structure as process control, with quality control involving process changes and costs independent of the rate of output. However, in this case quality control costs also increase with the number of distinct input sources, n , that are used. In some cases, inputs of differing quality and safety characteristics can be segregated by processing them in batches. This procedure typically involves an increase in cost with each additional input source, e.g., when it is necessary to stop production to clean equipment between batches. Thus, the cost structure is similar to the one described for process controls except that a family of average quality control costs exists, with successively higher costs associated with increasing values of n . It can therefore be concluded that, conditional on n , identity preservation provides larger firms with a cost advantage in the same way that process control does. However, because costs are increasing in n , the identity preservation strategy may be most well suited to small firms that purchase inputs from a small number of sources.

The above examples illustrate the types of relationships that are typical of quality control. The meat industry in the United States provides a good example of how controls can be combined. Organoleptic (sight, smell, touch) inspection and plant sanitary inspection by government inspectors has been mandated by law since 1906, and the mandatory HACCP and pathogen-control regulations instituted in 1996 require meat plants to utilize a combination of process controls and testing in addition to inspection.

3.2.2. Competitive supply

Following Rosen's (1974) description of a competitive industry with product differentiation, we assume that there are demanders and suppliers of a quality-differentiated

product sufficient to generate an equilibrium hedonic price equation for the industry. Consider a product y with a single, known quality attribute that can take on two values, low quality (L) and high quality (H). Profit-maximizing firms compete in a national market in which the demand functions for low- and high-quality foods are $Y_j^D = Y_j^D(p, I, \Delta, \Psi, N)$, $j = L, H$.

Letting $mc_{ij} = \partial c(y_i, q_j, \mathbf{w}, k_i) / \partial y_i = g_j(y_i, q_j, \mathbf{w}, k_i)$, where $i \in L, H$ indexes firms, the inverse marginal cost function is $g_j^{-1}(mc_{ij}, q_j, \mathbf{w}, k_i)$. The market supply function for each quality is then derived in conventional fashion as the sum of each individual firm's marginal cost functions where price p_j is equated to marginal cost mc_{ij} for each firm:

$$Y_j^S(p_j, q_j, \mathbf{w}, K_j) = \sum_{i \in j} g_j^{-1}(mc_{ij}, q_j, \mathbf{w}, k_i), \quad (18)$$

where K_j is interpreted either as a vector of the k_i or as the aggregate capital stock. As in the conventional theory of the competitive firm, price is equal to minimum average cost for each quality. Assuming that minimum average cost of production is greater for high quality than for low quality, it follows that market equilibrium prices p_H and p_L satisfy the condition $p_H > p_L$. Otherwise, production of the low-quality product would be shut down and the market would contain only the high-quality product.

Figure 2 shows the market equilibria for low- and high-quality products in price-output space and price-quality space. The figure illustrates that the set of equilibria in the low- and high-quality markets generate a positive relationship between price and quality, as indicated by the points A and B in the figure. This relationship suggests a

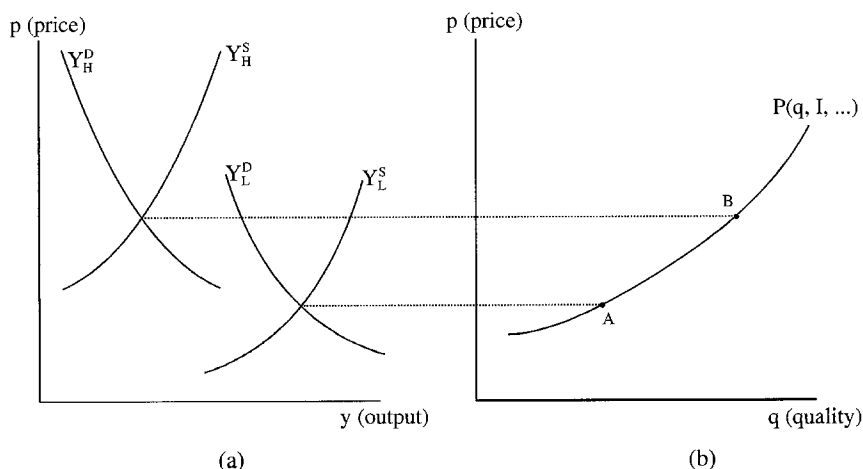


Figure 2. Demand and supply for quality (a) and hedonic price function (b).

generalization of the demand functions from the discrete quality case to a continuous quality case wherein Equation (8) is written as

$$Y^D = Y^D(\mathbf{p}, q, I, \Delta, \Psi, N), \quad (19)$$

where q is interpreted as a continuous index of quality and it is assumed that $\partial Y^D / \partial q > 0$. Thus, q can be interpreted as being inversely related to the parameter δ in the market demand function (7). Likewise, in Equation (18) the subscript j can be dropped and the supply function can be written $Y^S(p, q, \mathbf{w}, k)$ for which $\partial Y^S / \partial q > 0$. Then equating the quantity supplied and the quantity demanded gives the equilibrium price function

$$p = P(q, I, \Delta, \Psi, N, \mathbf{w}, K). \quad (20)$$

The reader will recognize (20) as a version of the hedonic price function derived by Rosen (1974) and used extensively in the economics literature to investigate relationships between prices and quality attributes of goods [Palmquist (1991)]. Comparative static properties imply that the hedonic price function is typically increasing in income I and h , factor prices $\mathbf{w}$, and decreasing in capital K .

The individual firm faces both long-run and short-run decisions as in the conventional theory of the firm. In the short run, the firm chooses output to maximize expected net returns, taking capital and expected quality as given. Expected quality is taken as fixed in the short run because the production of quality is closely linked to the firm's capital stock and technology. Quality is produced in the meat sector and other food industries through the use of various quality control technologies, including the Hazard Analysis Critical Control Points (HACCP) technology now required in the USDA regulations. These quality control programs require investments in specific capital and management that are, at least in part, independent of the rate of output in any given time period – these investments are a part of the plant's fixed capital and management. Thus, in the short run, a plant chooses to produce a particular output y , given its planned quality q , its capital stock k , and variable factor prices $\mathbf{w}$. Given its planned quality, the plant's expected product price is derived from the market equilibrium hedonic price function by solving $p = P(q, I, \Delta, \Psi, N, \mathbf{w}, K)$. Thus, in the short run the plant chooses y to maximize expected net returns

$$\pi = P(q, I, \Delta, \Psi, N, \mathbf{w}, K)y - C(y, q, \mathbf{w}, k), \quad (21)$$

taking q as given. The solution takes the form $y(q, I, \Delta, \Psi, N, \mathbf{w}, K)$. Differentiation of the first-order condition shows that $\partial y / \partial q \geq 0$ as $\psi_q \geq \varepsilon_{yq}$, where ψ_q is the elasticity of p with respect to q and ε_{yq} is the cross-elasticity of cost with respect to y and q . Note that theory implies that $\psi_q > 0$ and intuition suggests $\varepsilon_{yq} > 0$, but their relative magnitudes is an empirical question. Thus, theory predicts that as firms plan to produce a higher quality, they may produce either higher or lower rates of output. In the context of food safety regulation, the significant implication is that if regulations

impose a higher quality standard on firms, they may respond by increasing or decreasing output. If, for example, $\partial y / \partial q > 0$ for large firms but negative for small firms, food safety regulation could have the effect of concentrating output in larger plants.

In a longer-run sense the competitive firm can be viewed as choosing what quality of product to produce jointly with its output level. In this type of model, the firm views price as a function of quality, as in (20). If the quality that a firm can produce depends on its capital stock then the model could be structured as a dynamic investment problem. Taking capital as given for simplicity, the static profit maximization problem is

$$\max_{y,q} \pi = py - c(y, q, w, k) \quad \text{such that } p = P(q, I, \Delta, \Psi, N, w, K). \quad (22)$$

The solution satisfies $p - C_y = 0$ and $p_q y - C_q = 0$. The firm produces where price equals marginal cost, but in addition the marginal value of quality is equated to the marginal cost of quality. Second-order conditions can be shown to require convexity of the cost function in output and also require $p_{qq} y - C_{qq}$ but do not require convexity in quality for cost function. Special results can be derived for the quality control technologies described above. For example, consider the process control technology (11). The first-order conditions become $p = vc_y$ and $p_q y = vc_q + qc_q$. If $vc_q = 0$, then the first-order condition for quality is $p_q y = qc_q$. Because $qc(\cdot)$ is independent of y and increasing in q , it follows that the profit-maximizing value of q is positively related to the value of y (formally, differentiating with respect to q shows that the result depends on $qc_{qq} - p_{qq} y > 0$, which is implied by second-order conditions). More generally, however, for non-zero vc_q , the relationship between quality and output may be either positive or negative as in the short-run case.

3.2.3. Product differentiation, monopolistic competition, and reputation

Some market structures are conducive to a monopolistic situation. For example, Gertler and Waldman (1992) developed a model for nursing homes which supply a local market. By virtue of its spatial monopoly and its ability to differentiate its product in terms of quality, the nursing home can choose the combination of price and quality that maximizes profit subject to the demand function it faces. This model could be applied equally to monopolistically competitive producers of food products, e.g., firms producing specialty meats or organically grown produce, with each firm supplying products with distinct price and quality attributes.

Let the demand function faced by a firm be $Y^D(p, q, I, \Delta, \Psi, N)$ as before. The firm produces a single product y with quality q , solving the problem

$$\max_{p,q} \pi = py - c(y, q, w, k) \quad \text{such that } y = Y^D(p, q, I, \Delta, \Psi, N).$$

Note that in contrast to the competitive firm choosing quality and output by maximizing profit subject to the equilibrium hedonic price (Equation (22)), here the firm maximizes profit subject to the market demand function. Letting c_y be the partial derivative

of the cost function with respect to y , etc., the first-order conditions can be written as $(p - c_y)Y_p^D = -Y^D$ and $(p - c_y)Y_q^D = c_q$. The demand function satisfies $Y_p^D < 0$ and $Y_q^D > 0$, and the cost function satisfies $c_y > 0$ and $c_q > 0$. These conditions demonstrate that the price-making firm will set its price above marginal cost. As expected, the monopolistic firm will price higher than a competitive firm.

The monopolistic firm provides one example of a case in which firms set prices – that is, prices are endogenous. The case of a competitive, quality-differentiating firm (Equation (22)) also leads to a price-endogenous model. A key difference between these two models is that in the competitive model, price is equated to marginal cost, whereas in the monopolistic model it is not. But in some models of quality-differentiated markets, competitive firms also set price above marginal cost [Stiglitz (1989)]. In general, the literature shows that in product markets with imperfect information, the properties of market supply and market equilibrium depend on a number of factors affecting demand and supply, including the characteristics of the product, the cost of communicating information to consumers, and the ability of consumers to use information.

One way to look at the issue of product quality is to ask under what conditions the market will provide the degree of quality that consumers want to purchase. When information about product quality before the purchase is imperfect, then consumers are put in the position of buying a product whose quality is uncertain. When firms know quality but consumers do not, we have the well-known problem of asymmetric information, first examined by Akerlof (1970). In markets with asymmetric information, firms lack an incentive to supply a high quality product because consumers cannot distinguish high quality products from low quality products before purchase. This situation leads to a fundamental theoretical problem. If price is used by firms to communicate quality to consumers, then how will the process of competition work, wherein consumers seek out the lowest price?

In their seminal contribution to the reputation literature, Klein and Leffler (1981) provide a resolution to this paradox. They ask under what conditions will the unregulated market assure contractual performance, in the sense that firms will provide the product quality that consumers believe they are buying. They argue that as long as there is a substantial number of knowledgeable consumers in the market who demand a high quality product and are willing to pay for it, the higher price is sufficient to ensure that nonperformance (supplying an inferior product) results in a loss greater than the gain from nonperformance. Price in such a market equals minimum average cost, where minimum average cost includes conventional average production cost plus the cost to the firm of establishing its reputation for supplying high quality. Klein and Leffler refer to this latter cost as the cost of investing in “brand-name capital”. We shall refer to it here as the cost of establishing a firm’s quality reputation. Likewise, Grossman (1981) provides a model which, under suitable conditions in which consumers can verify product quality after purchase, markets exist for quality-differentiated products with consumers paying higher prices for higher quality products.

To illustrate the implications of models with reputation, consider the problem of the competitive firm that chooses both output and quality to maximize profit, as in Equa-

tion (22). However, in the case of the firm that must establish a quality reputation, the firm must bear a fixed cost attributed to the establishment of its reputation, so equilibrium requires the first-order conditions for (22) to be satisfied in addition to the condition that $\pi = F$ in long-run competitive equilibrium where F is the fixed cost associated with establishing a quality reputation. Thus, if p^* is the equilibrium price solving the problem defined in Equation (22), then the price that solves the profit maximization problem is equal to $p^{**} = p^* + F/y^{**}$ where y^{**} is the output corresponding to p^{**} . This result demonstrates that if the firm must establish a quality reputation, it charges a price that exceeds the price (and marginal cost) of the firm that does not need to establish a quality reputation. If the fixed cost of establishing a reputation is a function of the degree of quality, i.e., if F is a function of q and $dF/dq > 0$, it can be shown under reasonable conditions that the profit-maximizing level of quality will be lower than if F is independent of q . Note the similarity of this result to the preceding discussion of firm behavior with quality control technology whose cost is a function of q .

Quality control and product reputation. As will be discussed in more detail in the next section, food products may be either *experience goods*, in which case consumers can determine quality and safety attributes after purchase, or they may be *credence goods* – goods whose quality cannot be ascertained by consumers either before or after purchase. In the case of experience goods, there would appear to be a clear rationale for investment in quality control technology, because even though consumers may not be able to discern quality before purchase, through experience consumers learn which firms produce higher-quality, safer products. Thus, the reputation mechanism can serve to establish a separating equilibrium in which firms receive a higher price for higher-quality products.

In the case of credence goods, however, the reputation mechanism would appear to break down. Why would firms invest in quality control technologies if consumers cannot discern quality, even after purchase? One answer is that firms may still be able to establish high-quality reputations by identifying their products with the use of quality control processes. An example of this is the recent adoption of HACCP by a prominent seafood firm (Legal Seafood) in the United States that advertises its use of HACCP. By identifying its product with a quality control process, a firm may be able to convey product quality information to consumers and a separating equilibrium may be attained that efficiently sorts consumers and producers into markets for different qualities with corresponding prices.

In this respect, quality control may play a role similar to the role that Klein and Leffler identified for “brand-name capital”. The costs of quality control can be interpreted much like the costs of establishing brand-name capital. This interpretation of quality control costs may explain some aspects of firms’ behavior towards recent HACCP and related food safety regulations. One might well ask why the food processing industry would support regulations that do little more than impose onerous government compliance costs on the industry without effectively augmenting the industry’s ability to provide safer products. One answer may be that a significant part of the government’s regulatory

efforts is to educate (or persuade) the public that effective regulatory actions are being taken. This public education effort serves to subsidize the cost of brand name capital for firms that claim to be using more effective quality control processes.

3.2.4. Liability and the supply of safe products

Firms may perceive an incentive to produce products with safety characteristics because of the risk of being held liable for damages caused by products they sell. The economic theory of tort liability is based on the idea that the prospect of liability can induce firms (the potential injurers in cases of product liability) to take the socially optimal level of precaution that minimizes expected social cost associated with harm from a product. Define this expected social cost as the sum of the cost of taking precaution, $C(x)$, and the expected cost of an accident, $A(x)$. The optimal level of precaution that minimizes $C(x) + A(x)$ (assumed to be strictly convex in x) equates the marginal cost of precaution to minus the marginal expected cost of an accident. An efficient liability rule would induce firms to undertake precisely this level of precaution.

Shavell (1987) identifies conditions under which the tort system may prove effective: (1) when harm to an individual or a well-defined group is sufficient for the individual or group to have an incentive to sue the injurer for damages; (2) when injurers have sufficient resources to pay for the harm they cause; and (3) when individuals have information sufficient to demonstrate harm on an individual basis. Shavell notes that one situation in which liability is not likely to be effective is when consumers have difficulty knowing or proving harm *ex post*. Of course, this is exactly the problem that consumers face with contamination of food by microbial contaminants or harmful chemicals.

Other criticisms of liability include Huber's argument that in the United States the application of strict liability has led to the over-supply of safety and the under-supply of product quality, as firms choose to not supply certain products rather than face potentially costly liability suits. Kolstad, Ulen and Johnson (1990) argue that liability and statutory regulation may be complementary. Innes (1994) argues that with asymmetric information, as may be the case in food markets, liability rules with appropriate punitive damages can be more efficient than statutory standards.

Liability also has been analyzed in relation to research and development. Liability may discourage innovation [Litan (1991)], although Reinganum (1989) and Daughety and Reinganum (1995) show that rates of innovation depend in complex ways on incentives created by liability and other factors. Perrin (1997) analyzes the supply of safety (in the form of irradiated meat products) under the assumption that firms face liability for supply products contaminated with microbial pathogens. In his model, liability increases the incentive for firms to adopt irradiation technology that reduces the risk of selling an unsafe product, but the benefits of doing so also depend on consumers' information about health risks. More generally, the literature on induced innovation suggests that as regulations increase the costs of utilizing certain inputs, they may induce firms to innovate in directions that they otherwise would not have.

4. Product quality information, market equilibrium, and market structure

Section 3 established that a high degree of quality or safety generally costs more to produce than a low degree of quality or safety. Competitive firms are willing to supply consumers with safety attributes they demand as long as the firms are able to be remunerated for the cost of producing them. With the growing consumer concern with food quality and safety, product differentiation by nutritional and safety characteristics in the food industry is increasingly important. Product differentiation may be compatible with perfect competition, or may lead to imperfect competition [Eaton and Lipsey (1989); Stiglitz (1989)]. Following Antle (1995), this section sketches the role of information, demand, and supply in market equilibrium for food safety, although it is beyond the scope of this section to provide formal analysis of models of market equilibrium. There are few formal analyses of market equilibrium for food markets with safety considerations in the literature, exceptions being Falconi and Roe (1991) and Perrin (1997).

In the 1980s food manufacturers began to put health claims on food labels, and in 1987 the FDA issued guidelines for such claims, which previously had not been allowed. Caswell and Johnson (1991) describe the kinds of product differentiation efforts by food manufacturers that ensued. Some similar behavior has been observed in the marketing of milk not treated with recombinantly derived bovine somatotropin, the labeling of irradiated meat products, and organically grown or pesticide-free products. Clearly, a key issue in the behavior of both consumers and firms, and hence in the determination of market equilibrium, is the availability of information about product characteristics.

The literature has identified three categories of goods according to the way consumers obtain information about them [Nelson (1970); Caswell and Padberg (1992); von Witzke and Hanf (1992)]. Search goods are those for which consumers have perfect information before purchase; experience goods can be judged only after purchase; and credence goods are those whose quality cannot be judged even after purchase. Antle (1995) observes that, in the context of food safety regulation, another important distinction is the type of information the firm has about product quality. Particularly with chemical residues in foods and microbial contaminants, food producers may also lack good information about product quality and safety. Thus, for purposes of analyzing food safety, it is useful to distinguish between *asymmetric imperfect information* (information imperfect for consumers but not firms) and *symmetric imperfect information* (information imperfect for both consumers and firms). The distinction between symmetric and asymmetric information has important implications for market equilibrium and regulation for the simple reason that regulations cannot force firms to reveal information that they do not have.

4.1. Perfect information equilibria

Some food safety qualities are detectable by sight, smell, or touch – i.e., by organoleptic inspection. Also firms may reveal a food's qualities through labeling, as in the sale of

branded, genetically altered foods with desirable nutritional or safety qualities. In these cases, the consumer may have nearly perfect safety information. Rosen (1974) showed that even though products may be differentiated by quality attributes such as safety and nutritional characteristics, a competitive market can exist in which prices reflect quality differences. In the ideal case of perfect information, identical informed consumers, and free entry for identical, competitive producers of each quality, the market functions efficiently. It provides consumers with the product they demand at minimum average cost of production for that quality.

Of course, few food product markets meet the conditions of the perfectly competitive market, but many approximate them well enough to result in an efficient allocation of resources. There are also important violations of the perfectly competitive conditions that may result in an inefficient level of safety. We now consider those violations of the perfectly competitive market model, and discuss the effects they have on market equilibrium.

4.2. Experience goods

Imperfect information means that consumers lack perfect quality information before they purchase a product. But when consumers realize the quality of the product after purchase, reputation can play an important role in determining the property of market equilibrium, as discussed in Section 3.2. Foods are experience goods in the sense that certain toxic residues and microbial pathogens cause acute illness that the consumer can identify after eating the food. If consumers buy the product repeatedly, firms that provide a higher quality (safer) product can charge a higher price for it, and the market with imperfect pre-purchase information can achieve essentially the same outcome as the market with perfect information [Grossman (1981)], although firms may have to expend resources to establish a quality reputation [Klein and Leffler (1981)]. When consumers purchase a product only once, an efficient equilibrium can also be attained as long as consumers can exchange product information or otherwise obtain product information at low cost. Here again firms can establish a reputation for a high quality product and charge a commensurately higher price to cover the cost of producing the product and establishing its quality reputation.

Many food markets satisfy the conditions that allow firms to establish quality reputations. Repeat purchases are typical of most foods consumed at home. Moreover, low-cost information about product quality is available by word-of-mouth, newspapers, consumer information publications, and so forth. In addition, the rise of restaurant chains allows consumers to purchase food from the same firm whether one is near home or far from home.

4.3. Credence goods and information symmetry

Consumers are usually not able to know product quality either before or after purchase when quality involves the chemical composition of the food, contamination with toxic

chemicals, or the presence of microorganisms. Whereas acute effects of chemical contamination may be associated with the food source, the chronic effects of low-level exposure to toxins, such as cancer-causing substances, are difficult to know because the effects are delayed for many years or even decades. Moreover, the causes of cancer and many other diseases are not well understood, so it is difficult for consumers to associate exposure to any particular substance with the disease. Some acute effects of toxins or food-borne illness also occur after enough of a delay that consumers may not be able to associate the disease with the consumption of a contaminated food. Consumers also typically cannot discern quality that is related to the production process, as when food is irradiated, or milk is produced with animals treated with genetically altered growth hormones such as rBST.

In these examples of credence goods, it is difficult for firms to establish reputations for quality, and the distinction between asymmetric imperfect information and symmetric imperfect information becomes important. With the latter, the firm itself does not know all of the quality attributes and so cannot reveal them even if it wants to or is required to do so by law. Clearly, when consumers cannot distinguish low quality from high quality products, the reputation mechanism cannot work effectively to achieve an efficient level of safety. Consequently, a "Gresham's law" of product quality applies, with "bad" (low quality, low cost) products chasing "good" (high quality, high cost) products out of the market. Thus, under these conditions, the market fails to provide consumers who want a high quality, safer product with the opportunity to buy it. Moreover, because firms and regulators lack quality information, policies designed to fix information asymmetries, such as labeling requirements, will be ineffective. In this context, the recent literature on informational labeling [Caswell and Mojduszka (1996)] and HACCP as a regulatory tool [Unnevehr and Jensen (1996); Antle (1996)] becomes relevant. If it is possible to devise regulatory interventions that effectively transform credence goods into experience goods, then product information dissemination, performance standards, product quality reputation, and liability all have potential to lead to more efficient outcomes in food markets where safety is a concern.

An area of economics research that has not been exploited in the food safety literature is the field of mechanism design [e.g., Baron (1999); Chambers (1999)]. A number of issues that have been addressed in the literature appear to have potential for application to the area of food safety regulatory policy design. Safety-differentiated markets involve asymmetries of information between firms, consumers, and regulators, and the performance of the firm may or may not be readily observable by the regulator. These conditions are recognized to create problems of moral hazard and incentive compatibility and create strategic opportunities for the behavior of firms and for the design of regulations. Issues such as which form of regulatory designs are incentive compatible – i.e., induce the firms to behave in the manner desired by the regulatory agency – appear to provide fertile ground for research.

4.4. Heterogeneous consumer risk preferences, production costs, and incomplete markets

Even when information is perfect for consumers and producers, competitive markets may not provide the variety of quality and safety desired by all consumers in the way that it does in Rosen's model of competitive firms producing a continuous range of quality-differentiated products. Rosen's discussion of market equilibrium showed that the existence of equilibrium is often tenuous, especially when products exhibit multiple quality characteristics or there is not a continuum of firms willing to provide a range of quality-differentiated products. Equilibrium for all levels of product quality may not exist when consumers are heterogeneous, as implied by the model in Section 3.1 – i.e., when the population of consumers is characterized by a sufficiently large degree of dispersion of characteristics such as income, risk perceptions, vulnerability to risks, and knowledge. This may also occur when it is costly to provide as wide an array of different products as might be demanded by some consumers. The market for food safety may be incomplete in this sense, but this incompleteness need not necessarily represent an inefficient allocation of resources in the economy. Examples of when an incomplete market may have important welfare and policy implications are the different degrees of vulnerability of infants and children to pesticide residues in food [National Research Council (1993)], and the vulnerability of children, the elderly, and the immuno-compromised to food-borne pathogens [Steahr (1996a, 1996b)]. Spatial models of product differentiation can be adapted to formally address the conditions under which markets provide a complete set of quality-differentiated products [Eaton and Lipsey (1989)].

As an example, consider the provision of products with a high degree of perceived safety, i.e., produce grown without synthetic chemicals. In many markets in the United States, such produce is available from firms that have established reputations. In some markets organically grown produce is not available, yet there are no doubt people in those markets who would buy such products if they were available. Should we conclude that there is a market failure by virtue of the incompleteness of the market? To answer this question, it is necessary to understand how the market supplies safety-differentiated products. This requires an analysis of both demand and supply sides of the market.

People's attitudes towards risk and information about risks appear to differ substantially. There are many examples of different behavior toward risk under similar degrees of risk information. For example, despite ample warnings about the risks of food-borne disease, some people choose to eat uncooked or rare-cooked meats and seafood while others do not. Another factor that may explain differences in behavior is revealed by the household production model that was discussed in Section 3.1. According to the model, people not only have to be informed about risks, they also have to know or believe that they are vulnerable to it or are exposed to it. This prediction is consistent with the valuation studies cited in Section 3.1.

The cost of supplying safety characteristics also varies from product to product and will play a role in the market equilibrium outcome. In some cases, the cost of differentiating products by safety characteristic may be low, in which case firms will be able

to tailor products to small segments of the market. An example of this is the degree of doneness in cooked meat. This situation implies that the average cost curve is horizontal in the safety dimension over the range of product quality that can be supplied. In other cases, firms with fixed plant and equipment may only be able to produce efficiently one degree of safety because of economies associated with safety-specific capital, such as irradiation or anti-microbial processing technologies. Under these conditions, the average cost function has a U shape with minimum average cost at the efficient quality level, and only a limited range of quality is offered in the market.

On the demand side, risk preferences and vulnerabilities in a population of individuals can be described with a probability distribution as discussed in Section 3.1. When the distribution of risk preferences is tightly concentrated about some central value such as the mode of the distribution, and if producing products with a wide range of safety is more costly than producing one level of safety, competitive firms may only be able to supply a product with that modal degree of safety. Those consumers in the tails of the distribution who would prefer either a higher or lower degree of safety are not provided those product options. This situation is an example of how heterogeneous preferences and costs of production may lead to incomplete markets. If the preference distribution is bimodal the market may supply both low and high degrees of safety, but not a middle value preferred by some consumers. If the preference distribution is uniform over a range of safety and if a range of safety attributes can be produced at sufficiently low cost, it may be profitable for firms to provide an array of products with different safety qualities. The market may then be approximately complete with respect to degrees of safety demanded by consumers.

Let us now return to the question of whether an “incomplete” market is an indication of an inefficiently functioning market. Clearly, when firms are supplying the variety of products that it is profitable to supply, and there are no externalities in production or consumption that cause firms to under-supply, then the answer to this question must be no. In other words, the market is providing as much variety in safety as is economical, and the market is therefore functioning efficiently.

4.5. Consumer knowledge of safety

Section 3.1 showed that demand for food safety and willingness to pay for it depends on consumers' knowledge and perceptions of risk. By a knowledgeable consumer we mean one that is able to assess the quality attributes of a product if the information is available; a consumer lacking such knowledge is not able to assess product quality even if there is perfect quality information. Clearly, if none of the consumers were knowledgeable about food safety, there would not be a demand for safety. For most long-standing safety issues it can be assumed that there are many knowledgeable consumers, whereas most consumers may be unknowledgeable about new issues such as the use of recombinantly derived hormones to increase dairy cow production. The risk preferences of the knowledgeable consumers also can be assumed to be heterogeneous. We shall assume that the distribution of risk preferences among the unknowledgeable consumers is the same as it is among the knowledgeable consumers.

Under these conditions, competitive markets with perfect information, or with imperfect information and firm reputation, provide an efficient level of safety for the knowledgeable consumers, for the reasons described above. Moreover, in the case of homogeneous risk preferences, even if some consumers lack knowledge the market may be efficient because the knowledgeable consumers are sufficient to ensure a safe product. This situation is analogous to the way markets respond to a majority of consumers who are informed about market price [Stiglitz (1989)]. A group of informed consumers can be sufficient to ensure that all consumers receive a competitively priced product.

In the more realistic case of heterogeneous risk preferences, the market provides whatever safety characteristics are economically feasible given the distribution of risk preferences. The uninformed consumer is provided these options, but does not know how to evaluate them in terms of safety, and would have to select among them according to criteria other than safety, such as price. Assuming that unknowledgeable consumers select the product with the lowest price, and therefore the lowest quality, some of them will purchase a less safe product than they would if they were knowledgeable. In this sense the market fails to allocate resources efficiently.

4.6. Vertical integration

Many firms operate more than one plant. For analysis of the cost structure not of the plant but the firm, it is necessary to account for multiple plants producing in multiple locations. Both economies of scale and scope then become relevant, and the definition of returns to scale must be generalized [Baumol et al. (1982); Panzar (1989)]. Other issues that may be important in some analyses may involve multi-stage production or marketing processes, as would be the case with vertically integrated firms [Holloway (1996)]. These organizational issues could be important in the analysis of food safety to the extent that they affect the firm's ability to manage the quality of its products. For example, a vertically integrated vegetable production and marketing firm may be able to know whether pesticides were used in production and provide that information to buyers (i.e., preserve product quality identity) at the wholesale level at lower cost than a vegetable wholesaler that buys from a variety of producers. This difference in cost of information and associated costs of production could have important implications for industry structure, competition, and regulation. For example, suppose the demand for certifiably pesticide-free vegetables could be met at lower cost by the integrated operation. The imposition of regulations requiring product labels to indicate what pesticides were used in production could then have different impacts on cost of production for these two types of firms.

As Sexton and Lavoie (1999) note, there is a continuum of organizational arrangements in the food industry, from pure spot markets to complete vertical integration, with various contractual agreements in between. Williamson (1971) identified information costs as creating an incentive for firms to vertically integrate. He suggests that contracting may not be a viable solution when it is particularly costly to verify that contractual obligations are being met, e.g., in the case of credence goods and costly testing.

Following this line of reasoning, Hennessy (1996) constructed a model to illustrate the incentive to integrate food production and processing. This model provides an example of how process-control technology and testing are combined in quality control and how the characteristics of the technology may affect the economic behavior of agents and market organization. In his model, producers may choose to invest in quality control, while processors buying from producers may test for quality (e.g., as when dairy processors test for bacterial contamination). His model shows that when testing is costly and imperfect, market price between producers and processors reflects the imperfections in testing. In the limiting case in which informative tests do not exist, or the cost of tests is prohibitively high, buyers are not willing to pay a quality premium and producers are unwilling to invest in quality control. Vertical integration, if it eliminates the need for testing to determine quality, eliminates the externality associated with asymmetric information and thus leads to the efficient provision of high quality product.

An alternative view of food safety and vertical integration is presented by Antle (1998). He questions why the existence of imperfect testing leads to asymmetric information between producers and processors. The usual argument is that the supplying firm knows that it is using a reliable quality control technology, but the processor does not know. Antle discusses several logical difficulties with this argument. First, how does the producer know its quality control is "reliable"? Most quality control technologies are fallible and require testing to verify their performance (this is one of the principles of HACCP systems). Thus, assuming both producers and processors have access to the same testing technology which is less than 100 percent accurate, both producers and processors have imperfect information – the case of *symmetric* imperfect information referred to earlier in this section. Now the argument can be made that the producer knows its process has been tested and the processor doesn't, but testing can be contracted to an independent entity. Indeed, given that testing is in the interest of both the producer and the processor, it would make sense for them to negotiate to share the cost of testing. This line of reasoning implies that imperfect or costly testing need not give rise to asymmetric information, and thus need not create an incentive for vertical integration.

In the limiting case in which tests become completely uninformative, vertical integration does not solve the problem of providing high-quality products, because there simply is no reliable information about quality for either producer or processor, hence, asymmetric information cannot exist. This situation might be more closely compared to one of Knightian uncertainty. In this case neither vertical integration, nor regulatory intervention, is a viable solution to the provision of safer products [Antle (1996)]. Only improvements in testing or other quality control technologies can solve the problem.

There is an important difference between the example of a crop grown without a pesticide (a question of process identification and identity preservation) and the example of bacterial contamination. In the former, product quality information can be obtained by the producer at low cost and with high reliability, and differences between integrated and non-integrated firms derive from the need to preserve this information through the production and marketing process. In this case, therefore, asymmetric information could

plausibly exist, and information cost differences could encourage vertical integration. In the latter case, where testing is required for both buyer and seller, the information asymmetry argument is less compelling.

A related line of reasoning can be found in the contracting literature [Katz (1989)]. The processor can be viewed as the principal and the producer as agent. As noted above, the principal typically can observe at low cost the type of technology being used by the agent, but the principal cannot so readily observe the effort of the agent, i.e., how well the agent actually manages the quality control process. However, an independently administered test resolves this moral hazard problem by providing the producer with an incentive to operate an effective quality control process. A related point is that it is not obvious how vertical integration solves problems of moral hazard:

“It is far from self-evident that these problems should disappear simply because the two parties are labeled as being in a single firm. Grossman and Hart (1986) adopt the extreme view that vertical integration does nothing to alter either the set of feasible contracts between the stages of production or the goals of the self-interested decision makers at the two stages. While extreme, it seems to me to be a more defensible view than the opposite extreme that has been taken by much of the literature on vertical restraints and vertical integration” [Katz (1989, p. 660)].

There is a growing literature on vertical integration and its relation to quality-differentiated products. Recent papers have addressed the role of quality-differentiated products in market equilibrium [Motta (1993); Constantatos and Perrakis (1997)] and in strategic firm behavior [Caswell and Johnson (1991); Hackner (1994); Lehmann-Grube (1997)]. Application of more sophisticated models, including ones that account for the special structure of quality control technologies, may lend further insight into the benefits and costs of vertical integration and its relation to product differentiation and food safety. Clearly, vertical integration creates coordination costs in its own right, and the use of richer models may shed light on the economic reasons why agriculture typically organizes itself with many relatively small-scale producers engaging in contracts rather than with vertically integrated production and processing.

5. Quantifying the benefits and costs of food safety regulation

The introduction to this chapter noted that there are at least two reasons to quantify the benefits and costs of food safety regulations. First, economists need to assess whether or not food safety regulations are justified, i.e., whether they pass a benefit-cost test. This information is also needed by federal agencies to satisfy the demands of Presidential Executive Orders, the Government Performance and Results Act, and related legislative mandates. Second, if some form of regulation does yield positive net benefits, economists need to provide regulatory agencies with information about the relative efficiency of alternative types of regulation, e.g., economists need to assess whether process-based regulations are more or less efficient than performance standards.

The welfare-theoretic basis for benefit-cost analysis is well known and has been presented in detail elsewhere [see Just et al. (1982); Alston et al. (1995)] and is not reviewed

here. This section focuses on the literature that deals specifically with quantifying the benefits and costs associated with food safety regulations.

The FSIS regulatory impact assessment of HACCP and pathogen-reduction regulations [Food Safety and Inspection Service (1996)] will be used to illustrate the use and limitations of benefit and cost data in regulatory analysis. This assessment concluded that the benefits of implementing HACCP and pathogen-reduction regulations would range from \$0.99 to \$3.69 billion annually (1995 dollars) if the regulations were completely effective in eliminating the risk of illness and death from four major pathogens. Discounted over a 20-year time horizon at 7 percent, these benefits range from \$7.13 to \$26.59 billion. The costs of sanitation procedures, pathogen sampling, and HACCP plan development and operation were estimated to be on the order of \$100 million annually, and in the range of \$1–1.2 billion over a 20-year period. The FSIS analysis concluded that the net benefits of the regulations were likely to be positive for all levels of regulatory effectiveness in excess of about 16 percent. Roberts, Buzby and Ollinger (1996) and Crutchfield et al. (1997) provide summaries of the data and methods used in the assessment.

5.1. *Benefits of regulation*

The discussion in Section 3.1 showed that there is a substantial literature on the costs of illness associated with food-borne pathogens, and there is an emerging literature on the willingness to pay for safe foods. This literature can be combined with other scientific data to estimate the benefits that could be derived from a regulation that increases food safety. To illustrate, consider the following calculation for annual benefits B (measured in dollars) that could be performed for a regulatory impact assessment:

$$B = e \cdot p \cdot n(c \cdot s \cdot f_s + v \cdot d \cdot f_d).$$

Here e is the effectiveness of the regulation in preventing the incidence of the disease associated with a food-borne pathogen; p is the percent of food-borne illnesses associated with food; n is the size of the population; c is the cost of illness (in dollars) associated with that disease, or the average willingness to pay to avoid that illness; v is the value of a statistical life (in dollars); s and d are the observed frequencies of illness and death in the population associated with this pathogen; and f_s and f_d are expansion factors for illness and death that translate observed frequencies of illness or death into estimated rates for the population. These expansion factors are used to account for the fact that numbers of illnesses and deaths associated with food pathogens are typically under-reported. These annual benefits can be capitalized over some time period using a suitable discount rate.

The regulatory impact assessment carried out by FSIS applied this model to each relevant pathogen [see, e.g., Food Safety and Inspection Service (1996, Table 5)]. While this equation is straightforward to apply, given estimates of the parameters, the assumptions required to derive it are difficult to justify on scientific grounds. First, this equation

is based on a proportional relationship between pathogens in meat products and food-borne illness, where the factor of proportionality e is the effectiveness of the regulation in reducing pathogens in meat products. This proportionality assumption was made in the regulatory impact assessment conducted by FSIS and was strongly criticized in public comments. In its final regulatory impact assessment, the FSIS stated, "FSIS has not viewed proportional reduction as a risk model that would have important underlying assumptions that merit discussion or explanation. For a mathematical expression to be a risk model, it must have some basis or credence in the scientific community. That is not the case here. FSIS has acknowledged that very little is known about the relationship between pathogen levels at the manufacturing stage and dose, i.e., the level of pathogens consumed" [Food Safety and Inspection Service (1996, pp. 38945–38946)].

The proportionality assumption effectively reduces the health production function h in Equation (1) to being equal to the risk function r , thus eliminating from consideration the possibility that changes in averting behavior or knowledge could affect the impacts of the regulations. In addition, this assumption means that heterogeneity in the population's vulnerability to health risks is disregarded. One can only speculate how these assumptions affect the overall assessment of the benefits of the mandatory HACCP regulations. On the one hand, by assuming away the effects of averting behavior and accumulation of better information about health risks, the analysis may be overstating the effects of the regulations. On the other hand, ignoring the differences in vulnerability in the population could bias the estimates in either direction, depending on the prevalence of more and less vulnerable individuals in the population. Steahr (1996a, 1996b) presents data suggesting that the proportion of the population vulnerable to food-borne diseases may be increasing over time. An example of a complete risk assessment is the model developed for *Salmonella* Enteritidis in shell eggs and egg products [Food Safety and Inspection Service (1998)]. This model includes components for production, distribution, food preparation and consumption, and public health outcomes.

Whether or not the relationship between pathogens and health is proportional, a critical piece of information required for benefit estimation is the effectiveness (e) of the regulation in reducing pathogens in foods. When new approaches to regulation are being implemented, such as the use of mandatory HACCP, there is little experience or data upon which to base an estimate of regulatory effectiveness. This was true in the case of the HACCP regulations implemented in the United States. In its preliminary regulatory impact assessment, FSIS assumed that the regulations would be 100 percent effective in eliminating food-borne pathogens. After being criticized for this assumption, in its final assessment FSIS assumed a range of effectiveness between 10 and 100 percent and calculated the minimum level necessary to generate net benefits. According to FSIS, "A general comment related to the effectiveness issue stated that while HACCP remains an interesting theoretical concept, it is still only a concept that has never been tested on a meaningful scale under actual meat establishment conditions, and never proven to significantly improve the microbial quality of the finished product. . . . FSIS recognizes that the actual effectiveness of the final requirements in reducing pathogens is unknown at the present time" [Food Safety and Inspection Service (1996, p. 38968)].

Little research has been conducted on how to assess the likely effectiveness of new regulations. The inadequacy of data for assessing the effectiveness of regulatory interventions is illustrated clearly by the existing analyses of the mandatory HACCP program being implemented by USDA. The only attempt to assess the effectiveness of HACCP *ex ante* known to this author is the study by Knutson et al. (1995). In that case, a group of researchers was asked to provide estimates of the effectiveness of the proposed HACCP regulations. The subjective estimate of the microbiologists that participated in the study was that it would be 20 percent effective, and no reasonable range of values was given for this estimate (i.e., a subjective standard error). Clearly, the lack of data on the effectiveness of the regulations is a major gap in the knowledge base needed to assess its benefits. Without better information, all one can effectively do is use the data on the value of a health risk reduction as an upper bound on the possible benefits of a regulatory intervention, with the lower bound being zero.

A third key assumption regards the expansion factors used to apply the valuation data to the population at large. There are some scientific data for the estimation of unreported illnesses and deaths, although comprehensive estimates of the number of human illnesses caused by many food-borne microorganisms are unavailable. Based on two studies of illnesses and deaths associated with food-borne disease, recent estimates for the United States are from 6.5 to 33 million annual cases of acute illness caused by food-borne microorganisms, and from 500 to 9,000 deaths [Council for Agricultural Science and Technology (1994)]. This wide range of estimates presents a great deal of uncertainty about the magnitude of the problem.

In addition to its use in regulatory impact assessments, data on household behavior is needed to design effective policies. As Antle (1995) emphasizes, there is a range of food safety policy options, from provision of information, product quality certification and labeling, to liability law and statutory regulation. Bockstael, Just and Teisl (1994) emphasize that the behavior of consumers is particularly important in assessing how the provision of information could be utilized to correct information-based market failures and thus provide a viable substitute for statutory regulation. In a theoretical analysis, Eom (1995) addresses the issues of consumer's risk perceptions in the context of a model in which consumers have imperfect information about risks but also learn. Like the model developed in Section 3.1, Eom's analysis implies that the value of risk information could be derived from the behavioral relationship between risk and the consumer's food consumption, averting behavior, and mitigating behavior (e.g., demand for medical services). By taking into account learning behavior, Eom's analysis also shows that these relationships should change over time in response to newly available information and consumers' experiences. Detailed household data would be required to implement empirically a detailed examination of household production relationships regarding food demand, averting and mitigating behavior, and learning. To go beyond studies that simply value alternative health states, to the level of understanding the underlying structures that explain behavior, researchers will have to collect the type of detailed data needed to model household behavior. There are precedents for conducting

this type of research, e.g., the use of household production models to investigate labor supply and health [Strauss and Duncan (1995)].

5.2. Costs of food safety regulation

As noted in Section 3.2, a firm producing a quality-differentiated product can be represented as using a multi-output process that can be either joint or non-joint in output and output quality. As noted above in Section 3.2, some quality control activities fall into each of these categories, so the quality-adjusted cost function is specified to represent food processing technology in the form

$$C(y, q, \mathbf{w}, k, \alpha, \beta, \gamma) = vc(y, q, \mathbf{w}, k, \alpha) + qc(q, \mathbf{w}, k, \beta) + fc(k, \gamma) \quad (23)$$

where total cost $C(\cdot)$ is composed of a component of variable cost $vc(\cdot)$ that is joint in conventional production inputs and quality control inputs; a component of variable cost $qc(\cdot)$ that is nonjoint in conventional inputs and certain quality control inputs (thus it is independent of output y but depends on quality q); and a conventional fixed cost component fc that is independent of both output and quality. Here α , β , and γ are parameters of the respective components of the cost function.

Following Antle (1999), regulations can take one of two forms, performance standards or design standards. A performance standard imposes the requirement that the plant achieve a level of product quality, q_p , without specifying the technology that must be used. For a level of product quality q_0 before regulation, and assuming the plant does not need to modify its technology or capital stock to meet the performance standard, the performance standard $q_p > q_0$ increases cost by

$$\Delta c(y, q_0, q_p, \mathbf{w}, k, \alpha, \beta, \gamma) = \Delta vc(y, q_0, q_p, \mathbf{w}, k, \alpha) + \Delta qc(q_0, q_p, \mathbf{w}, k, \beta), \quad (24)$$

where

$$\begin{aligned} \Delta vc(y, q_0, q_p, \mathbf{w}, k, \alpha) &\equiv vc(y, q_p, \mathbf{w}, k, \alpha) - vc(y, q_0, \mathbf{w}, k, \alpha), \\ \Delta qc(q_0, q_p, \mathbf{w}, k, \beta) &\equiv qc(q_p, \mathbf{w}, k, \beta) - qc(q_0, \mathbf{w}, k, \beta). \end{aligned}$$

A design standard specifies the technology that a firm must use, rather than the outcome that must be achieved as in a performance standard. A design standard will generally require firms to modify their plant and equipment and the production process to meet the government standards. The mandated technology is represented by the capital stock k_d and the cost function parameters α_d , β_d , and γ_d . The design standard does not specify the new level of product quality that is achieved, q_d . Significantly, this level of quality is not known *ex ante*, as in the case of the new HACCP regulations promulgated by USDA wherein FSIS does not know how effective the regulations will be at the time the

regulations are imposed. Following Equation (24), the cost of a process design standard is given by

$$\begin{aligned} \Delta c(y, q_0, q_d, \mathbf{w}, k_0, k_d, \alpha_0, \beta_0, \gamma_0, \alpha_d, \beta_d, \gamma_d) \\ = \Delta vc(y, q_0, q_d, \mathbf{w}, k_0, k_d, \alpha_0, \alpha_d) + \Delta qc(q_0, q_d, \mathbf{w}, k_0, k_d, \beta_0, \beta_d) \\ + \Delta fc(k_0, k_d, \gamma_0, \gamma_d). \end{aligned} \quad (25)$$

The USDA's mandatory HACCP regulations and standard operating procedures are process design standards because they specify the process to be used, not the safety attributes of the end products. But the regulations also involve performance standards for detecting *Salmonella* and generic *E. coli*. The combined performance and design standard results in a cost impact represented as in (25) except that the performance goal q_p replaces q_d .

5.2.1. Empirical approaches to cost estimation

Before turning to the empirical literature, several general observations can be made about methodological aspects of the problem, based on the discussion of theory presented in Section 3.2 and on the more general theory of the costs of regulation.

A first observation is that in addition to the changes in benefits and costs associated with consumers and producers, complete benefit-cost assessments need to account for the costs of designing, overseeing, and enforcing regulations. Such cost estimates should account for the deadweight losses associated with taxation as well as the costs of resources used by the regulatory agencies.

A second point is that the strategic response of firms to regulations also should be taken into account. For example, USDA's decision to require firms to remove fecal contamination from carcasses may discourage firms from conducting their own quality controls, because if the firm finds evidence of contamination on a carcass the USDA inspector must condemn an entire day's output. As another example, one might ask why some firms in the food processing industry favor mandatory HACCP regulations while others oppose it. Considering that smaller firms may be put at an economic disadvantage by the regulations provides some insight into this issue. The literature on optimal regulatory mechanism design recognizes the possibility of such strategic behavior [Baron (1999); Chambers (1999)]. One implication is that a short-run or static analysis of the benefits and costs of regulations could be misleading, and could cause analysts to underestimate the true costs if they lead to industry concentration and imperfect competition.

A related point about longer-terms effects of regulations has to do with impacts on research and development and innovation. Regulation may have adverse effects on innovation and long-term productivity, although this must be assessed in terms of the factors that affect firms' incentives to innovate [Reinganum (1989); Daughety and Reinganum (1995)]. In principle, these long-term costs of regulation would be accounted for in benefit-cost analyses, although in practice they are not measured due to data limitations.

The preceding discussion shows how the costs of performance and design standards can be measured, given knowledge of the plant-level cost of production before and after the regulations are implemented. Until recently, however, there was a dearth of literature on the cost structure of meat and other food processing plants and on potential costs that food safety regulations might impose on plants. Three approaches have been used recently to estimate regulatory costs, described here as the accounting approach, the engineering-economic approach, and the econometric approach.

Accounting approach. The FDA and the FSIS estimated the costs of mandatory HACCP regulations for their regulatory impact assessments using an accounting approach [Food and Drug Administration (1994b); Food Safety and Inspection Service (1996)]. This type of approach has also been used in several recent studies of HACCP implementation [e.g., Cato and Lima dos Santos (1999); Colatore and Caswell (1999)]. In this approach, the effects of regulations on plant labor requirements and capital stock are identified and calculated, without estimating a parametric representation of the cost function. Data from pilot programs or from surveys of plants that have adopted quality control systems are used to construct estimates of the costs of the components of the quality control system, such as higher labor costs needed to operate a HACCP system, or additional capital requirements for process controls.

The accounting approach is operationally straightforward and can accommodate detail specific to quality control systems. However, there are several methodological shortcomings. First, when all aspects of the quality control system are not observed in use in plants that are representative of the population being regulated, it is unlikely that all of the inputs required will be identified, and it is also unlikely that input levels assumed in the accounting exercise will correspond to the input levels that cost-minimizing firms would use. When the cost estimates are being conducted by regulatory agencies that have a vested interest in showing that the costs of regulations are low, one could expect these estimates to be biased downwards. Second, the accounting approach is unable to measure the effect of the regulations on the overall operating efficiency of a plant, hence, the effect of quality control on cost of production represented by the term $\Delta vc(\cdot)$ in Equations (24) and (25) will not be captured. Finally, because detailed data on a large number of plants is costly to collect, a small number of plants typically is used as the basis for cost estimates, and it is unlikely that they will be representative of a large and diverse industry such as the food processing industry.

Economic-engineering approach. Prior to the development of duality-based econometric models for production analysis, the economic-engineering approach was widely used. French (1977) provides an overview of the economic-engineering approach to the analysis of the cost structure of processing operations. In this approach, detailed engineering data are combined with data on input costs to construct a quantitative model of the production process. This type of process-based model of the plant's production function can be used to derive an empirical cost function. This approach provides a detailed picture of a plant's production process, but it is costly to implement for each

plant studied. For an analysis of the costs of regulation in an industry with many distinct plants, the cost of using this approach for a large number of plants is usually prohibitive, so a small number of “representative” plants is typically modeled. Consequently, like the accounting approach, the economic-engineering approach may fail to capture the industry’s heterogeneity and may not provide cost information that is representative of the industry.

A study by the Economic Research Service of USDA was conducted to assess the cost structure of meat packing plants using the economic-engineering approach [Duewer and Nelson (1991)], although the data from this study were not used to assess the possible costs of food safety regulation. This study illustrated how a small number of size categories can be used to try to represent the range of plant sizes in the industry. A recent study by Jensen and Unnevehr (1999) utilized the economic-engineering approach to estimate the costs of carcass rinses, sanitizing sprays, steam vacuums, and water pasteurizers in pork processing. They found that the cost function is upward-sloping for microbial pathogen reduction, thus verifying the hypothesis that cost of production is increasing in product safety (defined as pathogen presence). They also found that some interventions or combinations of interventions are more cost effective than others. The costs of these specific interventions were found to be on the order of less than 2 percent of processing costs. These cost estimates can be interpreted as corresponding to the term $qc(\cdot)$ in Equation (23). If the production process is non-joint in output and safety, then these results can be used to estimate the impacts of these technologies on total cost of production. However, if these processes affect the speed of slaughter lines or other aspects of plant operation, they would need to be treated as joint with the overall production process and the effect on the term $vc(\cdot)$ would also need to be measured to obtain an accurate estimate of the impact on total cost of production.

Econometric approach. Econometrically estimated cost functions also can be used to measure the potential costs of food safety regulations. While these models usually cannot provide the level of process detail that is possible with accounting or economic-engineering models, they provide other advantages. Econometric methods are able to utilize data sets, such as the Census of Manufactures data, that are representative of the industry. Being based on the observed behavior of plants in the industry, econometric models reflect actual production choices of plant managers. Econometric methods also provide a statistical basis to test hypotheses related to behavior and production structure, such as the hypothesis discussed in Section 3.2, that the technology is joint in output and product quality.

At the time of this writing, four econometric studies have been reported in the literature. A study by Perrin (1997) examines the benefits and costs of meat irradiation. A representative cost function was estimated from data derived from engineering cost studies of irradiation, under the assumption that the cost of irradiating meat is additive (i.e., nonjoint in inputs) with the rest of the production process. In the case of irradiation applied to meats after they have gone through the slaughter process and other processing, this nonjointness assumption appears reasonable (although it could not be

tested with the data). The cost function was then utilized in a comparative static welfare analysis to assess the net benefits of utilizing irradiation.

Klein and Brester (1997) estimate a translog cost function to examine the effects of USDA's zero-tolerance directive for fecal contamination on the cost of production. This directive requires plants to remove all identifiable feces, ingesta, and milk found on carcasses before they are washed. As an example of how this directive could affect productivity and cost of production, they report that the Food Safety and Inspection Service of USDA instructed its inspectors to slow slaughter lines if inspection procedures could not be adequately performed [Reed, as cited in Klein and Brester (1997)]. This observation implies that the production process is joint in output and safety (assuming the procedures for removing fecal matter actually reduce pathogens).

Klein and Brester estimated a translog cost function based on the general cost function specification $c(y, \mathbf{w}, R)$ where y is output, $\mathbf{w}$ is a vector of prices of capital, labor, cattle, energy and other inputs, and R is a measure of regulatory compliance costs. This formulation allows them to test the hypothesis that safety (as proxied by the regulatory compliance, under the assumption that safety is increasing in regulatory compliance) is joint with the rest of the production process by testing for the statistical significance of R in the cost function. Their data consisted of 70 observations obtained from the financial statements for five plants of a major U.S. beef packing firm, covering semi-annual periods from November 1988 through May 1995. Regulatory compliance costs were calculated as the amount of downtime on production lines caused by complying with the zero tolerance directive since its enforcement in March 1993. The estimated model strongly rejected the null hypothesis of non-jointness in output and safety. Assuming their results are representative of the industry, Klein and Brester estimated the costs of the zero tolerance directive for meat plants to be in the range of \$3 billion. They also noted that plant managers expect these costs to fall over time as they learn how to implement the regulations more efficiently. This observation is consistent with the above discussion of performance and design standards. From Equation (25) it follows that an estimate of regulatory costs holding capital and technology fixed would provide an upper bound estimate of cost.

Antle's (2000) study of U.S. beef, pork, and chicken slaughter and processing plants was designed to estimate the variable cost function $vc(\cdot)$ in Equation (23) and test for the jointness of output and quality. To account for the fact that product quality is not observable, Antle showed that the cost function can be estimated by combining a hedonic model with a cost function model, under the assumption of a competitive market structure as discussed in Section 3.2. The cost functions strongly reject the hypothesis that output and quality are non-joint, and show that cost of production is increasing with product quality, implying that more stringent quality regulations (such as food safety regulations) will result in higher costs of production. Assuming regulations are 20 percent effective, the impact of regulations on the industry's variable cost of production were estimated to be in the range of \$500 billion to \$5 billion (1995 dollars). This result implies that the costs of food safety regulation could plausibly exceed the benefits estimated by FSIS. The data were also stratified into small and large plant size groups. The

results showed that the potential regulatory costs per pound of product faced by small beef and poultry plants was not substantially higher than the costs for large beef and poultry plants, except for very small plants.

Ollinger (1998) used Census of Manufactures data to estimate total cost functions for beef, pork, and miscellaneous meat products of the form $c(y, \mathbf{w}, D)$, where y is output, $\mathbf{w}$ is a vector of factor prices, and D is the number of plant deficiencies, i.e., the number of violations of sanitary regulations noted by the Food Safety and Inspection Service. These plant deficiencies are interpreted as a proxy for the safety attributes of a plant's products, in the sense that a lower value of D is interpreted as indicative of a safer product. Ollinger also found that cost of production was decreasing in deficiencies, again verifying that higher product safety is associated with a higher cost of production.

One problem in using variables such as plant deficiencies as a proxy for product safety is that these deficiencies are not necessarily related to pathogen levels in products. Indeed, in current regulations performance criteria for HACCP or other pathogen-related regulations are based on tests for the presence of pathogens. If product safety is a function $S(D, A)$ where D is deficiencies and A represents other safety-related actions, the elasticity of cost with respect to D will be less (in absolute value) than the elasticity of cost with respect to S because reductions in sanitary deficiencies explain only a part of product safety.

The hedonic method uses proxy variables for non-safety quality and therefore may tend to overestimate regulatory cost, whereas uses of proxy variables for safety may lead to an underestimate of regulatory cost. Interestingly, this observation suggests that application of these two methods should provide bounds on the possible range of regulatory costs. Hopefully, better data and models will make more accurate *ex ante* estimates of regulatory costs possible in the future.

5.2.2. Costs in regulatory impact assessment

The plant-level costs of food safety regulations are identified above in terms of the costs of complying with regulations, plus the effects of regulations on the operating efficiency of the plant. Equations (23) and (24) show that, for a complete estimate of the cost of a mixed design standard and performance standard, information would be required on a number of variables: the performance standard being implemented; changes in the capital stock required to meet the design standard and to comply with the performance standard; the effects of the design and performance standards on the efficiency of the production process; and the variable and fixed costs associated with quality control that are non-joint with the production process. In an *ex ante* regulatory impact assessment, many of these factors are clearly not known. Under certain assumptions, the accounting, economic-engineering, and econometric methods discussed in Section 5 each can be used to construct estimates of these costs.

In the FSIS (1996) accounting analysis, various data sources were utilized, including USDA data from previous quality control initiatives, a pilot HACCP program undertaken in the early 1990s with nine plants, databases maintained for its meat inspection

system, and private sector financial databases. The FSIS's method for covering the relevant population of plants was to utilize their lists of inspected plants to stratify the population into groups based on plant size, type of process (slaughter versus processing), and type of species (beef, pork, poultry). Using these data, FSIS then constructed estimates of the costs of each component of the regulations for each plant type: training employees to develop and maintain a HACCP system; costs of implementing standard sanitary operating procedures; and costs of assumed process modifications. Included in the costs of operating the HACCP system were labor and materials costs of keeping records and conducting product quality tests, and estimates of the capital requirements for additional controls that would need to be added to typical plants.

The data used for this accounting exercise present several significant limitations. While the Food Safety and Inspection Service inspects over 6,000 establishments, much of its cost data came from a voluntary pilot program involving only nine plants. Clearly, such data cannot be representative of the larger population of regulated establishments. Additional information was apparently based on expert judgment of USDA personnel, without validation against a representative sample of data from plants in the industry. As noted by Belzer, "... the analysis contains several material errors in its cost assessment that severely understate the likely costs of the rule. First, the estimated cost of required SSOPs (standard sanitary operating procedures), HACCP (hazard analysis critical control points) plans, and generic *E. coli* testing includes only the cost of writing the plans themselves, training current employees, and performing the microbiological tests. The costs associated with the operational changes necessary to comply with SSOPs and HACCP plans were not included" [Belzer (1999, p. 20)].

The accounting approach followed by FSIS also requires the assumption that quality control costs are additive to other costs in the production process. Thus, the FSIS cost estimates can be interpreted as the component $\Delta q_c(\cdot)$ in the above discussion of performance and design standards (Equations (24) and (25)). The estimates of process modifications made in the FSIS analysis correspond to $\Delta k(\cdot)$ in Equation (24). Effective higher quality standards are also likely to reduce the overall operating efficiency of slaughter and processing, by affecting key factors such as the speed at which a slaughter line can operate, how frequently the line must be stopped, and the amount of time and labor required for cleaning and maintenance. This effect is represented by the presence of the quality variable in the variable cost term $vc(y, q, w, k)$ in Equations (23) and (24). As noted earlier, all of the econometric studies completed thus far have found strong evidence that the impact on overall operating efficiency represents a significant cost of quality regulations, possibly larger in magnitude than the other costs measured in the FSIS regulatory impact assessment. Under the assumption that regulations would be 20 percent effective, Antle's (2000) data show that an upper-bound cost estimate would be in the range of \$750 million to \$6.7 billion (1995 dollars). With 20 percent effectiveness, the annual benefits of the regulations would be in the range of \$200 to \$738 million. These higher costs raise questions about the social value of the regulations.

6. Conclusions

Food safety provides economists with a diverse array of challenging issues that are high on the public policy agenda. Based on the literature reviewed in this chapter, it is clear that much work remains to be done both in the theoretical and empirical areas.

In the theoretical dimension, there is clearly a need for in-depth analysis of markets with imperfect information, consumer and producer heterogeneity, firms with multiple output technologies, and industries characterized by both perfect and imperfect competition. While such analysis is being conducted in the economics profession, there is a clear need for these analyses to be tailored to the conditions of food markets and applied to issues such as optimal food safety policy design. A deeper understanding of the nature of the information regimes that exist or could exist in food markets with changed or new policies and institutions is needed. The literatures on environmental regulation, mechanism design, and related topics should provide useful insights in this field and shed new light on the debate over the use of market-based mechanisms versus statutory regulation.

The empirical studies of demand for food safety and the valuation of food safety regulations show that much more useful work remains to be done. Further research needs to explore the adequacy of the cost-of-illness approach to health valuation. While a number of studies have estimated willingness to pay for safer foods, there is a need for a systematic assessment of willingness to pay to avoid illness associated with the principal pathogens and chemical risks that can be used as the basis for benefit valuation in regulatory impact assessment. Valid behavioral risk models that account for both supply and demand heterogeneity need to be developed to replace the proportionality assumption used to estimate benefits in recent regulatory impact assessments.

On the supply side, the characteristics of food production technology need to be better understood and incorporated into analysis of firm behavior and industry and market structure. In the regulatory domain, the implications for industry structure of changes in food demand and safety regulation need to be assessed. Data on actual pathogen levels now becoming available need to be combined with cost of production data that are representative of the industry to better estimate the costs of pathogen reduction. The benefits and costs of design and performance standards need to be studied. Alternatives to statutory regulation, such as product labeling and provision of product quality and safety information, need to be analyzed using more rigorous theory and with better empirical data and models.

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MARKETING AND DISTRIBUTION: THEORY AND STATISTICAL MEASUREMENT

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Abstract

Agricultural marketing and distribution are broad areas that cover a wide assortment of pricing and market structure issues for agricultural commodities and processed food products. A synthesizing framework is developed in order to discuss the relevant *Handbook* chapters and an assortment of additional marketing topics. The first two sections of this chapter deal with traditional marketing topics: price forecasts, pricing models that emphasize form, spatial and intertemporal features of a market, and tests of pricing efficiency. A third section is devoted to the rapidly growing area of food-market industrialization, including various aspects of information, the changing role of the consumer, and contracting issues. The last section presents a series of discussions on political and institutional constraints in international commodity marketing such as state trading enterprises, export subsidy programs, case studies of trade disputes, and an analysis of the multinational enterprise.

JEL classification: Q13

1. Introduction

The purpose of this chapter is to discuss certain elements of marketing and distribution in agri-food markets. An attempt is made to both synthesize various aspects of the *Handbook* material and to review and discuss topics not contained in the *Handbook*. The first four chapters of this section of the *Handbook* deal with topics traditionally defined as agricultural marketing and distribution: (1) storage and price stabilization; (2) industrial organization of agricultural processing and distribution; (3) spatial price analysis; and (4) marketing margins. The material in the last two chapters on individual consumer demand and food safety is somewhat separate from agricultural marketing as it is traditionally defined. Individual consumer demand is a broad area of research within which commodity prices are normally treated as exogenous.¹ Similarly, although the economics of food safety cuts across the entire marketing chain, explicit links to agricultural marketing are only beginning to emerge. Rather than attempting to cover all three of these broad and complex topics, this synthesis will remain focused on the more traditional agricultural marketing literature.

The literature on agribusiness is not explicitly discussed in this chapter. Agricultural marketing has tended to focus on entire markets and has included topics such as competitive price analysis (demand, supply, and market price equilibrium), tests of allocative efficiency (time, space, and form), and industrial organization. On the other hand, agribusiness and the business-school view of marketing, which includes the identification and evaluation of a company's market size, pricing potential, and product and promotion strategy, tends to focus on management within a firm or on industry competitive analysis [Ritson (1997)]. Although topics that relate to food-marketing management and competitive analysis are important and research in this area is rapidly growing, they are not explicitly discussed in this *Handbook* nor in this synthesis.

An inevitable consequence of writing a survey article with such a broad scope is that important papers are sometimes overlooked. The authors apologize, in advance, to those authors affected by such oversights and for any errors that relate to how various published works are interpreted and discussed.

1.1. Agricultural marketing paradigm

In this section, a synthesizing framework for the marketing literature is set forth (see Figure 1). Drawing from Kohls and Uhl (1998), the various North American institutions and marketing arrangements for agricultural commodities are briefly discussed in the context of this framework. In Figure 1, the vertical market structure is depicted as heterogeneous agricultural products that are shifted from production units (usually

¹ Articles published in the *American Journal of Agricultural Economics* are classified according to subject by the American Agricultural Economics Association. For the years 1994 to 1997, 55 articles were classified as "Consumer Demand", 66 articles were classified as "Agricultural Products: price analysis, subsector models marketing, futures", and 38 articles were classified as "Industrial Organization and Market Structure".

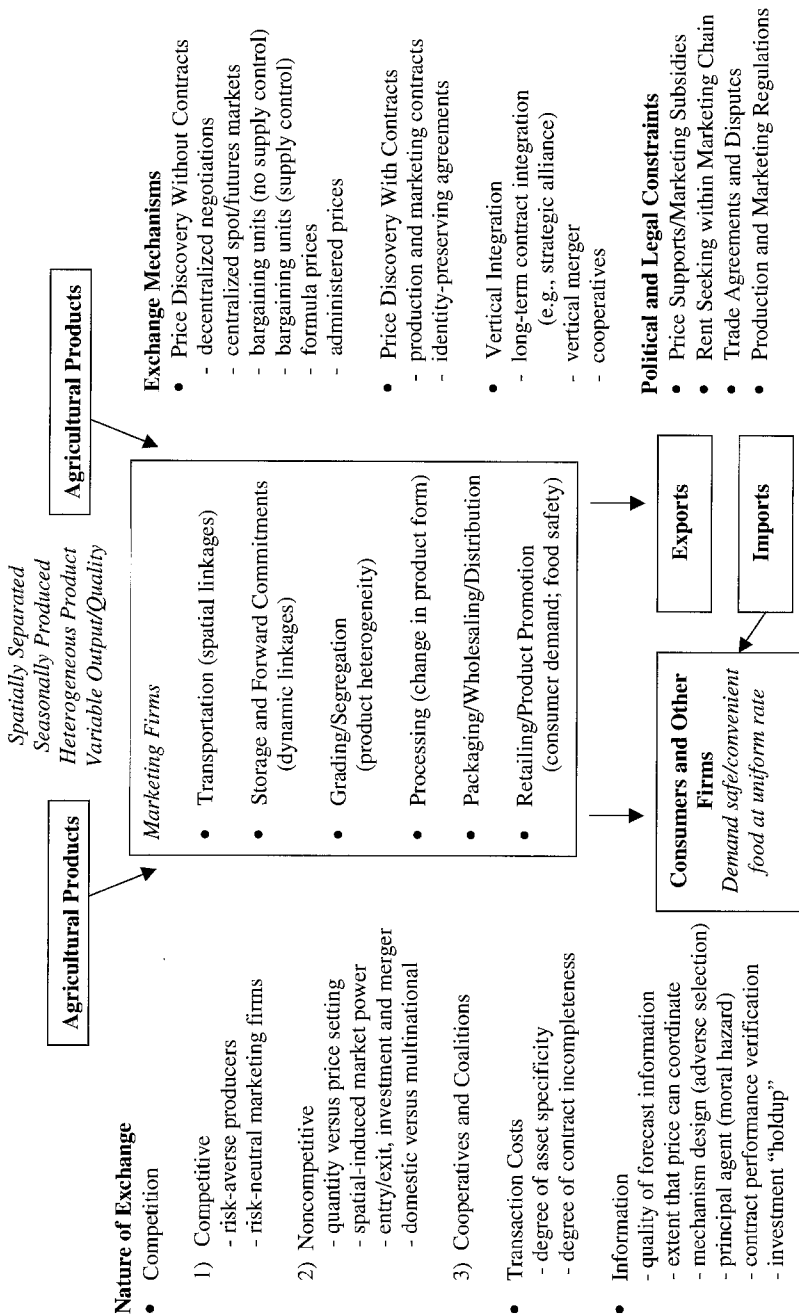


Figure 1. Overview of agricultural marketing.

farms) through a series of marketing firms and final consumers. The production units are often separated spatially, and the quantity and quality of their output is typically seasonal (or cyclical) and variable because of biological constraints, weather, insects, disease, and other random elements. The marketing firms are also spatially separated and supply a wide array of transformation services (for example, transportation, storage, grading, processing, wholesaling, retailing, and promotion). Consumers and downstream firms demand a safe and convenient finished product that is uniformly available over time and which is efficiently priced. Many of the final processed commodities are sold in both the domestic and export markets. Those sold in the domestic market are often sold in direct competition with imported food items.

The right-hand column of Figure 1 lists the main exchange mechanisms for agricultural products as they move through the vertical marketing chain. Despite the large number of transactions that typically comprise the marketing chain, the literature focuses on the exchange between the primary producer and the immediate buyer. The first of the three broad categories of exchange mechanisms is price discovery without contracts. In this case, primary producers negotiate the terms of trade with procuring firms and there are no *ex ante* commitments between buyers and sellers. The market may either be decentralized (for example, a grain producer who negotiates with an elevator company, a cattle buyer who visits a ranch, or a fruit producer who sells at a roadside stall) or centralized (for example, a cattle auction or a wholesale market for vegetables).

In some cases, a bargaining association collectively negotiates the price for producers without direct supply control. For example, a self-imposed marketing order enables growers of certain types of vegetables to sell collectively, and in western Canada, certain types of grain are collectively sold through the Canadian Wheat Board (CWB). A bargaining association may also operate with direct supply control (examples of such industries include U.S. tobacco producers and Canadian poultry producers). In the absence of collective bargaining, decentralized prices may be based on a centrally determined reference price by means of a formula that facilitates adjustments for transportation, quality differentials, and other factors. Such "street-price" formulas are common in the cases of grain and eggs. In some cases (for example, milk and dairy products), prices are administered by government and are thus supported and regulated in a variety of ways.

The second major type of exchange mechanism is price discovery with some form of *ex ante* contractual agreement between sellers and buyers. The contract generally serves as a vertical coordinating mechanism because price, alone, is inadequate. Within the contract, the price of the commodity may be fully specified prior to delivery or may be dependent upon conditions at the time of delivery. The simplest type of contract specifies a delivery acceptance guarantee if certain quantity, quality, and delivery time-frame conditions are met. More sophisticated contracts may specify inputs to be used during the production process along with possible managerial assistance or supervision. Sometimes the sole purpose of the contract is to ensure that farm inputs (for example, seeds of chemically resistant plant varieties) remain in control of product developers.

Contracts need not only be of the form whereby producers and processors negotiate directly. For example, rather than a farmer signing a forward-pricing contract with a grain elevator company, he or she instead may use the futures or options market to hedge a commodity. Alternatively, a basis contract may be signed, in which case the procurement price at the time of delivery is guaranteed to equal the prevailing futures price less a prespecified margin.

The last type of exchange mechanism listed in the right-hand column of Figure 1 is vertical integration. With vertical integration, price discovery is no longer central to the marketing transaction because the firms in question either have common management or they operate with a comprehensive long-term contract. Vertical integration, often viewed as an extreme form of vertical coordination, is common with many agricultural commodities such as sugarcane, potatoes, and fresh vegetables. A producer-owned co-operative that operates a processing facility is a common example of vertical integration. Sexton and Lavoie (2001) analyze various forms of vertical coordination and integration in food markets, and they discuss marketing institutions such as marketing orders and marketing boards.

The left-hand column of Figure 1 provides a description of the nature of the exchange within the vertical marketing system. As before, the emphasis is on the exchange between primary commodity producers and immediate buyers rather than on the marketing transactions of downstream firms. There are three key characteristics of the exchange that have been emphasized in the literature: (1) the level of competition among buyers; (2) the level of transaction costs that characterize the exchange; and (3) the extent to which information constrains the exchange. Commodity producers are generally modeled as competitive and risk-averse. Marketing firms (if not vertically integrated with producers) are assumed to behave either competitively or noncompetitively and are normally modeled as risk-neutral. Noncompetitive behavior takes a variety of forms (such as quantity-setting or price-setting oligopoly) and has many different dimensions (such as spatially induced market power and whether or not the firm operates within a single industry or as a multinational).

Exchange relationships between commodity producers and marketing firms can also be described in terms of transaction costs (see the left column of Figure 1). If the commodity has a specific use – it is highly perishable or has no substitutes – and if there is a high cost of writing and enforcing contracts to deal with uncertainty and asymmetric information, then transaction costs are said to be high because the buyer or seller may behave opportunistically. Similarly, transaction costs may be high if a marketing firm has specific input requirements, if input attributes are costly to identify, or if the cost of searching for acceptable inputs is high. Transaction costs affect the efficiency of the exchange and the exchange mechanism itself.

Information constraints take a variety of forms. Nondiversifiable risk and lack of reliable price and quantity forecasts will impact the efficiency of the exchange and the chosen exchange mechanism. The extent to which price alone can reflect the demand characteristics of a downstream firm or final consumer is also important when exchange information is incomplete. Similarly, asymmetric information, in the form of moral haz-

ard, adverse selection, and contract performance verification, constrains many market transactions and often results in an inefficient market outcome or an investment holdup problem.

The bottom right corner of Figure 1 contains a short description of additional constraints and distortions within the marketing chain. Most important, agricultural commodities often have price supports or marketing subsidies that distort the marketing process. Interestingly, when studying agri-food markets, it is easy to get the impression that rent seeking in the form of demanding protection or a subsidy is often more important to firms than the actual marketing process. Figure 1 also reveals that marketing generally has a trade component, and marketing constraints that arise from trade agreements or disputes must be considered. (Trade is covered in a separate section of this *Handbook*.) Finally, there are often numerous production and marketing regulations relating to food safety, quality control, and the environment that constrain the overall marketing process.

1.2. Synthesis outline

There is considerable scope for research in agricultural marketing. The key words and phrases in Figure 1, such as spatial, heterogeneous, risky, intertemporal, imperfectly competitive, transportation cost, and asymmetric information, have formed the theoretical basis of much of the analysis in agricultural marketing. The theories and accompanying empirical models have been developed both inside and outside the agricultural economics literature.

The material in Sections 2 through 4 is primarily a review of select topics from this section of the *Handbook* and from the broader marketing literature. Section 5 contains several short case-studies and a more general discussion that focuses on institutional and political constraints in agricultural marketing. Throughout the various sections, suggestions are offered regarding the direction of future research. Section 6 contains concluding comments.

The approach used here to organize and discuss agricultural marketing research is illustrated in Table 1. The various topics are grouped into one of four broad areas: (1) Forecasting and price analysis; (2) Assessing pricing efficiency; (3) Information, the consumer, and contracting; and (4) International marketing. In the first category (to be discussed in the next section), structural sectoral and time series approaches to forecasting are reviewed. The focus then shifts to structural models that have been used primarily for price analysis. Examples include models of the vertical marketing chain, intertemporal models that involve storage and commodity futures, and imperfectly competitive spatial models. While many of these more specialized models are built specifically for policy analysis, the discussion itself will not include policy considerations.

In Section 3, empirical tests of pricing efficiency are reviewed and discussed. The first topic is marketing margins and the emphasis is on testing for noncompetitive pricing. Methods of testing for intertemporal pricing efficiency are then examined. The last topic deals with spatial pricing efficiency and regional market integration.

Table 1
Organization of agricultural marketing research

I.	Forecasting and price analysis
A.	Forecasting models
(i)	Structural sectoral models
(ii)	Time series models
B.	Structural price analysis models
(i)	Vertical markets with a focus on marketing margins
(ii)	Intertemporal models with a focus on storage and commodity futures
(iii)	Spatial models with a focus on imperfect competition
II.	Assessing pricing efficiency
A.	Marketing margins and noncompetitive pricing
B.	Intertemporal pricing efficiency
C.	Spatial pricing efficiency and market integration
III.	Information, the consumer and contracts
A.	Information
(i)	Auctions
(ii)	Industrial organization
(iii)	Grading and blending
(iv)	Information technology
B.	Changing role of the consumer
C.	Contracting in the pork and poultry sectors
IV.	International marketing: institutions and political constraints
A.	State trading enterprises
B.	Export subsidy programs
C.	The Canadian wheat board debate
D.	The tomato war
E.	Role of multinationals

In Section 4, the discussion departs somewhat from traditional agricultural marketing to consider recent marketing topics that pertain to information, the consumer, and vertical coordination contracts. These three attributes of agricultural markets are important characteristics of the industrialization process that is currently transforming food production and marketing. Although the literature in this area is still comparatively small, it will undoubtedly grow at a rapid rate in the coming years. The role of information as a determinant of market structure and efficiency is one of three major themes. The changing tastes and attitudes of consumers and the impact of this change on the industrialization process are also examined. Section 4 concludes with a discussion of production and marketing contracts for pork and poultry.

In Section 5, the additional complexities associated with international marketing are highlighted. First, the controversial issue of state trading of agricultural commodities is discussed. Following this discussion, export promotion programs such as the U.S. Export Enhancement Program (EEP) are examined. Attention then shifts to the debate

concerning the Canadian Wheat Board (CWB) as a single-desk marketer of wheat and barley. Next, the ongoing dispute between the United States and Mexico regarding trade in tomatoes is briefly summarized. Section 5 concludes with a discussion of multinationals in the context of international agri-food marketing.

2. Price analysis and forecasting

Agricultural economists have a long tradition of building models of competitive markets with the primary objectives of forecasting and policy analyses. The secondary objectives are to better understand markets and to generate hypotheses [Tomek (1994)]. The main focus in this section is on forecasting models and structural models that are built for understanding price determination.

2.1. Forecasting models

There are many methods for forecasting supply, demand, and price. The emphasis in this section is on price forecasts because most users of forecast information are ultimately concerned with price. There are numerous suppliers of forecast information, such as government, university extension agents, and the private sector. Some forecasts are based exclusively on the subjective opinion of industry experts and some forecasts rely on both a quantitative model and a subjective opinion.² Little has been written about subjective forecasting procedures and therefore discussion in this section is restricted to forecasting with a quantitative model. Structural sectoral models and time series models are the two basic methods used to generate forecasts. Allen (1994), Bessler (1994), Freebairn (1994), Tomek (1994), and Armstrong (1994) provide comprehensive reviews and critiques of the literature based on these two types of models.

Most sectoral forecasting models are linear and contain a variety of technical relationships, such as livestock birth rates and oilseed crushing margins. Sectoral models also contain many types of structural equations that relate to production, herd replacement, and demand by various industry sectors such as processing, fresh market, and export. Single-sector models focus on a single market, whereas multi-sector models explicitly link interdependent markets (for example, feed and livestock). Because of highly diverse forecasting objectives and constraints, most models range from two to four equations though some use several dozen equations [for example, Chen and Bessler (1990), use 67 equations in their cotton model]. Large-scale econometric models that attempt to endogenize virtually all variables (for example, macroeconomic, capital accumulation, and prices in nonagricultural sectors) are also used for forecasting purposes; however, they tend to be used for policy analysis rather than for agricultural marketing.

² Kastens et al. (1998) discuss the wide range of forecasting procedures used by individuals who complete the Annual Outlook Survey administered by the American Agricultural Economics Association.

Because of the diverse and uncertain nature of agriculture, there has been a strong demand for high-quality production and price forecasts by farmers, agribusiness, and government. Moreover, forecast requirements tend to be very specific regarding time frame, geographic location, and product, and therefore many different forecasts are generally in demand at a given point in time [Freebairn (1994)]. Despite the apparent demand for quality agricultural forecasts and the high volume of published forecast information, academic involvement in the development and evaluation of sectoral forecasting models has dropped off significantly since the 1970s. Allen (1994) discovered that 43 studies involving sectoral models were published in the 1970s compared to 22 in the 1980s. Publishing in the 1990s appears to be continuing this downward trend.

Methodological advances in the construction and evaluation of sectoral forecasting models have been sparse over the last twenty years. The basic approach is to place the entire linear model in a large matrix and then construct a restriction matrix to account for variables that do not appear in certain equations, whether it be for theoretical reasons, econometric identification purposes, or to enforce linear restrictions on sets of coefficients. The model is then estimated using an econometric procedure, such as restricted three-stage least squares, and forecasts are generated by solving for the market equilibrium with forecasted values of the exogenous variables substituted in.

In contrast, academic interest in the time series approach to forecasting has risen sharply over the last twenty years. Accompanying this interest have been rapid developments of time series procedures (some developments were initiated by agricultural economists but most were adopted from other fields). Univariate and multivariate time series analyses have been used extensively since the early 1980s to forecast agricultural production, prices, and other relevant variables. Univariate analysis is generally associated with autoregressive integrated moving average (ARIMA) models and the Box-Jenkins approach. Among the first studies to apply this framework to economic forecasting in agriculture was Leuthold et al. (1970). The most common form of multivariate analysis is vector autoregression (VAR). Bessler (1984) introduced agricultural economists to VAR techniques.

VAR can be described as a linear approximation to the reduced form of any nonlinear structural model without the typical restrictions to account for theoretical relationships and identification issues [Holden (1995)]. Each variable depends on its own lagged values as well as on the lagged values of all other variables in the system. Only the list of relevant variables and their form (for example, levels versus differences) needs to be specified, because statistical tests are used to determine the optimal lag length. The primary use of a VAR is for forecasting and constructing forecast confidence intervals. Nevertheless, certain forms of structural analyses are of particular use in the context of agricultural marketing. The most popular forms of structural analyses are tests for causality (for example, Granger-Causality), impulse response analyses (that is, multiplier analysis), and determining the forecast error contribution of each variable.

One of the main difficulties with an unrestricted VAR model is that a large number of parameters need to be estimated, and therefore the standard errors of the estimates are often unacceptable. Parameter restrictions, such as incorporating symmetric and non-

symmetric random walk priors or general Bayesian priors, are used to reduce the severity of this problem [see Kaylen (1988), for a review]. Vector autoregressive moving average processes (VARMA) are sometimes used as a representation of an infinite order VAR (with the VARMA process, the error term in the VAR model is assumed to be autocorrelated rather than white noise). If exogenous variables such as weather shocks are truly exogenous to the VAR system, then a more general VAR specification (sometimes referred to as a transfer function model or a generalized distributed lag model) is required. Error correction models (the change in variable depends on the deviation of that variable from its equilibrium relationship with other variables) and cointegration models (linear relationships between sets of nonstationary data are exploited) are routinely used to accommodate non-stationary data. The VAR forecasting model can be generalized in the context of a state-space model (that is, the variable in question depends on the current value of an unknown state variable). Here the coefficients are allowed to systematically or randomly vary and the Kalman filter is often used in the estimation process.

Allen (1994) compares (pairwise) the forecasting accuracy of 129 agricultural series from 49 studies and concludes that composite forecasts, which are constructed by combining the forecasts from two or more models using a variety of weighting schemes, are the most successful. In general, Allen is disappointed with the rate of progress in agricultural forecasting. He contends that the fascination with the subtleties of different econometric methods has produced numerous articles but has not greatly influenced performance. Allen suggests that more attention should be paid to forecast evaluation, and forecasting models should be developed only where they will most likely be useful. Similarly, Kastens et al. (1998) find that increased use of econometric models does not appear to have enhanced forecast accuracy. They also question the comparatively large amount of resources that extension economists devote to forecasting in light of comparable forecasts published by the USDA and forecasts that are provided by commodity futures prices. The general finding is that extension economists are not generating superior forecasts in the case of crops but they may have an edge in the case of livestock.

Tomek (1994) identifies a number of conditions for improved agricultural forecasts: better quality data and forecast evaluation, and more careful analysis, which includes checking for data outliers and rigorously testing for the appropriateness of theoretical restrictions, exogenous variables, and stationarity assumptions. He is not optimistic about increased academic involvement in forecasting models because of the relatively high development costs and uncertain benefits in terms of publishable results. Freebairn (1994) suggests that even small gains are often of considerable economic value and economists should not abandon structural models too quickly. He suggests that there are many advantages of structural models over time series models (for example, the source of the forecast errors can be identified with a structural model). Bessler (1994) emphasizes that confidence intervals or probabilistic forecasts are required for effective decision making, but that this information has typically not been supplied in the past.

Given the above discussion, it is important to continue to question where the agricultural economics profession is headed in terms of price forecasting. Unfortunately,

it appears unlikely that advances in methodology (at least in the short run) will significantly improve the accuracy of forecasting models. Even if impressive advances are made, the associated gains may be offset by the fact that markets are industrializing (e.g., contracts are replacing spot markets) and thus pricing relationships are becoming more complicated and data on these relationships are becoming increasingly scarce. It would appear that private sector firms with an in-depth knowledge of a particular industry will increasingly take over the role of developing forecast information. Such information will likely be generated by combining various (simplified) aspects of time series, structural, and subjective forecasting methods while paying particularly close attention to institutional detail. Because forecasting results will shift toward being proprietary rather than public, the market value of such results is likely to rise significantly over time.

2.2. *Other types of structural models*

Structural models designed for forecasting generally lack detail regarding form, time, and space, so specialized models are often built for specific problems. These specialized models are generally not used for price forecasting but instead are used to examine price formation, market failure or policy issues. In the discussion to follow, the various specialized models are organized according to form, time, and space.

2.2.1. *Form*

The basic problem is as follows. Agricultural producers supply a certain commodity to a series of marketing firms, and eventually a finished product is sold to consumers or down-stream firms. Each marketing firm adds value and therefore increases the wedge between the retail price and the price paid to the agricultural producer. If all market participants behave in a perfectly competitive fashion, can a model be developed that provides a descriptive characterization of the price paid to the grower? If so, then it should be possible to examine the factors that affect the size of the marketing margin and that cause the farm price to vary from season to season. As well, if a sufficiently rich data set is available, then it should be possible to construct an empirical model (with theoretical restrictions in place) to obtain elasticities and other estimates of the structural relationships from the set of estimated equations.

The basic modeling approach and various extensions are discussed by Wohlgenant (2001). (A useful pedagogical version is contained in Chapter 5 of [Helmberger and Chavas (1996)]). In Wohlgenant's model, a raw agricultural commodity is used along with a set of exogenously priced productive factors to produce a homogeneous product that is sold in a competitive market. Comparative static analysis is used to identify theoretical relationships between exogenous industry variables and the size of the marketing margin. If the system is totally differentiated and the variables are converted to logs, a robust specification of an econometric model results. Important parameter estimates that can be obtained are the elasticity of price transmission (that is, the relationship between

the farm price and the retail price) and the elasticity of the derived demand schedule for the raw commodity. The model is greatly simplified by assuming that inputs are used in fixed proportions and the underlying technology exhibits constant returns to scale. A series of theoretical restrictions are imposed prior to econometric estimation of the system.

The impact of risk on marketing margins has also received considerable attention. Brorsen et al. (1985) show that an increase in output price risk increases the expected marketing margin for firms in a competitive industry. Holt (1993) estimates the risk premium in beef marketing margins and simulates short-term equilibrium risk effects. He concludes that at various points in time, risk has had a significant impact on beef production as well as on farm and retail prices for beef. Feuz et al. (1995) also estimate risk premia for U.S. slaughter cattle, but the source of these price discounts stems from buyer uncertainty regarding cattle quality. Fausti and Feuz (1995) explain specific price differentials for slaughter cattle marketing alternatives (for example, live weight versus dressed weight). They show how these differentials can be the result of uncertainty over cattle quality by risk-averse buyers. Finally, Kraft et al. (1996) show that the size of the margins in marketing grains and oilseeds are risk-dependent.

The various marketing margin models have been highly useful in terms of facilitating a rigorous theoretical and empirical examination of a relatively complete vertical marketing system. However, what if markets are noncompetitive? And what if vertical coordination mechanisms (or vertical integration) eliminate the need for competitive price determination? How is the theory specified along with an appropriate model for estimation purposes? Also, there are often numerous layers in the vertical marketing system, and the producers' cost often only represents a small fraction of the total value of the finished product. In such a case, a standard model that lumps all marketing firms together is often not capable of fully characterizing the equilibrium marketing margin. Developing multilayered models is not necessarily a useful way to proceed, however, because such models may be too complex to properly analyze and the appropriate data may not be available.

In general, the marketing margin model discussed above misses important market characteristics relating to time, form, and space and does not account for how rent seeking by processors influences outcomes [Schmitz et al. (1999a)]. For certain markets, these characteristics are crucial and therefore attempts should be made to incorporate them into the basic model. High fixed costs in transportation, warehousing, and processing imply that marketing firms often operate with increasing returns to scale and will operate at a loss if the marketing margin is set equal to the marginal cost of supplying the marketing service. Some attempt should be made to deal with the issue of how fixed costs are allocated within a competitive vertical marketing chain. Perhaps a general equilibrium analysis may be necessary to fully understand the factors that impact the marketing margin in the long run. A computable general equilibrium model of agricultural marketing was developed by Peterson et al. (1994), but it is not possible to derive general conclusions from their results.

Many firms deal with multiple commodities, joint products, and explicitly segmented markets. Issues such as hedonic and component pricing are therefore important. Using retail-level hedonics to value milk components has been a particularly important area of research [St. Pierre and Scobie (1987); Lenz et al. (1994); Coggins and Hammond (1994)]. Other areas of application include apples [Manalo (1990); Tronstad et al. (1992)], peaches [Parker and Zilberman (1993)], beef [Lin and Mori (1991); Wahl et al. (1995)], and grapes [Folwell et al. (1990); Golan and Shalit (1993)]. Much of the research relating to hedonic and component pricing is econometric-based and therefore is more closely related to demand system analysis than to agricultural marketing.

2.2.2. *Time*

Intertemporal price analysis models generally incorporate features such as price uncertainty, formation of price expectations, storage, and commodity futures. The standard problem is as follows. Competitive farmers who are averse to risk produce a commodity on a seasonal basis and this commodity must be stored and sold gradually over a marketing period. Continuous shocks in supply and demand generate a continuously changing selling price. Futures contracts facilitate hedging, arbitrage, and speculation [Feder et al. (1980)]. In recent models, the standard assumption is that all economic agents have rational expectations and therefore the equilibrium is dynamically consistent.

Helmberger and Chavas (1996) analyze price and price movements in a basic intertemporal storage model. In addition to presenting a series of useful comparative static results, they use stochastic dynamic programming to solve an empirical model with parameter estimates from a quarterly model of U.S. soybeans. Wright (2001) constructs a more general dynamic model of production, consumption, and storage. Storage is shown to have an important price-smoothing feature and therefore factors that affect an agent's incentive to store will normally have direct price consequences. Tronstad and Taylor (1991) also consider optimal storage, sales, and hedging strategies within a stochastic dynamic framework. They show the importance of tax considerations in such an analysis. Netz (1995) argues that with an efficient futures market, storage is more elastic with respect to cost and therefore will absorb a larger proportion of supply and demand shocks. Benirschka and Binkley (1995) have an interesting model in which the time in storage and the rate of expected price appreciation is proportional to distance to market. Fackler and Goodwin (2001) and Wright (2001) both discuss how storage can change the nature of intertemporal spatial price relationships.

The results of the storage models discussed above provide useful insight when attempting to understand market dynamics for commodities such as grains, oilseeds, cotton, and wool. There are several important limitations, however, and there remains scope for considerable research in this area. For example, the incentive to store is normally analyzed at the primary commodity level. Certainly storage is an important feature for firms throughout the vertical marketing chain and different types of firms will have different incentives to store. Developing a better understanding of the incentive to store within the whole marketing chain should significantly enhance the accuracy of intertemporal price analysis. A second limitation is that storage models are typically based on the

assumption of spot market transactions and perfect competition (the case of monopoly is briefly discussed in Wright's chapter). In reality, marketing and processing firms often behave noncompetitively, are often vertically integrated, and are increasingly reliant on contracts when buying and selling commodities. Consequently, storage will be a strategic choice variable for firms and modeling such a problem would be much more complex than is currently the case.

Closely related to storage is the topic of price stabilization. Price stabilization is generally viewed as policy analysis rather than marketing. Nevertheless, many of the basic concepts underlying price stabilization literature are directly applicable to commodity marketing. In particular, modeling the source of price uncertainty within a market and the associated welfare effects in the absence of stabilization programs are key features of the stabilization literature. Wright shows how key market parameters such as demand and supply elasticities, the curvature of the demand schedule, and production lags impact price uncertainty. Earlier literature was particularly interested in the welfare effects associated with the stabilization of both storable commodities [Feder et al. (1977); van Kooten and Schmitz (1985)] and nonstorable commodities [van Kooten et al. (1988)].

There are numerous papers that focus on the futures market component rather than on the storage component of the intertemporal marketing model. Carter (1999) provides an extensive review of the literature on commodity futures. The four main areas covered are: (1) hedging; (2) price information and efficiency; (3) evolution of futures trading; and (4) price behavior. Category (1) is covered in the production-under-uncertainty section of the *Handbook* and category (2) is covered in the next section of this chapter. Category (3) is not of central interest in this chapter other than to note that the market for financial futures and nonagricultural futures has grown immensely over the last two decades, and agricultural commodities now comprise less than 10 percent of the worldwide futures and options trading volume. Not surprisingly then, the recent literature on commodity futures (which is still a sizeable component of the agricultural economics literature) is small in comparison to the recent literature on non-commodity futures. The remainder of this section is devoted to category (4), which is the price determination aspect of commodity futures. The standard theory of pricing in futures and options market is well explained in the many textbooks on commodity futures [for example, Blank et al. (1991)].

Carter suggests that the two most important theories of intertemporal price behavior are the theory of normal backwardation [Keynes (1923, 1930); Hicks (1946); Dusak (1973)] and the price of storage theory [Kaldor (1939–40); Working (1948, 1949)]. With normal backwardation, the futures price is postulated to be a downward-biased estimate of the forthcoming cash price because speculators demand an implicit risk premium from hedgers. The price of storage theory rejects the notion that futures markets are primarily used to transfer risk from hedgers to speculators. Rather, it is assumed that intertemporal price relationships are determined by the marginal cost of storing the commodity over time. An important component of marginal storage cost is convenience yield. Convenience yield is a negative storage cost that stems from the implicit value

of having stocks on hand. Convenience yield is highest when stocks are low, and approaches zero for high stock levels.

The theory of normal backwardation has always been controversial. Originally the risk premium was modeled as a variable strictly within the futures market. Dusak (1973) suggested that a risk premium for futures contracts should be determined within the context of an economy-wide capital asset pricing model. Carter (1999) provides a review of the numerous studies that use different methodologies, or different price data, to test for the existence of a risk premium in commodity futures. In recent years, highly sophisticated testing procedures have been employed. Examples include arbitrage pricing models, multi-beta asset pricing models, nonparametric tests, and conditional latent variable models. In general, evidence in support of a risk premium is mixed and in those cases in which the results are positive, the magnitude of the risk premium is usually small.

Carter (1999) points out that the storage theory of futures price allows for a risk premium component and is therefore a relatively general theory. However, the convenience yield aspect of the theory has turned out to be controversial. For example, Wright and Williams (1989) argue that measured convenience yield may be illusionary and may be due instead to the spatial aggregation of stocks. Brennan et al. (1997) support this notion in the context of grain handling in western Australia. They show that, when prices are measured at the local level, there is generally a monetary reward associated with storage. Convenience yield is therefore not necessarily a valid concept. Nevertheless, studies of convenience yield with aggregate data generally find that marginal convenience yield varies seasonally, as is predicted by theory [for example, Fama and French (1987)].

Carter (1999) suggests that the theory of commodity futures pricing has not advanced significantly since Gray and Rutledge (1971) wrote their important survey article on commodity futures. Moreover, much of the recent literature on commodity futures fails to address the fundamental issues. One important exception is the Leuthold and Tomek (1980) paper on commodity futures markets for non-storable commodities. In recent years, the number of papers that examine structural pricing issues in commodity futures has been comparatively small. Out of many dozens of articles recently published in the *Journal of Futures Markets*, only a few deal explicitly with price determination issues for agricultural commodities. For example, Malliaris and Urrutia (1998) analyze the relationship between trading volume and futures price variability and they test several hypotheses using a broad base of commodity futures data. Perrakis and Khoury (1998) analyze the impact of asymmetric information. Kimle and Hayenga (1994) discuss how cash settlements are gradually replacing the delivery of the physical commodity in the futures market for hogs because of the sharp decline in hog deliveries at terminal markets. Unterschultz et al. (1998) examine window contracts (an over-the-counter derivative that provides marketing firms with a price ceiling and a price floor) in North American markets for hogs.

An obvious limitation of much of the commodity futures pricing literature is that marketing firms are implicitly assumed to behave competitively. While the competitive market assumption may be valid in many situations, especially for agricultural markets,

futures markets often exist for commodities in noncompetitive industries (for example, coffee). Moreover, given the relatively rapid pace of mergers and consolidation in many markets, the assumption of perfect competition is becoming increasingly unrealistic. There is limited literature that examines forward markets as a determinant of the cash market equilibrium when firms are oligopolistic rather than competitive [for example, Allaz (1992); Allaz and Vila (1993); Thille (1996)]. The basic result of this literature is that an oligopolistic firm can use the forward market to strategically influence its rival's behavior in the spot market. However, in equilibrium, industry output is higher than it is in the absence of a forward market, which implies that the forward market generates a pro-competitive effect. Vanzetti and Kennedy (1990) construct a deterministic dynamic game of strategic trade policy with competitive storage.

To what extent do futures market improve price formation and market efficiency? The debate concerning futures market performance began in earnest after the work of Gray (discussed in [Gray (1977)]). In 1958, the U.S. Congress abolished trading in onion futures after seemingly poor performance of this contract, and Gray was strongly opposed to this cancellation. In addition to Gray's critique, the early literature on this issue [much of which is contained in a special volume edited by Peck (1977)] largely contends that futures markets have the capability of significantly enhancing market performance. As Carter (1999) points out, this early literature is particularly credible because it is based on careful theoretical and institutional analysis and extensive empirical verification. After an extensive review of the literature, Kamara (1982) also strongly supports the view that the social value of futures markets is high because such markets improve pricing efficiency and resource allocation. The extent that futures markets will remain valuable given the rapid pace of industrialization of many agri-food markets is an issue that is definitely worth exploring.

2.2.3. *Space*

Models of perfectly competitive firms/countries that operate in a spatial environment are often built to test for market efficiency and integration or to assess regional or national product flows. These models are reviewed in the next section of this chapter. Competitive spatial optimization models that are designed to predict commodity flows from surplus to deficit regions [pioneered by Takayama and Judge (1964)] generally fit into the agricultural trade literature and therefore are not reviewed here.³ In this section, spatial models are analyzed from an industrial organization perspective. Specifically, firms that operate in a spatial environment recognize that they have market power, and therefore pricing decisions are noncompetitive.

It is well known that if firms have different geographic locations or have different locations in product space, noncompetitive pricing can result. Classic references include Hotelling (1929), Chamberlain (1933), Salop (1979), and Greenhut et al. (1987).

³ It is worth noting that Batterham and MacAulay (1994) extend the basic spatial optimization model by linking it to a farm-level linear programming model.

Brander (1981) and Brander and Krugman (1983) note that with spatial market power, intraindustry trade might occur even if the product is perfectly homogeneous. Agricultural markets provide a rich set of examples of spatially separated firms that procure a homogeneous commodity (for example, railways, grain merchants, sugar processors) or firms that produce a differentiated product at a given location (for example, food manufacturers and agricultural chemical companies). In many cases, marketing margins, market efficiency, and the distribution of net returns within a particular region will be significantly impacted by the extent that geographic space or product space results in market power for participating firms.

Greenhut et al. (1987) provide a comprehensive analysis and review of various non-competitive spatial models. Their analysis is divided into two distinct sections: models of plant gate freight-on-board (f.o.b.) pricing and models of discriminatory farm gate pricing (also referred to as uniform pricing). With f.o.b. pricing, competing firms set a single price at their plants and farmers fully absorb the associated transportation costs. In this case, farmers are assumed to deliver to the firm that offers the highest net delivered price. As in nonspatial models of imperfect competition, the procuring firm is assumed to form conjectures regarding how its market radius will change if price is marginally increased. The three basic conjectures are Loschian (cartel), Hotelling-Smithies (Nash), and Greenhut-Ohta (competition). With discriminatory pricing, firms set different prices for different farmers (equivalently, farmers face a common f.o.b. price but different farmers receive a different level of transportation subsidy from the firm). The economics literature contains extensive discussion regarding the relative social efficiency and distributional consequences of the two types of pricing schemes.

Sexton and Lavoie (2001) discuss the literature on noncompetitive pricing by agribusiness firms that sell differentiated products at a particular geographic location. The remainder of this section is devoted to discussing the literature on spatially separated firms in agricultural markets. Durham et al. (1996) conclude that in California's tomato processing industry, discriminatory pricing encourages market overlap and excessive transportation costs when compared to the f.o.b. counterfactual. Kawaguchi et al. (1997) generalize the Takayama and Judge (1964) spatial equilibrium model to allow for an endogenous level of market power. They estimate their model using data from the Japanese dairy industry and find that actual prices are reasonably consistent with the Cournot-Nash equilibrium solution. Bailey et al. (1995) use mapping data to show that procurement areas for U.S. feeder cattle are sizeable, irregularly shaped, and have substantial overlap. Moreover, producers generally receive higher prices when markets overlap. T. Schmitz (1995) developed a spatial oligopoly model to explain pricing patterns in the Canadian broiler market. Also, Schmitz et al. (1997) develop an international trade model in barley that captures the price premiums earned by state-trading enterprises that compete with multinationals. Price discrimination in international markets has also been demonstrated by Brooks and T. Schmitz (1999).

Another area of research that involves spatially induced noncompetitive pricing is rail transportation for grain. For example, Vercammen (1999) constructed a detailed model in which Canada's two major railways, the Canadian National Railway and the Cana-

dian Pacific Railway, compete for grain in a deregulated environment by choosing the freight rate at several hundred individual delivery points. Iterative numerical techniques are used to approximate the Nash equilibrium. Depending on the assumption about trucking costs, equilibrium freight rates range from a low to a moderately high marginal cost markup. Fulton et al. (1998) also model the western Canadian grain transportation system, but they do so at a more aggregate level, and they include additional features such as a downward-sloping demand schedule for grain at export position and positive supply response. Their simulation results also indicate a sizeable increase in western Canadian rail freight rates if deregulation allows railways to freely choose rates.

3. Evaluation of pricing efficiency

In the previous section, a wide array of forecasting and price determination models were reviewed. In this section, the focus is on empirical models that are designed to test for pricing efficiency. As in the previous section, the discussion is broken down according to form, time, and space.

3.1. Form

Testing for pricing efficiency with respect to marketing margins typically involves testing for market power among marketing firms that are purchasing commodities at the farm level. Sexton and Lavoie (2001) and Wohlgenant (2001) provide a comprehensive review of the literature in this important area. The discussion to follow is primarily based on Sexton and Lavoie's chapter. Static models of noncompetitive pricing are considered first and attention is then turned to the more complex dynamic models.

The static models are generally based on one of two alternative specifications. With the first approach, a conjectural variation assumption is used to parameterize the level of noncompetitive pricing. The parameter of interest is a variable that ranges from 0 (perfect competition) to 1 (cartel). Specification of a functional form allows an estimate of this variable to be obtained. The model is made appropriate for the long run by specifying a fixed cost and a zero profit condition, which thereby allows the number of firms within the industry to be endogenous. With the second approach, fixed proportion inputs are assumed, such that aggregation becomes exact. The output market behavior parameter takes the form of a weight that expresses the importance of the demand function relative to the marginal revenue function. A similar weight measures the importance of the raw product supply function relative to the industry marginal cost function. These weights are estimated together with the various schedules that comprise the model and are used to infer the degree of noncompetitive pricing. Sexton and Lavoie provide a good summary of the test results in key agricultural and food industries. They also provide a good critique of the overall approach, and they discuss implications for public policy and antitrust.

Sexton and Lavoie suggest that antitrust enforcement within agricultural markets is considerably less now than it was 30 years ago. Has the empirical work reviewed by

these authors had an impact on antitrust decisions? Consider the following merger scenarios. On July 8, 1999, the U.S. Department of Justice announced that Cargill, Inc., could proceed with its controversial purchase of Continental Grain Co.'s Commodity Marketing Group, as long as certain grain facilities in various states were divested. For example, Cargill was required to enter into a through-put agreement to make one-third of the loading capacity in its Havana, Illinois, river elevator available to an independent grain company [Muirhead (1999)]. A similar example is the Sunkist Case [Mueller et al. (1987)] in which Sunkist was required to divest some of its packing facilities to comply with antitrust legislation. Lastly, according to Smith (1999), Smithfield is to buy Tyson's hog production business. Smithfield, already the largest hog and pork processor in the world, will control 13 percent of the industry's production. Were the antitrust decisions associated with these three mergers dependent on the results of any of the studies reviewed in this *Handbook*? Despite its importance, this question is virtually impossible to answer, given the confidentiality of the agreements reached between the Justice Department and the merging firms.

The dynamic models of noncompetitive pricing (reviewed by Sexton and Lavoie) are primarily analyzed through the lens of game theory. The most basic class of models is one in which oligopolistic firms may refrain from the temptation to defect from a cartel relationship because the subsequent cost of their punishment for defection outweighs the short-run gain. The problem facing the cartel is that of determining whether excessive production is due to member defection or simply a demand shock. Sexton and Lavoie discuss several interesting empirical applications (for agriculture) of this "trigger" pricing model as well as related models with more complex intertemporal relationships. Another class of game theoretic pricing models discussed by Sexton and Lavoie involves endogenous entry and exit over time. With these additional considerations, sunk costs play a key role, and variables such as advertising and new product development are likely to be used as strategic barriers to entry.

A reasonable criticism of the literature on noncompetitive pricing is that theoretical and empirical methodology is often emphasized at the expense of not including detail about important industry characteristics and not working with high quality data. Also, it is important to ask whether recent studies in this area are any more revealing about noncompetitive pricing than are early works such as Hall et al. (1979) and Just and Chern (1980). For example, consider the U.S. meat packing industry, which has been the subject of several investigations concerning non-competitive pricing. One major undertaking is the set of studies commissioned by the Grain Inspection, Packers and Stockyards Administration (GIPSA) of the U.S. Department of Agriculture (USDA) [including Azzam and Anderson (1996); Ward et al. (1996); Texas Agricultural Market Research Center (1996); Hayenga et al. (1996); and Kambhampaty et al. (1996)]. In addition, GIPSA released its own report [USDA (1996a)]. The USDA's "Concentration in Agriculture: A Report of the USDA Advisory Committee on Agricultural Concentration" [USDA (1996b)] reviewed the meat packing studies listed above.

There is little consensus among committee members as to whether or not the beef packing industry is competitive. Other findings on the effects of packer concentration

have also not resolved the debate. For example, the study by Schmitz (1990) on captive supplies in the beef industry reached somewhat different conclusions than did Ward et al. (1996). According to the USDA Advisory Committee [USDA (1996b)], "it was impossible to reach consensus on what we consider some of the most important issues before the committee" (p. 29). For example, on the issue of captive supplies, the committee notes in USDA [1996b, p. 30]:

Those, like GIPSA, who dismiss captive supply's negative price effects simply recite that if 20 percent of the demand for fed cattle is removed, so is 20 percent of the supply, and the net effect on the market is zero. While the argument is logically appealing at first glance, it does not hold water. First, as recognized by GIPSA, captive supply cuts the tops off the market, by assuring that the packers never get truly desperate for cattle, or 'close to the knife' in industry terms. The packers have the flexibility to use the cattle they control when they want them without ever getting into the bidding wars that are the occasional salvation of feeders.

The general conclusion one reaches is that the debate concerning the competitive nature of the beef packing industry is far from over. This also appears to be the case for highly concentrated industries such as the pork processing sector.

3.2. Time

Agricultural economists have long been preoccupied with intertemporal pricing efficiency. The Efficient Market Hypothesis (EMH) states that an asset price reflects all known information so that agents are unable to use public information to engage in profitable trades [Fama (1970)]. Fama classifies efficiency tests as either weak, semi-strong or strong. An efficiency test typically consists of measuring the adjustment of the futures price to a particular information set: (1) historical prices for the weak form; (2) historical prices plus all relevant public information for the semi-strong; and (3) "inside" information for the strong form. In his review of commodity futures markets, Carter (1999) provides an extensive review of the literature on intertemporal pricing efficiency. A brief summary of this review follows.

Early tests for intertemporal efficiency were based on the assumption that prices and/or returns in an efficient market follow a martingale stochastic process. It was later established, however, that the periodic failure of the martingale property does not necessarily imply an inefficient market. Mechanical filters used to determine whether systematic profits can be earned in a particular market have formed the basis for many Fama weak-form tests over the years. Several studies conclude that these tests cannot substitute for statistical analysis. A somewhat separate strand of literature assessed intertemporal efficiency by testing the forecasting ability of the futures market. For example, many studies test for efficiency by determining whether an econometric-based forecasting model can outperform the futures market. Recently, there has been consider-

able controversy regarding appropriate testing methodology when assessing a model's forecasting performance.

Kellard et al. (1999) also discuss pricing efficiency within a commodity futures market. They suggest that empirical evidence on intertemporal efficiency in commodity futures markets is mixed and tends to be highly specific to the chosen commodity, the time period analyzed, and the testing methodology employed. They also suggest that a major limitation of the efficiency literature is that there is generally no attempt made to quantify the degree of price inefficiency. Their paper goes on to propose a measure of relative efficiency and to present a test for inefficiency across a range of commodities using a co-integration methodology. Their basic finding is that spot and futures prices are co-integrated (with a slope coefficient close to unity) in the long run but often they are not co-integrated in the short run. Specifically, in the short run, past information is still useful in predicting spot price movements and therefore the market is inefficient.

In addition to the topics covered by Carter (1999), recent papers have dealt with an assortment of issues related to intertemporal pricing efficiency. For example, Malliaris and Urrutia (1996) test whether futures prices for six agricultural commodities are independent. Interdependence is postulated because of substitutability and complementarity across pairs of commodities. Barrett and Kolb (1995) and Dutt et al. (1997) focus on the spreads within the set of commodity futures prices. In the first case, the relative profitability of trading on price spreads is examined by determining if price spread behavior varies across the calendar months of the year and if the time to contract maturity affects the size of the spread. In the second case, the authors question the relative effectiveness of different regulations that govern spread positions. Fortenbery and Zapata (1997) present an interesting case study of pricing efficiency in the recently established U.S. futures market for cheddar cheese. Finally, Hilliard and Reis (1999) question the assumption that commodity futures prices are log-normally distributed. They suggest that a jump-diffusion process may be more appropriate, given that prices tend to "jump" when new information arrives.

A somewhat different literature is concerned about the linearity assumption that underlies most models of pricing efficiency. Kohzadi and Boyd (1995) find evidence of chaos and nonlinear dynamics in cattle prices and therefore conclude that conventional linear forecasting models are not efficient. Burton (1993) constructs three comparatively simple commodity models that give rise to chaotic price behavior. Chavas and Holt (1991, 1993) find evidence of nonlinear dynamics and chaos in both the dairy and pork markets. Yang and Brorsen (1992) show that cash price changes are not normally distributed nor are they independent. Accounting for these features can significantly improve forecasting accuracy.

Event studies are a special class of models that test for pricing efficiency. Carter (1999) cites a number of studies that demonstrate that futures prices react quickly to the release of USDA livestock and crop reports. The central idea of pricing efficiency is that, when the report is released, the price reaction should only be in response to unanticipated information. Recent studies conclude that the informational value of the reports has declined since the mid-1980s and crop reports are not necessarily worth the tax-

payer's cost. Carter and Galopin (1993) argue that if a report is valuable, then a futures trader should be willing to pay for advanced access to that report. Despite the significant price reaction when the reports are released, Carter and Galopin find that accessing reports in advance would not result in significant profits. Nevertheless, Clayton and Claffey (1993) argue that the USDA market information is an important determinant of market efficiency for agricultural commodities. In contrast, Sheldon (1996) questions the future value of publicly supplied market information, given that spot markets are being replaced by contractual arrangements.

3.3. *Space*

Fackler and Goodwin (2001) provide descriptions of various hypotheses about how prices respond to an exogenous shock in spatially distinct markets. They also discuss how to empirically test these hypotheses and how to measure specific relationships. At the one level, they are interested in market efficiency, as determined by the extent that the law-of-one-price holds in the short and long run. Equivalently, they are checking for the nonexistence of arbitrage opportunities. The law-of-one-price states that spatial arbitrage should prevent the difference in price (for an identical commodity at two different locations) from exceeding the unit transportation cost. At a second level, Fackler and Goodwin measure the extent of market integration (that is, the extent to which prices in one market are influenced by a price change in a spatially distinct market), as reflected by the expectation of the price transmission ratio. These concepts, when they are applied to international trade, are of particular importance.

Fackler and Goodwin indicate that empirical analyses can be grouped according to whether the dynamic structure of the underlying model is specified exogenously or is fully endogenized. The latter type of model generates more general results and clearly demonstrates that seemingly simple assumptions such as shipping delays will result in failed tests of traditionally defined market efficiency and integration. Early empirical studies rely on correlation coefficients or simple regression results to test the hypotheses of spatial market efficiency and integration. Dynamic regression models and switching regime models have been used to correct for the many underlying weaknesses of earlier methodologies.

Examples of such tests include Granger causality, impulse response analysis, vector autoregression models, and cointegration analysis. Other areas of research reviewed by Fackler and Goodwin include analyses of the determinants of market integration and empirical rational expectations models. Brorsen et al. (1991) use time series methods to test the relationship between market structure and spatial price dynamics in the milled rice industry. They found that price adjustments were slower for more concentrated regional submarkets. Walburger and Foster (1997) decompose live cattle prices into a trend common to all regional cattle prices and regional deviations around that trend. Regional deviations are then related to a series of factors that include measures of noncompetitive pricing.

4. Information, the consumer and contracts

As indicated in the Introduction to this chapter, information, the consumer, and contracts are all important elements of the industrialization process in agri-food markets. Although these markets have been in an industrialization mode for many years, the speed of industrialization has increased substantially in recent years [Drabenstott (1994)].⁴ Boehlje (1996) describes agricultural industrialization as the “application of modern industrial manufacturing, production, procurement, distribution and coordination concepts to the food and industrial product chains” (p. 30). He suggests that agriculture is changing from a commodity industry to one with highly differentiated products. Systemization and routinization of the production system, specialization, and scheduling and utilization are all important characteristics of effective agricultural industrialization. Barkema and Drabenstott (1995) indicate that agricultural industrialization stems from two fundamental changes in the food system: (1) Food markets are being splintered into smaller niches because consumers are demanding food with increasing levels of variety, convenience and nutrition; and (2) Farm technology is enabling the food system to deliver a set of narrowly defined food products more precisely. As a consequence of these changes, Urban (1991) notes that “identity-preserving” grains with specialized end uses are being produced more frequently and are moving within a highly industrialized marketing and distribution chain.

Industrialization has an international dimension as well. Traill (1997) discusses globalization in food industries. He suggests that consumer markets are developing cross-border segments, that trade in processed food items is growing strongly despite limitations such as the handling of bulky and perishable foods, and that foreign production by multinational food enterprises is increasing. Goldberg (1993) indicates that in the United States, 25 percent of agricultural input suppliers, 1 percent of farmland, 10 percent of food manufactures, and 15 percent of food retail operations are owned and managed by non-U.S. entities. Sporleder (1995) analyzes strategic agreements between firms in the form of vertical strategic alliances. He suggests that these alliances are fundamentally different from other types of vertical corporate arrangements. Van Duren et al. (1995) discuss case studies of four successful vertical alliances and suggest that a successful alliance depends on trust, a dedication to the partner, and a mutual commitment to remain independent.

The discussion in this section begins by examining the role of information in agricultural marketing and market industrialization. The role of the consumer in the shift toward industrialized agriculture is then considered. Section 4 concludes with a review of vertical coordination contracting, with particular reference to the pork and poultry sectors.

⁴ See [Kohls and Uhl (1998)] for a specific description of the industrialization process in several U.S. industries.

4.1. Information

In the context of agricultural marketing, information has many dimensions. For example, Section 2.1 was devoted to analyzing the quality of price forecasts and market outlook reports. The material on futures markets in Section 2.2 and on intertemporal pricing efficiency in Section 3.2 is also, to a large extent, about the relationship between market information and commodity prices. This current section is devoted to other aspects of information within the marketing channel.

4.1.1. Auctions

Historically, auctions have been an important marketing mechanism for livestock and are generally considered to be an effective mechanism for compiling information about buyer demand. Various forms of vertical coordination and other aspects of market industrialization are gradually (or, in some cases, rapidly) eliminating the need for auctions. Even when spot markets remain, the usefulness of auctions is declining because price alone often does not adequately reflect information about specific consumer preferences and the set of complex technical and regulatory constraints that face the various marketing firms. Increasing buyer concentration is another possible reason for why the popularity of auctions is on the decline. In an attempt to address the problem of incomplete information and buyer concentration, many auctions now connect buyers from different geographical regions electronically (tele-auctions) or they allow buyers to bid on cattle that are still in the feedlot (video auctions).

Bailey et al. (1993) conclude that prices at cattle feeder auctions have fallen significantly over time due to increasing buyer concentration. Bailey and Peterson (1991) and Bailey et al. (1991) found that net cattle prices were statistically higher at video auctions than conventional auctions after adjustments were made for structural differences. However, the relationship between various structural characteristics and the price of cattle was apparently similar across the two types of auctions. Turner et al. (1991) obtained similar results when comparing tele-auctions to conventional cattle auctions.

Auctions remain an important marketing institution for a wide assortment of agricultural commodities, so despite the decline in their use, more research in this area appears warranted. One useful way to proceed is to examine the more general literature on auctions as a means of identifying relevant issues and methods of analysis. Examples of this literature include Brannman (1996), Baldwin et al. (1997), and Rusco and Walls (1999) who examine issues concerning collusion at timber auctions. Lyon (1986) and Hausker (1992) discuss and model auctions for the case of tradable emissions permits.

4.1.2. Industrial organization

A rapidly emerging area of research in agricultural marketing involves identifying the role of transaction costs as a determinant of market arrangements. Informational constraints are key components of transaction costs, as explained by Sexton and Lavoie

(2001). Asymmetric information and uncertainty result in incomplete contracts and this incompleteness, combined with asset specificity, gives rise to the potential for opportunistic behavior by one or more of the contracting parties. Theory predicts that vertical integration and various other forms of vertical coordination will emerge within the marketing chain if the transaction costs are sufficiently high.

Asymmetric information can also result in moral hazard within the marketing chain. Sexton and Lavoie (2001) and Sheldon (1996) discuss how moral hazard gives rise to a principal-agent type of problem when processors are contracting with growers. The basic model involves a risk-neutral processor who designs a production contract for a risk-averse grower when the production process is risky and not fully observable. The contract must be such that the grower does not bear an excessive level of risk, yet, at the same time, the contract must provide adequate incentives for the grower to devote a sufficient level of resources (for example, effort) to the production process. The second-best contract often involves a fixed payment plus a payment that depends on quantity, quality, or both. The fixed payment has good risk properties but poor incentive properties, whereas the conditional payment has good incentive properties but poor risk properties.

Incomplete information also gives rise to the need to monitor and/or test food products within the marketing chain. Hennessy (1996) develops a model in which food products must be tested by processors to ensure that quality standards are adhered to (for example, bacteria counts in milk must be kept sufficiently low). But the testing procedure is subject to error, and because of these errors, the average price received by farmers who invest in quality-enhancing technologies is somewhat lower than what would be the case with complete information. The lower expected price reduces the incentives for these farmers to invest in quality-enhancing technologies. Hennessy concludes that such underinvestment is inefficient within the marketing chain and therefore marketing firms may choose to vertically integrate.

4.1.3. Grading and blending

Another important informational aspect of marketing is grading and blending. Hennessy (1995) suggests that if consumers can easily identify quality, then grading is only beneficial in that it is more efficient to grade at an aggregate level than at the individual consumer level. The real benefit of grading is realized when consumers are not good at identifying quality, in which case "bad" drives out "good" (that is, adverse selection prevails) and the reward for quality enhancement disappears. Hennessy (1995) constructs a "self-protection" model of grading in which resources throughout the marketing system are channeled in a way that protects the value of the commodity. He shows that quality enters the marketing chain multiplicatively and therefore coordination failures can occur. As well, resource allocations within the marketing channel may be complementary and therefore information constraints may reduce industry expansion. Grading has important consequences within the marketing chain because it provides firms with the incentive to blend/clean heterogeneous products in order to increase the products'

total value. The literature on blending/cleaning is not reviewed here because it is closely related to production economics rather than the field of agricultural marketing.

Hollander et al. (1999) construct an adverse selection model in which market structure determines the amount of grading in a particular industry. The standard thinking is that producers of high quality products will normally favor a grading system if consumers cannot easily identify product attributes. Hollander et al. explain that in some cases, high quality producers may be reluctant to participate in a grading or certification scheme because of the adverse effects caused by low quality producers who also utilize the scheme. This result is particularly pronounced if high quality firms account for a comparatively small share of industry output and if the majority of the product is high quality. Another interesting result is that imperfect competition generally results in an excessive level of grading.

Jones (1999) describes how the increasing rate of market coordination is the result of economic rents that are created by inefficient grades and standards. In particular, federal grades and standards in the grain and oilseed markets facilitate the price discovery process. If these variables are not set efficiently, the information gap will generate an incentive for marketing firms to engage in coordination activities. As evidence of these incentives, Jones indicates that non-grade quality factors tend to be important determinants of price at the processing level. Jones also indicates that the cost of searching for a product with desired attributes represents a sizeable transaction cost for processors, and these costs are consuming an increasing share of industry profits.

4.1.4. Information technology

Streeter et al. (1991) and Hughes (1995) argue that information technology has both facilitated and caused marketing efforts to shift toward discovering consumer preferences and has generally facilitated the shift toward vertically linked food markets. Information technology has undoubtedly resulted in heightened consumer awareness of food product attributes (for example, nutritional, food safety, and environmental aspects). Partly as a result of this heightened consumer awareness, food manufacturers and retailers are increasingly reliant on information technology (for example, scanner data that is matched with consumer profile data) in understanding the buying patterns and demand characteristics of consumers. Hughes (1995) describes how information technology stimulates demand by lowering retail food prices through reduced food distribution costs, improving product quality and variety, and enhancing the overall food shopping environment. A recent grocery industry initiative entitled Efficient Consumer Response (ECR) calls for grocery manufacturers, wholesalers and retailers to be linked electronically in order to improve the efficiency of the entire grocery delivery system [Kinsey and Senauer (1997)].

Information technology is also key at the production end of the marketing chain. Increasingly, the identity of products is preserved throughout the entire production and marketing chain. When identity is preserved, food processing firms can offer certain guarantees regarding production practices and nutritional content. The classic example

of this type of process is a slaughter steer with a bar code on its ear tag. Scanning the bar code provides a meat processor with complete information about the animal. In general, knowledge is key in industrialized agriculture and the exploitation of knowledge-based opportunities (through strategic alliances, for example) is fast becoming an important determinant of success.

4.2. Changing role of the consumer

Throughout the discussion above, several references were made to the consumer in the context of the industrialization process. Barkema (1993) and many others argue that consumers have become more discriminating when making food consumption decisions. In the past, it was primarily the consumer who undertook the task of meal preparation with unprocessed food inputs. As Barkema (1993) points out, faster-paced lifestyles and more dual-career households have led consumers to demand food that is more convenient to prepare. Shifts in ethnic profiles and an increased global conscience have also led consumers to demand a much more diverse grocery selection than was previously the case. Equally important is the increase in consumer awareness about nutrition and food safety.

What are the implications of this shift in consumer demand for food? Barkema (1993) suggests that farm products must now flow into the processing sector through smaller marketing channels and these products are increasingly subject to a set of stringent quality standards. In effect, the value-added process is pushed back toward the farm gate. As well, product development increasingly begins at the farm gate rather than at the processing firm and, as discussed in the previous section, identity preservation throughout production and marketing is now common. With micro-niche marketing, price is often inadequate for coordinating consumer demand and farm-level investment and production decisions. Consequently, a major impact of the change in food demand by consumers has been a shift in the marketing mechanism, away from price and grades and toward sophisticated production/marketing contracts or vertical integration.

If changes in consumer demand result in an increased level of vertical coordination and integration, then the following question should be asked: Do the efficiency gains that stem from integration necessarily result in lower marketing margins (lower margins imply higher commodity prices for farmers and/or lower retail prices for consumers)? This is an important question that, for the most part, has not been addressed in the agricultural economics literature. In the general economics literature, much of the debate concerns whether or not upstream vertical integration will eliminate competitors (and thereby raise the consumer price) because after integration, competitors may be denied inputs that are supplied by the upstream firm [Rosengren and Meehan (1994)]. Vertical foreclosure of this form is (theoretically) ambiguous and is therefore largely an empirical question. Rosengren and Meehan (1994) find no evidence of noncompetitive outcomes that are attributable to vertical foreclosure in a sample of cases that have been challenged by the U.S. Justice Department and by the Federal Trade Commission at various times from 1963 to 1982. Empirical work of this sort for agricultural markets is certainly warranted.

4.3. *Contracting in the pork and poultry sectors*

Vertical coordination through direct ownership or contracts varies widely from industry to industry. Kinnucan and Nelson (1993) suggest that vertical control accounts for over 90 percent of the sales volume in industries such as sugarcane, fluid milk, potatoes, citrus fruits, broilers and eggs. Vertical coordination in the pork industry is still below this level, but the rate of increase in various vertical arrangements is changing rapidly. In recent years, a considerable literature has developed on vertically coordinated pork production and marketing.

Tsoulouhas and Vukina (1999) indicate that in North Carolina, which is one of North America's main hog-producing regions, more than 80 percent of hogs are currently produced under contract. Kliebenstein and Lawrence (1995) argue that coordinated pork systems foster specialization of production, induce more rapid adoption of technology, and utilize information more efficiently with regard to consumer preferences and animal genetics. Hurt (1994) reveals that industrialization has reduced the number of U.S. hog producers from 670,000 farms in 1980 to 236,000 in 1994. Rhodes (1995) indicates that even very large scale hog operations (for example, 90,000 sows) continue to exploit economies of scale.

Of interest in this section is the form of the contractual relationships between producers and processors in vertically coordinated markets such as those for hogs and poultry. With an integrator contract, the processor and grower each supply a predefined set of inputs to the production process, and the payment schedule normally has risk-reducing and incentive-preserving features. For example, in hog production, a cost-plus contract conditions the price received by the grower on a production budget, which includes feed prices and a built-in fixed profit level per animal. A price-window contract has upper price and lower price boundaries. Within these boundaries, the producer receives the market price, and outside these boundaries, the price risk is shared by the producer and the processor.

Tsoulouhas and Vukina (1999) cite bankruptcy protection for processors as a possible explanation for why the performance reward component of an integrator contract differs across industries (specifically, turkey, broiler, and swine). Generally speaking, fixed performance standards are used in swine production, two-part piece-rate tournaments are used in broiler production, and a combination of the two types of contracts are used in turkey production. With a fixed performance standard, a performance bonus is paid only if actual performance exceeds some predetermined technological standard. With a two-part piece-rate tournament, a bonus (penalty) is paid if performance is greater (less) than the average level of performance for a comparable group. Tournaments are useful because they help eliminate industry-wide uncertainty and therefore are more efficient at sharing risk than are fixed performance contracts.

Using data from the U.S. broiler industry, Knoeber and Thurman (1994) test three specific hypotheses concerning performance in tournaments versus linear evaluation schemes (with these latter schemes the bonus depends on outcome differentials rather than a simple ranking). They find that if the level of the prize changes but the prize dif-

ferential does not, then performance is not affected. As well, with a mixed tournament, more able players tend to choose less risky strategies. Finally, it is normally efficient for the tournament organizers to offer handicaps to players of unequal quality. Chavas (2001) also discusses various types of contractual production arrangements.

In general, there is considerable research potential in the area of agricultural marketing contracts. Allen and Lueck (1998) use a transaction cost framework for determining the type of farming enterprises that are most likely to engage in contracting. They suggest that agricultural production is normally seasonal and random, which makes specialization difficult and increases the moral hazard cost. As the importance of specialization and the length of the production stage increases, or as the cost of monitoring labor and the sensitivity of crop value to task-timing decreases, contracts should be more widely observed. This type of approach is highly insightful and additional research of this type will prove valuable.

Another area that warrants additional research is the relationship between risk and contracting. The principal-agent approach to contracting emphasizes the risk-sharing features of the contract. Knoeber and Thurman (1995) find that the bulk of price risk in the U.S. broiler industry is shifted from growers to processors as a result of the widespread use of production contracts. Johnson and Foster (1994) indicate that in the traditional hog-producing regions of the U.S., risk-averse producers desire some form of vertical coordination whereas risk-neutral producers generally prefer independent production. Hueth and Ligon (1999) show that, as a result of imperfect quality measurements, efficient contracts do not necessarily shield producers from all idiosyncratic price risk because of moral hazard considerations. In contrast to many of these findings, Allen and Lueck (1995) argue that a risk-neutral transaction cost approach to contracting is generally more insightful than one that relies on risk-sharing as the motivation for the contract.

It is useful to briefly review the results of a recent survey on contracting in the U.S. hog industry [Hennessy and Lawrence (1999)]. Nearly 100 large-scale hog producers responded to a series of questions about the advantages and disadvantages of contracting. The most frequent response was that contracting increased financial leverage by substituting contractor capital for producer capital. Other important advantages of contracts include a mitigation of regulatory constraints and the sourcing of quality labor. The most frequently cited disadvantage of contracting was that it reduces the operator's control of his or her operation.

5. International marketing: institutions and political constraints

International marketing involves dimensions beyond domestic marketing: multinationals interfaced with government monopoly buyers and sellers, government trade policy, dumping, and international subsidy wars. The importance of different institutions in the marketing of commodities cannot be over-emphasized [Schmitz (1986)]. For example, the world wheat and barley markets consist of both multinationals and single-desk buyers and sellers. The multinationals include Cargill Inc., Continental Grain, and Louis

Dreyfus. Single-desk sellers include the Canadian Wheat Board (CWB) and the Australian Wheat Board (AWB). Single-desk buyers include the Japanese Food Agency (JFA) and the China National Cereals, Oils and Foodstuffs Imports and Export Corporation (COFCO). In addition to the state traders mentioned above there are state trading entities that involve governments indirectly. One such example is the Commodity Credit Corporation (CCC) of the United States. In the day-to-day operations of the market, there is an additional component of price discovery through futures markets, which are located in several locations, including Chicago.

In this section, international marketing and the role of institutions will be highlighted by briefly discussing state-trading enterprises, export subsidy programs, the debate concerning the Canadian Wheat Board in the marketing of wheat and barley, and the continuing U.S.-Mexico tomato war. The section concludes with a discussion of the role of multinationals in international marketing.

5.1. State trading enterprises

Agricultural markets play hosts to a wide array of state trading enterprises in both developed and developing countries [Ackerman and Dixit (1999)]. State traders of grains such as the Canadian and Australian Wheat Boards and the CCC have been extensively analyzed (more discussion to follow). There are many other examples of marketing boards and state trading enterprises that operate in a variety of global agri-food markets. For example, the Food Corporation of India is the exclusive exporter of products such as onions, and it is the only importer of rice and wheat. Similarly, the Vegetable Production and Marketing Board of Israel is the exclusive exporter of vegetables. Other government agencies in Israel have exclusive export power in the exportation of groundnuts, ornamental plants, non-citrus fruits, and eggs and poultry products. In Jamaica, the Cocoa Industry Board arranges for the exports of cocoa, and coffee and bananas are exported by other marketing boards. In South Korea, the Minister of Agriculture, Forestry and Fisheries is the exclusive importer of malting barley and rice.

In terms of theoretical analysis, Krishna and Thursby (1992) discuss the different structures of marketing boards (e.g., a producer cartel versus a monopsonistic buyer of competitively supplied products) and optimal policies to deal with the different objectives of these boards in developing countries. Cardenas (1994) examines the relationship between the stabilization and redistribution functions of a marketing board, with an empirical focus on coffee in Africa and Latin America. Studies that examine economic aspects of specific international marketing boards are too numerous to review and discuss.

Agri-food cooperatives are also often involved in international markets. For example, the New Zealand Dairy Cooperative is a major player in the international market for processed milk and milk products. In South Korea, the Chiju Citrus Growers Cooperative is a sizeable importer and exporter of citrus fruits. A U.S. cooperative, Ocean Spray, is a major processor of cranberries and contracts with producers in the U.S., Canada and other countries. Are these large-scale cooperatives equivalent to the state trading

enterprises discussed above? More specifically, are they potentially in violation of the international trade rules and thus open to challenge by the WTO? These are largely empirical issues and, unfortunately, very little data exists to address this particular issue.

5.2. Export subsidy programs

Export subsidies are commonly used to enable exporters to increase their share of world markets. Export subsidies include a variety of different mechanisms such as export credit guarantees, rail transportation subsidies, and direct price subsidies to exporters. Two of the best known (and perhaps most controversial) export subsidy programs are the U.S. Export Enhancement Program (EEP) and the restitution scheme of the European Common Agricultural Policy (CAP). The focus of this section is on the EEP.

Gardner (1996) discusses the history and political economy of the EEP. He indicates that the EEP was created in 1985 in response to a severe decline in U.S. farm income (particularly from wheat) and to the extensive use of export subsidies by the European Community. EEP payments have been minimal over the last five years, largely because of a rebound in commodity prices. The EEP authorizes payments to exporters who sell in targeted export markets. EEP criteria include: (1) the subsidy must result in increased sales; (2) the subsidized sale should only displace the sales of competitors who operate with their own export subsidy; (3) there should be a net gain to the U.S. economy; and (4) the program should be budget neutral.

Gardner indicates that the average EEP subsidy reached \$38 per ton in 1987 and EEP exports in 1988 reached about 26.6 million metric tons (approximately half of U.S. wheat exports). Undoubtedly, a subsidy of this magnitude has had important consequences for world trade flows and prices. Despite the gains in market share and U.S. farm income that are attributable to the EEP, the EEP program resulted in a substantial cost for the U.S. economy. Gardner indicates that the EEP likely resulted in a \$1 dead-weight loss (from a U.S. perspective) for every dollar earned by U.S. farmers.

Schmitz and Furtan (1999) also discuss the implications of the EEP in the context of the debate concerning state trading enterprises and export dumping. The existence of export subsidies such as those provided by the EEP raise serious questions about a country's use of export dumping laws. For example, the U.S. has challenged many of its competitors through its anti-dumping provisions. However, the U.S. is one country, and there are many others (such as the European Union) that have historically been dumping in international markets. Restitution payments by the European Union, and EEP payments by the U.S., provide the means by which these countries can dump into world markets by selling below "full cost of production" [Schmitz and Gray (1992)].

5.3. The Canadian wheat board debate

During the last several years there has been an intense debate concerning the efficiency of international grain markets. A particularly important debate concerns the procurement and selling practices of the Canadian Wheat Board (CWB) – a dominant player

in the international grain market. There have been numerous evaluations of the CWB [for example, Kraft et al. (1996); Schmitz et al. (1997); and Carter et al. (1998)], though there is a noticeable lack of consensus among these studies. This stems largely from the fact that international grain markets are highly complex, and furthermore, there are severe data limitations that make analyses difficult.

Carter's (1993) analysis of the CWB barley marketing strategies concluded that the CWB is inefficient and that its current monopoly status should be changed to allow for a "continental" barley market whereby both the CWB and the private firms could sell to the United States. Carter's conclusions were based on several pieces of data and on the results of a Canadian regional forecasting model. Schmitz et al. (1993), in a separate study, found that significant losses would occur if the CWB were to give up its monopoly status as a barley exporter. They based their arguments on agronomic data of barley production along with a spatial price model of the world barley market. Further evidence by Brooks and T. Schmitz (1999) and by Schmitz et al. (1997), who used CWB sales data in their analysis, generally supports these results. The approach by Schmitz et al. (1997) uses a maximization model in which the CWB maximizes producer returns jointly across both feed barley and malting barley markets. At the same time, Carter and Loyns (1996) released a study that supported Carter's earlier findings that the CWB was inefficient. Their study used several approaches and pieces of data, including the costs of marketing barley between the producer and the port of exit.

Kraft et al. (1996) released a study on the effectiveness of the CWB in marketing wheat. Using CWB sales contract data, they found that the CWB earned price premiums that were greater than what would be the case if the CWB were replaced by multiple sellers. However, Carter and Loyns (1996) contend that even if the CWB could earn price premiums, farmers would still be worse off under the CWB because of its inefficiencies. Carter and Loyns (1996) attribute CWB inefficiencies to such factors as protein giveaways and excess cleaning charges.⁵

Why were these results so different? In the barley case, there were significant differences of opinion and in empirical estimates about the size of the U.S. market for both Canadian feed and malting barley. There was also little agreement on the impact of the U.S. Export Enhancement Program (EEP) on the ability of the CWB to price discriminate. However, the data clearly show that the CWB's price premiums for both barley and wheat were the highest when EEP payments were the greatest. This is what one would expect, since the degree of price discrimination practiced by the multinationals was a function of EEP levels. Other differences include supply response parameters and the degree to which current CWB operations restrict grain sales to the United States.

The institutional dimensions of marketing have been discussed in the General Agreement on Tariffs and Trade (GATT) and by the World Trade Organization (WTO), through which state trading is being challenged. However, Schmitz and Furtan (1998) and Schmitz et al. (1999b) argue that institutions such as the CWB are not necessarily in violation of WTO rules. For example, historically the CWB practiced hard price

⁵ The interested reader can find added dimensions to the debate by referring to Schmitz et al. (1997).

discrimination (price discrimination in the absence of subsidies, including EEP, which allows for soft price discrimination). This is allowable under GATT, even though price discrimination may lead to trade distortions. Also, such issues as the setting of initial prices by the CWB are not trade-distorting since initial prices are established after planting time. Also, the CWB and the AWB may be offsetting distortion brought about by single-desk buyers, such as COFCO and JFA.

In all of the above arguments there are many complicating factors and questions. For example, how is the CWB's marketing affected by transportation constraints? What is the impact of the futures market on the pricing of grain by both multinationals and state traders? Also, the activities of state traders such as COFCO are tied closely to Chinese agricultural policy, which makes it very difficult to separate the effects of single-desk buying activities from agricultural policy dimensions such as price supports. Finally, what is the competitive norm? If, for example, all single-desk buyers and sellers in the grain trade were removed, would the multinationals that replace them behave more competitively? Could all of the inefficiencies found by Carter and Loyns (1996) have been rectified by the CWB system without resorting to a multinational system? If one did a comparable accounting analysis of multinationals, looking especially for inefficiencies, would a similar conclusion to that of Carter and Loyns (1996) be reached?

5.4. The tomato war

The marketing of tomatoes has led to interesting problems in international marketing and is illustrative of a performance issue that is related to other traded commodities. Significantly, Florida tomato growers have continuously challenged the flow of tomatoes from Mexico into the United States. Schmitz et al. (1981) evaluated the 1978 agricultural dumping charge brought by the Florida winter vegetable producers against the Mexican growers. They examined "fair value" in the context of three antidumping criteria: (1) prices at home and abroad; (2) selling below cost of production; and (3) satisfying the third-market test. Using the latter criterion, the U.S. Department of Commerce ruled in favor of Mexico. However, the authors contend that the third-market test leads to ambiguous results. They also conclude that the law should be changed so that future cases can be decided on a "normal business practices" concept, which will account for production and costing decisions that are unique to highly perishable products.

Bredahl et al. (1987) provide a theoretical framework for why one might expect different outcomes in the tomato war between Mexico and the United States. They compare the free trade solution to both a voluntary export restraint policy by Mexico and an import-export cartel solution. Using rent seeking agreements, they show that tariffs, for example, are competitive strategies whereas voluntary export quotas are cooperative strategies. They analyzed the marketing order battle for the 1970 to 1975 period and concluded that the outcome led to a competitive strategy.

The tomato war heated up again in the debates over NAFTA. In 1995, the Florida tomato industry filed a Section 201 action. Section 201 allows the U.S. President to impose a variety of sanctions against imports if they enter the United States in such

increased quantities as to be the substantial cause of actual or threatened serious injury to a certain industry. The International Trade Commission (ITC) rejected the action.⁶ In early 1996, the growers once again filed a Section 201 claim, but again, the ITC ruled that there was no evidence of serious injury to a properly defined U.S. industry. In March 1996, the more widespread U.S. industry of fresh and chilled tomatoes initiated a dumping charge whereby foreign entities were charged with selling their product for less in the U.S. than at home. In October a settlement was reached and the dumping action was halted. According to Gordon (1997, pp. 1–2),

Mexican tomato growers agreed to maintain a floor under the price at which they export tomatoes. If the price floor does harm Mexican exports to the U.S. it will terminate the agreement and force a removal of the dumping action. If the floor does not harm Mexican exports and the Florida growers continue to lose their U.S. market share they may wish to end the agreement and renew their dumping charges.

In the above dispute, economists representing the Florida industry made numerous claims supporting the dumping action. An important factor, they argued, was the devaluation of the Mexican peso, which was not in the spirit of NAFTA. Due to the charging of relative prices, domestic consumption declined while Mexican exports increased.

It is too early to determine whether or not the agreement fits any of the models outlined earlier by Bredahl et al. (1987). Regardless, it is an interesting case of minimum prices being set for an internationally traded commodity. Whether or not the agreement leads to one of the noncompetitive solutions outlined by Bredahl et al. (1987) depends on many factors such as the rent seeking activities of wholesalers in Mexico, and the degree of foreign U.S. investment in Mexico's tomato production. For example, a firm producing in both Florida and Mexico would push for either a voluntary export restraint policy or an import-export cartel type arrangement. Note that the U.S. did not impose tariffs, as such an action is difficult given NAFTA: tariffs injure Mexico, which need not be the case under a minimum price agreement.

5.5. Role of multinationals

In most of the literature reviewed, little attention is paid to the scope of business activities that a firm undertakes. Many of the firms that are engaged in the processing and marketing of U.S. farm products are multinational in scope (for example, Arthur Daniel Midlands and Cargill, Inc.). Pricing efficiency, from their standpoint, is therefore multinational in scope, since physical boundaries are essentially non-existent. For example, ADM is one of the largest soybean processors in Brazil and is also a major marketer of Brazilian soybean oil. Other activities include the production and marketing of high fructose corn syrup. Cargill Inc. has marketing and processing facilities worldwide including grains, oilseeds, beef and fertilizer.

⁶ The reasons given are contained in [Gordon (1997)].

Economic theories of the multinational enterprise are not well advanced. Rugman and Cruz (1994) suggest that multinationals are continually evolving in a way that employs the resources of the firm in the most strategic and cost-efficient manner. They also develop a theory of business networks as an explanation of how multinational enterprises organize themselves. The key feature of this theory is that the multinational is at the center of a business network, which consists of suppliers, customers and competitors. The multinational provides strategic leadership to all partners in the network and leads the way to achieving global competitiveness. Eaton, Lipsey and Safarian (1994) developed a conceptual model of multinational agglomeration (i.e., a clustering of plants within a business network). They describe how agglomeration depends positively on economies of scale and negatively on transportation and communication costs. It would appear that both the business network model and agglomeration model are highly relevant for developing a better understanding of agribusiness multinationals. Another stream of literature on the multinational enterprise that is relevant for agriculture involves the issue of transfer pricing and tax avoidance.

While the theory of the firm continues to progress [Coase (1937); Williamson (1995); and Grossman and Hart (1986)], there has been little application of these theoretical developments to the multinational enterprise. For example, existing theory does not appear helpful in terms of explaining the high degree of vertical integration, from production through refining, in the U.S. sugar industry [Moss and Schmitz (1999)]. As well, what explains why Cargill, Inc., has expanded its beef processing capacity by locating, in part, in Canada? Does game theoretic analysis offer any useful insights? It would appear that rent seeking is an important component of a multinational's strategy to access markets and to maintain, or increase, domestic and export market shares. However, theories of this sort are basically non-existent.

The agricultural economics field would be wise to devote considerable effort to understanding the behavior of multinationals, not only in terms of marketing, but also in terms of the organizational framework within which marketing and processing occur. In spite of data limitations, is it possible to properly analyze this subject, given that little or no data are available on prices and market shares? Our answer is "perhaps", but significant effort would be required in terms of developing new theories, undertaking careful institutional analysis, and extensively analyzing the data which are available.

6. Conclusions

Agricultural marketing and distribution is a broad research area that covers many different aspects of pricing and market organization. At this point it is useful to comment on the general state of this literature. Beginning with price forecasting, it appears that academic interest in structural forecasting models has all but disappeared, whereas there is still some interest in using the time series approach. One concern is that interest in

time series forecasting methods is driven primarily by advances in methodology rather than the desire to produce price forecasts that have a measurable social benefit. As agricultural markets continue to industrialize, intertemporal pricing relationships will undoubtedly become significantly more complex and thus the task of producing socially useful forecasts is likely to become much more challenging.

The industrialization of agricultural and food markets also implies that basic price analyses will become increasingly complex and the traditional emphasis on form, time and space may no longer be sufficient. Indeed, an increasing degree of vertical coordination implies that demand and supply schedules and market equilibrium concepts are becoming less meaningful. Similarly, as commodities are increasingly targeted toward specialized niche markets, the standard assumption of homogeneous quality is now somewhat obsolete. Finally, economists appear to be wary of the perfect competition paradigm in price analyses in an increasing number of agricultural markets. The above suggests that traditional procedures used to assess marketing margins, intertemporal pricing relationships, and spatial pricing relationships will likely provide less insightful and less accurate results in the future.

There is considerable room for improving basic structural models of price determination. One suggestion is to develop better models of vertical coordination and, in particular, contracting. There are a large number of papers in the general economics literature that deal with the economics of contracts, and they are likely to be relevant for agricultural markets. This resource should be better exploited. Similarly, it is important to more carefully incorporate uncertainty and information constraints into pricing models in order to better account for principal-agent relationships, risk-sharing incentives and, more generally, transaction costs. Another suggestion is to pay more attention to product heterogeneity and account for features like differentiated niche markets and institutional constraints such as grading schemes. Modern theories of how and why firms in coordinated markets use the futures markets also need to be developed, especially given the lack of progress in this area over the last couple of decades. Finally, economic decisions that affect the market equilibrium are often motivated by market distortions such as subsidies and border protection, and, more generally, rent seeking incentives. These distortions should be more carefully incorporated into marketing models.

Of course relevant empirical models should be developed alongside the theoretical models of price analysis. Many years ago, in his Presidential address to the American Economic Association, Professor Leontief praised the American Agricultural Association for its empirical application to solving real-world problems. Given the topics reviewed in this chapter, it appears that empirical work is becoming increasingly difficult, because less and less data is being collected and institutional detail that cannot be easily incorporated into the model structure is largely ignored. Unfortunately, the perception generally remains that high quality empirical research necessarily requires sophisticated methodology. Thus, research efforts are often devoted to enhancing highly technical methodological detail, rather than to collecting better data or to clearly describing and analyzing the various institutional constraints. The problem of collecting appropriate data and information will become increasingly difficult as markets continue

to industrialize. From this perspective, research that utilizes high quality data will become comparatively more valuable in the future.

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PRODUCTION AND MARKETING

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Abstract

Important advancements in agricultural economics have combined the insights of the economic discipline and its analytical paradigm with the practical and scientific knowledge of agriculture. We discuss advancements made in the areas of production and marketing, the characteristics of agricultural economics that distinguish it from general economics, and close with a discussion of the future of agricultural economics.

JEL classification: Q10

1. Introduction

Agricultural economics has been distinguished by a set of particular questions and problems. This volume addresses economic analysis focusing on agricultural production and marketing. In these components, important advancements in agricultural economics have combined the insights of the economic discipline and its analytical paradigm with the practical and scientific knowledge of agriculture.

Historically, developments in agricultural economics and its underlying industries have been highly complementary. This synergy reflects one of the major themes of land grant universities, viz. the integration of scientific and practical knowledge to solve current and expected problems [Rausser (1999)]. This theme was institutionalized by the traditional placement of departments of agricultural economics within state universities' colleges of agriculture and the national Agricultural Experiment Station system. As experiment station researchers, members of agricultural economics departments are charged explicitly by the Hatch Act with undertaking research that contributes to the continued development and success of agriculture and rural America, including agricultural production, marketing, and management of the environment and natural resources.¹ The Hatch Act of 1887, which established the Agricultural Experiment Station system, states the purpose of this system as "... to aid in acquiring and diffusing among the people of the United States useful and practical information on subjects connected with agriculture, and to promote scientific investigation and experiment respecting the principles and applications of agricultural science. . ." [United States Department of Agriculture (1987, p. xxvi)]. This institutional structure has facilitated a continuing dialogue regarding the purpose and usefulness of agricultural economics research between researchers and stakeholders. This encourages agricultural economists to focus on practical questions, often with immediate applications.

2. Characteristics of agricultural economics

The chapters in this volume address the essential discoveries of agricultural economics on topics related to the production and marketing of food and fiber. While these topics are centered on agriculture, agricultural economics research also contributes to broader economic thought. These contributions have been heavily influenced by the discipline's research culture, and as a result, its fundamental methodology. Five distinguishing characteristics tend to define agricultural economics and differentiate its analytical frameworks from economics as a whole: the tendency to view economics and economic analysis as part of a larger, coordinated social-natural system; the emphasis on integrating

¹ For example, the University of California, Davis, Agricultural Experiment Station Guidelines state the following: "State agricultural experiment stations are expected to propose and conduct research projects, supported with Hatch formulas and matching funds, which comply with the purposes of the Hatch Act and which have relevance to the special conditions and needs of the respective states".

economic and scientific modeling; the emphasis on the importance of time and space for understanding economic phenomena; the emphasis on identifying the flexibility or inflexibility of factors of production and economic agents; and the emphasis on the importance of institutions.

Due to these characteristics, modern agricultural economics would be more familiar to Smith, Malthus, and Marshall than would modern economics as a whole. Agricultural economic research seeks to answer real world questions, and to emphasize testing economic theory against the available evidence. While this may limit the contributions of agricultural economics to directly extending the bounds of economic theory, in many cases agricultural economic research on real world questions has led to theoretical contributions. This certainly has been the case for research on commodity storage and expectations. The agricultural economics research philosophy, however, tends mostly to result in contributions to the methodology of measuring economic phenomena and testing economic theory [Houck (1986)]. Equally important, it results in economic research that is relevant to those outside the economics profession, to the direct and indirect industry users of economic analysis.

2.1. Integrated economic analysis

Agricultural economics' charge within the land grant universities, government agencies, and NGOs, has been to further public understanding of the production and marketing of food and fiber and the management and preservation of the environment and natural resources. This focus has influenced the direction of agricultural economic research. Agriculture has certain characteristics that distinguish it from other industries. First, markets are relatively unstable, due to the effects of weather, the low price elasticity of farm-level commodities, and the perishability of some products. Second, productivity in agriculture has increased remarkably over the past century, so that the average real price of food has declined even though demand has increased. Innovation and technical change have been very important for agriculture. Third, the family farm has been an important institutional form in agriculture. For much of the agricultural sector's history, family labor has been a critical component of total labor, oftentimes making it difficult to disentangle production and consumption decisions [Chavas (2001), Chapter 5, this Handbook].

The integrated systems perspective emphasizes the importance of measurement and empirical tests of theoretical constructs. This emphasis is complemented by the interactions between businessmen, scientists, and agricultural economists, which have aided agricultural economists in data collection. Ultimately, these forces have led to a much closer relationship between theoretical and empirical research in agricultural economics than in other fields of economics, and a willingness to adopt techniques from outside economic theory. As discussed later in this chapter, agricultural economists were early users of advanced statistical techniques in economic analysis. Numerous other examples of techniques adopted by agricultural economists include developments in operations research, notably linear, quadratic, and integer programming.

Encouraged by their research clientele, agricultural economists applied operations research techniques to evaluate production and distribution problems. This research was

closely coordinated with actual business operations, which enabled stringent practical testing of available techniques. Partially in response to the inadequacies of received linear programming techniques, Judge and Takayama introduced quadratic programming problems into the economic literature (1973). Operations research techniques continue to be used today by agricultural economists to examine questions such as the implications of produce grading systems and food safety monitoring systems [Starbird (1994); Starbird (2000)]. In addition to using these techniques, agricultural economists have continued to contribute to the development of these methodologies. Howitt (1995) introduced a new technique, positive mathematical programming, which facilitates the calibration of simulation models of production and resource use using nonlinear cost or yield functions. Since its introduction, this methodology has gained acceptance among consumers of economic research, especially government agencies in Europe and the United States. The emphasis on integrating economic analysis into a larger system to solve actual problems encourages the adoption of new techniques, in contrast to the use of artificial questions to illustrate techniques, a common indictment of much of modern economics. (See, for example, the essays in Medema and Samuels (1996), or Colander (1991).)

2.2. Integration of economics and the natural sciences

An emphasis on integrating economics and the natural sciences is the second distinguishing characteristic of agricultural economics. At the most basic level, agricultural economists must recognize the biological differences between highly perishable commodities, such as strawberries, and storable commodities, such as wheat, in order to effectively describe price discovery, evaluate the potential for the exercise of market power, and determine relevant markets. Similarly, resource constraints are an explicit consideration when analyzing industries that produce food, fiber, and energy. Even these basic allowances for physical properties transform the conclusions of economic analysis.

Agricultural economists have moved to more sophisticated and complex ways of modeling interactions between economic and scientific factors. For example, in order to accurately estimate a production function it is necessary to recognize biological limits on the productivity of inputs such as fertilizer for crops or feed for livestock. Studies of pest control integrate biological models of the relationships among populations of crop pests, their predators, and beneficial insects. Studies of timber and fisheries management account for biological growth patterns. Studies of pollution incorporate models of how contamination moves through the natural system. This physical modeling is necessary in order to understand what regulatory mechanism will minimize the economic and environmental costs of pollution and pollution prevention activities. Intuitively, in all these cases, agricultural economists start from the recognition that the natural world imposes market imperfections that are not considered in the stylized economic paradigm of perfect complete markets.

2.3. *Time and space*

The third distinguishing characteristic of agricultural economics is a focus on the importance of time and space. The economic engineering literature assessed productive efficiency and economies of scale in food processing in a temporal-spatial framework. Bressler and others at the University of Connecticut first used this method in the early 1940s to examine the Connecticut dairy industry. After Bressler's move to the University of California, Berkeley, the scope of this work expanded significantly. In the fifties, French, Sammet and Bressler and others further developed this method in various applications to California agricultural processing. [French (1977) discusses this literature and major contributors in more detail.] These studies demonstrated it was essential to include time in order to properly model production functions that can be used in production planning.

Within the supply chain, space and time are important determinants of product form. There are widely different transportation costs per unit product value in agriculture compared to other industries. These costs have led to agricultural economists addressing the question of in what *form* a product should be shipped from its production region to its ultimate consumer. For example, should soybeans be shipped from the Midwest to food processing plants across the country, or should soybeans first be processed into oil and meal, and each of those shipped to its demanders? Similar questions arise with regard to poultry versus grains transportation costs. Such questions were first identified by industry members who sought to determine optimal processing plant geographic placement.

Temporal and spatial dimensions are essential for answering many economic questions. The study of commodity storage, and its contributions to the expectations literature, stemmed from the recognition that time and space are critical for well-functioning markets. The agricultural-urban migration that characterizes developing economies is another economic question with an explicit time dimension: what is the correct rate of rural to urban migration [Taylor and Martin (2001), Chapter 9, this Handbook]?

2.4. *Flexibility and inflexibility*

The classical economic paradigm assumes that transactions are frictionless, and that inputs may be smoothly and costlessly reassigned among possible uses. Due in part to its recognition of the role of land in agricultural production, agricultural economics has made various findings that emphasize the importance of the relative flexibility of production inputs. Floyd (1965) examined how the relative elasticities of input supplies determine the returns to different factors of production, and the implications for the distribution of rents resulting from different forms of governmental intervention. Chavas (2001) (Chapter 5, this Handbook) argues that the future success of agriculture will depend on the flexibility of agricultural resources. Regions with flexible resources will continue to support an innovative and progressive agricultural sector.

2.5. *Institutions*

The economics discipline has recently rediscovered the importance of institutions for economic outcomes. Frameworks of analysis in agricultural economics have generally maintained the critical role of institutions throughout the twentieth century. The focus on institutions in agricultural economics is due in part to the diversity of public and private institutions within agriculture. This institutional diversity affected the economic evaluation of production and marketing as much as have biological and physical differences across various industry segments. State trade organizations, such as the Canadian Wheat Board, marketing orders for milk and many types of produce, and farmer cooperatives are all examples of institutions that influence their respective markets significantly.

Agricultural economics research on incentives and institutions in production has led to a number of important economic insights. Sharecropping, a classic example of an agricultural economic problem, first entered economic thought with Marshall's famous footnote (1890, p. 644, footnote 2, Eighth Edition) long before the development of agricultural economics as a distinct field. Agricultural economics has maintained the early focus on incentives and institutions that has only recently returned to economics. Perhaps the best example of this contrast is the incentive work done in agricultural finance, which predates seminal principal-agent work in general finance theory, such as Leland and Pyle (1977) and Stiglitz and Weiss (1981). Baker (1968) examined the effects of interest rate and non-interest rate loan terms in agricultural finance in the 1960s. His focus was on the influence of liquidity and incentive alignment on optimal resource allocation, which differs from the information and incentive focus of the later non-agricultural finance work [Barry and Robison (2001), Chapter 10, this Handbook].

Almost without exception, the contributions of agricultural economics to economic thought stem directly from one or more of the above characteristics. Quite simply, the agricultural economics approach may be summarized in terms of the following questions: Since markets aren't perfect, what are the effects of identified imperfections? Which imperfections are important? How might they be mitigated or eliminated? In pursuit of answers to these questions, agricultural economics has contributed to econometrics and economic theory, and has furthered our understanding of how markets and economic actors actually operate, as opposed to how they are presumed to operate in theory.

This research perspective is reinforced by the close relationship of agricultural economics to the sector under analysis, as well as other disciplines, such as biology and chemistry, that are applied to the study of agriculture. It is further reinforced by the direct link of empirical questions with the interests of actual economic actors. Particularly in agriculture, which has been characterized historically by a high level of government intervention as an engine for income and wealth redistribution, these economic actors will critically evaluate economic analysis, and will identify material omissions. These feedback loops, as well as the institutional design of the land grant universities discussed above, have aided in reinforcing the empirical focus of agricultural economics.

3. Volume contents

The chapters in this volume discuss two areas of agricultural economic analysis: production and marketing. Volume II focuses on other areas that draw on these two basic components: agriculture, natural resources and the environment; agriculture in the macroeconomy; agricultural and food policy; and trade and food security. In this section, we briefly summarize the contents of the chapters in this volume. The objective of each chapter is to present the major questions, findings, methodologies, and research contributions. We focus on integrating the chapters and their major research contributions in order to provide a unified portrait of the relevant subject matters.

Many contributions are due to the combination of the emphasis on real world problems and the availability of data in agriculture and food consumption. Agricultural economists have made substantial contributions to applied econometric analysis. In the interwar period, agricultural economists were the first and primary users of advanced statistical techniques within the economics profession [Leontief (1971); Fox (1986)]. In the 1920s and 1930s agricultural economists conducted seminal statistical studies of demand, supply, and production. Chapter 1, "Production and Supply", begins by tracing the development of production economics from this earlier period.

Mundlak (2001) (Chapter 1, this Handbook) examines theoretical and econometric advances in the modeling and estimation of production and supply functions. Agricultural economics has contributed a number of improvements in the specification and estimation of production functions. One of the earliest known uses of the translog production function, predating Christensen, Jorgenson, and Lau's (1973) work by sixteen years, was Halter, Carter, and Hocking (1957). In addition to these econometric advancements, agricultural economists have been essential in advancing the economic understanding of the production process, particularly the incorporation of time and space.

Unfortunately, not all research is characterized by the distinguishing characteristics of agricultural economics. Mundlak identifies production research to date using the dual approach as an example of such a failure. He develops the primal and dual approaches, and compares their advantages and disadvantages. He evaluates the contribution of these approaches to our understanding of agricultural production and supply. He concludes that the dual approach has failed to match expectations regarding its potential for contributing to empirical knowledge of production processes.

However, the dual approach has been used to evaluate issues related to productivity and to input use in agricultural production [e.g., Chambers and Lichtenberg (1994)]. In addition, the dual approach has proven fruitful in examining the agricultural processing sector [e.g., Paul (1999a, 1999c)]. Such work suggests that the contribution of the dual approach to empirical knowledge of production processes is non-negligible, and growing [see Paul (1999b) for the details].

Agriculture faces a high degree of production uncertainty relative to other industries, due to the effects of weather and other natural phenomena. Accordingly, agricultural economists have been contributors to analytical frameworks for assessing the effects of uncertainty and risk on decision making, as emphasized by Moschini and Hennessy

(2001) (Chapter 2, this Handbook). While theoretical studies illustrate the importance of risk aversion for understanding producer behavior, many of the empirical studies seeking to implement this theory are problematic, since they use aggregated data. Empirical analysis is generally complicated by the need to estimate risk preferences and technology jointly. In spite of these difficulties, some progress has been made in empirically determining risk preferences. Empirical studies have used hypothetical lotteries, real lotteries, and actual data on production decisions in order to elicit information on risk preferences. In general, producers appear to be moderately risk averse. Evidence on the magnitude and form of risk aversion is less conclusive.

Another major contribution focuses on understanding the importance of price uncertainty and the role of expectations in the price determination process. As discussed in Nerlove and Bessler (2001) (Chapter 3, this Handbook), the first work that accounted for the influence of expectations was done primarily by agricultural economists. This early contribution is commemorated in the classic hog-corn cycle model of adaptive expectations and the rational expectations based commodity market with storage model introduced by Gustafson (1958a). Nerlove and Bessler (2001) (Chapter 3, this Handbook) describe alternative models of expectation formation, in addition to fully rational expectations, and then summarize the existing empirical evidence regarding the applicability of rational and quasi-rational models of expectation formation.

Testing rational expectations is problematic. Indirect tests, restrictions on parameters in an econometric model, are joint tests of expectations formation and the behavioral assumptions (e.g., profit maximization) imposed on agents. On the other hand, tests based on direct observation, whether experimental or non-experimental, may be contaminated by the methodology. The direct approach may partially overcome this limitation in some cases. This is suggested by the authors' conclusion from the literature that aggregations of individual expectations are more likely to be consistent with rationality than are individual expectations. Even more recently, as discussed by LaFrance (2001) (Chapter 18, this Handbook), agricultural economics is beginning to grapple with the question of how a market equilibrium is reached. When consumers must form price expectations, the market price cannot be exogenous.

Sunding and Zilberman (2001) (Chapter 4, this Handbook) discuss agricultural innovation and adoption. By any measure, this body of research ranks as one of the major contributions of agricultural economics to the broader economic literature [Johnson (1986)]. Research on this topic incorporates developments from all of the preceding chapters. The induced innovation literature, begun by Hayami and Ruttan, links the creation of new innovations to economic incentives. They hypothesized that innovation occurs in response to economic signals. For example, if an input is particularly scarce, so that its price is relatively high, then induced innovation predicts that innovations that conserve this input are likely to emerge. Similarly, environmental regulations are likely to induce innovations that reduce pollution. In the post-war period most commodities have been in relative oversupply in developed countries, inducing declining real prices. Accordingly, agribusiness innovation turned to generating greater value-added to the products produced from these commodities.

Sunding and Zilberman investigate the technology adoption process. The literature in this area was initially empirical. While the earliest studies of adoption were done by rural sociologists, Griliches' (1957) study of the adoption of hybrid corn in Iowa incorporated economic variables in order to explain the pattern of adoption. He demonstrated that profitability considerations affected the parameters of the S-shaped diffusion process he and the rural sociologists had observed. The S-shaped model of diffusion has become widely used in the economics literature, to model consumer durables and other goods. Various theoretical explanations have since been developed in an effort to explain the observed facts as an outcome of farm-level adoption decisions. Imitation models, threshold models, and learning by doing models emerged to explain these facts. This work and second-generation empirical work have established that risk is a critical factor in the adoption process.

There are two types of structural change processes that are important in agriculture: those driven by external factors and those driven by internal factors within the agricultural production and marketing chain. Chavas (2001) (Chapter 5, this Handbook) examines the evidence supporting the structural evolution of agriculture. One of the implications of his discussion is that a narrow examination of production agriculture alone will provide an incomplete picture of any structural change. Technical change has been an important determinant of farm structure indicators, such as farm size and scope of production activities, but in many instances this technical change originates outside the farm production component.

Still another set of critical external factors is related to macroeconomics and trade phenomena. In particular, there have been numerous macroeconomic events reflected in exchange rates and interest rates that have had dramatic impacts on the performance of the agricultural sector [Rausser et al. (1986)]. The most significant events occurred in the early part of the twentieth century, the Depression of the 1930s, the rapid inflation and exchange rate deregulation of the early 1970s and the interest rate and exchange rate "overshooting" that unfolded in the early 1980s.² A fundamental empirical question is whether these events have led to permanent structural changes or non-sustainable, cyclical agricultural sector adjustments [Rausser et al. (1982)].

The second type of structural change involves the direct transformation of activities within the production and marketing chain due to technological, organizational, or other innovations. Many observers believe that innovations in biotechnology and information technology are driving a movement from bulk commodity markets to differentiated niche markets at earlier and earlier stages of the agricultural production and marketing chain. Specialized products meeting specific requirements increase the value of improved communication between different stages of production. In turn, this may increase the benefit of vertical integration, as demonstrated by Hennessy (1996) and

² Macroeconomic linkages with agricultural sectors are formally examined and investigated in Volume II for developed economies in the chapter by Ardeni and Freebairn and for developing economies in the chapter by Schiff and Valdés.

Perloff and Rausser (1983). There has been a substantial amount of descriptive work regarding the changes associated with a movement from commodities to differentiated products. [A partial list of this work includes Urban (1991); Manchester (1994); Boehlje (1995), and Boehlje (1996); and for a more complete review see Hennessy (1996).] Drabentstott (1994) and others have postulated a transaction cost based explanation for this shift, which they refer to as agricultural industrialization.

Alternatively, this shift may be viewed as a process of value-added differentiation, where members of the agrofood chain identify and match heterogeneity in consumer preferences and product attributes. Under value differentiation, there exist complementarities across production and marketing activities undertaken by the agrofood chain [Goodhue and Rausser (1999)]. Due to these complementarities, small changes in the cost of detecting customer preferences and niche markets, producing differentiated products, evaluating input characteristics, or coordinating multiple production and marketing activities may result in large changes in the amount of all of these activities undertaken by the firm. Biotechnology has the capacity to facilitate increased product differentiation at earlier levels of the production chain [Rausser (1999)]. Intellectual capital and the property rights over its products are the foundation of this evolution. Traditionally, public knowledge has formed the basis of agriculture as a commodity business. Private intellectual capital, in biotechnology and elsewhere, is rapidly becoming the basis for value-differentiated agriculture.

Analytically, value differentiation may be modeled using supermodularity. Unlike conventional marginal economic analysis, supermodularity is capable of explaining changes in clusters of activities undertaken by firms. It allows for non-convexities, and increasing returns to scale. Supermodularity is useful for evaluating non-additive joint returns to activities; that is, returns that are not the sum of the marginal returns that would be realized if each were implemented separately.

Value differentiation is a systemic approach to explaining internally generated changes in the agrofood chain. For this chain, understanding specific components and their linkages is critical to insightful model specifications. Agricultural economists have devoted a substantial amount of analytical attention to agricultural inputs and the associated markets. Six chapters in this Handbook focus on various agricultural inputs. The inputs addressed have special characteristics that lead to interesting economic questions. Land, the archetypal fixed factor, is an important agricultural input, and is addressed in Chapter 6. Human capital is an input that has private and social returns. Various aspects of human capital are important to agriculture, and are addressed in Chapters 7 through 9. Agricultural finance and credit are subject to information and incentive problems (Chapter 10). Historically, much agricultural research has been government funded, although this research arguably was not all public good research (Chapter 11).

Chapter 6, "Land Institutions and Land Markets", by Deininger and Feder (2001), illustrates the importance of institutions in economic analysis. Land is both a production input and an asset. If the institutions governing land ownership and rental are designed appropriately, individuals will invest in land improvements and will be able to obtain credit, using land as collateral [Rausser et al. (1984)]. Deininger and Feder discuss the

land and property rights literatures that paved the way for a wave of agrarian land reforms in Third World countries. When land reform failed, it was often due to insufficient recognition of the importance of institutions.

Even in countries with established land institutions, the functioning of land markets has merited a significant amount of analytical attention. Neoclassical economic theory predicts that land values are a function of the expected returns to agriculture. In the 1970s, however, U.S. agricultural land values increased rapidly, far outstripping likely increases in expected returns. This increase, followed by the dramatic fall in land values in the early eighties, led to the consideration of other factors that may affect land values. Feldstein (1980) presented the first theoretical basis for another commonly accepted belief in agriculture: that inflation increases *real* land values. According to Feldstein's model, differences in the tax system imply that inflation increases the real value of land.

Alston (1986) integrated these two explanations into a single theoretical framework. Further, he demonstrated that Feldstein's result was dependent upon a specific assumption regarding the relationship between nominal interest rates and the inflation rate under taxation. The sign of the relationship between inflation and real land values is theoretically ambiguous. Empirically, Alston found that inflation has a negative effect on land values, and that most of the gains in land values during the seventies were due to changes in the expected returns to land. In another empirical study, Burt (1986) finds that a distributed lag model of past rents matches the pattern of land prices, and that inflation and interest rates do not provide additional explanatory power.

Just and Miranowski (1993) develop a structural model of land values that incorporates the above-mentioned approaches, as well as credit constraint considerations. They find that returns to land, inflation, and changes in the real return to capital are important explanatory factors for land prices. In contrast to Burt and Alston, Just and Miranowski impose values for most of their relevant parameters before estimating the model. However, the results remain robust to reasonable perturbations of these values. In sum, the Just and Miranowski analysis along with earlier empirical papers suggest that land values are a function of expected returns—both from production and from post-tax realized capital gains relative to gains on other forms of capital.

In Chapter 7 Huffman (2001) evaluates the evidence on the importance of human capital, particularly formal education, in agricultural production. There is strong evidence that education levels significantly affect productivity and performance in both market and non-market production. This evidence is further supported by agriculture-specific evidence that shows the returns to education increase in agriculture over the course of the economic development process. However, other evidence implies that these returns accumulate to owner-operators and managers. This is because returns to education are negligible in casual labor markets in developing countries and field worker markets in the U.S. The results also demonstrate that it is important to distinguish among types of labor.

Schultz (2001) (Chapter 8, this Handbook) focuses on the role of women in agricultural households. He identifies three economic advances that have been essential in understanding this role: Becker's conceptualization of the family as a uniform coordina-

tor of time allocation and consumption decisions, agricultural household modeling, and the relaxation of Becker's framework to allow individual household members to have different objectives. Schultz discusses how the available empirical evidence provides very little information regarding which theory or theories of family behavior are most applicable. Often, it is impossible to discriminate across explanations. In part, this is due to the factual observational equivalence of the underlying theoretical frameworks.

Schultz's chapter integrates his view of the current literature with discussions of the econometric problems involved in answering questions regarding women's labor, family, and education decisions. Often, models of the agricultural household's decision making are predicated on the assumption that production and consumption decisions are separable. Schultz notes that it is surprising that econometric evidence to date cannot reject the separability assumption, even in a developing country context. To be sure, this econometric failure may again be due to the nature of the available evidence. Other studies suggest that families seek to smooth consumption relative to income. Consumption-smoothing activities conceal links between production and consumption decisions in actual outcome data, biasing tests toward acceptance. This behavior is consistent with the permanent income hypothesis. When markets are not available, other risk-sharing institutions, such as risk-pooling and gift-giving, are used. Empirically, such behavior results in observable outcomes that in many cases may be analyzed as if production and consumption decisions were separable. Accordingly, Schultz emphasizes that production and consumption separability specifications often may be used to analyze observed outcomes without any losses due to lack of generality.

Taylor and Martin (2001) (Chapter 9, this Handbook) address the theory and evidence regarding migration and rural population change, and the effects on agricultural production. The redistribution of labor from agriculture to industry lies at the heart of Lewis' two-sector model of economic development. The authors synthesize the theoretical work that examines the factors underlying the migration decision. They particularly emphasize the predictions of these theories that can be tested empirically. They review the modeling approaches that have been used to test these theories, discuss major empirical findings, and revisit the theories of migration given these findings. Empirically, age or income differentials across regions are a significant explanatory variable for migration, which is consistent with either a neoclassical or a Todaro expected income theory of migration. The probability of finding a job or the expected wage rate in the region is also significant, when included, which further supports the Todaro approach. The new economics of labor migration theory, which includes micro-level factors, such as liquidity constraints and networks that affect migration, has been subjected to fewer tests due to the relative paucity of the necessary household-level data. In general, the available tests tend to support theoretical predictions. The evidence regarding the effect of migration on agricultural production is less clear-cut; there is no consensus regarding when the rate of out-migration is too low, too high, or satisfactory.

Barry and Robison (2001) (Chapter 10, this Handbook) assess the agricultural finance literature. Applications of modern finance theory are used to examine issues that are particularly important due to the structure of the agricultural sector. The authors

evaluate the applicability of tools including principal-agent theory and financial contracting. They address agricultural lender-borrower relationships in some detail. Even in developed countries, non-financial considerations such as social capital have explanatory power for these relationships. The authors consider the credit rationing evidence in agriculture, finding that internal credit rationing by producers themselves, rather than external rationing by lenders, is consistent with the evidence.

Agricultural research, and the process by which it is transmitted to producers, referred to as extension, has traditionally been supplied by both the public and private sectors. Public sector funding has created a need for assessing the benefits and costs of these programs. In Chapter 11, Evenson (2001) discusses the economic impact of agricultural research and extension activities. He presents the estimated rates of return for agricultural research and extension programs available in the current literature. In general, the rates of return are high, with the majority exceeding 20 percent. Evaluating the growth implications of the estimated rates of return, he concludes that with some exceptions the rates of return are consistent with observed economic growth.

Just and Pope (2001) (Chapter 12, this Handbook) synthesize the above chapters on agricultural production and important agricultural inputs. They first discuss the uniqueness of agricultural production technology in section two. Unlike most production processes, agricultural production is generally distinguished by biologically determined stages of production, which temporally separate production decisions. The importance of biology means that uncertainty is an important characteristic of agricultural production, due to weather, pests, disease, and similar factors. Historically, agricultural production has been characterized by a large number of small producers each generating multiple products. Hence, output mix, heterogeneity, and aggregation have been important considerations for analyzing agricultural production. Next, Just and Pope derive estimable production relationships between inputs and outputs from economic fundamentals. They investigate the need to distinguish between technology and behavior and policy effects when modeling agriculture production. Moreover, they address the alternative ways of representing production problems, and identify common methodological errors in the literature and their effects. After summarizing the state of the empirical literature regarding important production questions, they identify two priorities for further work in this area: first, paying more careful attention to issues related to heterogeneity and aggregation across firms, and second, collecting better data, so that, for example, a farm-level problem can be modeled using farm-level data.

Much as Mundlak concluded that the contribution of the dual approach to our understanding of agricultural production has been negligible, Just and Pope conclude that the net contribution of empirical agricultural production economics to our understanding of agricultural production has been small. Their conclusion is based on two basic failures: the failure to use individual-level data to test individual-level hypotheses, and the failure to account for the increased number of joint hypotheses that aggregation and the use of aggregate data require. Nevertheless, valuable contributions of agricultural economics has been distinguished by its attention to heterogeneity in time, space, and observational units. Just and Pope suggest that the discipline's treatment of aggregation has not

respected the importance of heterogeneity. Hence, they conclude that recent work in agricultural production economics that is not based on these distinguishing characteristics provides negligible value added to either the economics profession or the public.

A common source of individual-level production data would provide numerous opportunities for testing theoretical hypotheses at the most appropriate level, and would facilitate work on the empirical importance of aggregation. However, results from aggregate data that depend on joint hypotheses, or that have observationally equivalent explanations, are not valueless, as Just and Pope suggest. They are simply weaker tests of the hypotheses in question. Results may be consistent with the hypotheses, rather than confirming them; or they may suggest that at least one of the joint hypotheses should be rejected.

Unlike the Just and Pope assessment of agricultural production economics, work in agricultural marketing recognizes explicitly that joint hypotheses must be identified and that multiple explanations may be observationally equivalent, particularly if individual-level data is not available. Consistency is a useful criterion under some circumstances; its danger lies in justifying market interventions when other consistent explanations would not do so. Williams (1987) demonstrates that non-linear transaction costs result in aggregate behavior that is observationally equivalent to behavior generated by risk averse agents in a commodity market with storage. Hence, these behaviors cannot be used as government justification to protect market agents from risk. Paul (1999a) compares findings from aggregate and plant-level data on the U.S. meatpacking industry, and concludes that the aggregate data results are consistent with the plant-level results. Both data sets support the hypothesis that increasing concentration is due to cost efficiencies.

Williams (2001) (Chapter 13, this Handbook) uses the case of the coffee industry to illustrate that risk-based and transaction cost based models of commodity futures and spot markets both explain many observed behaviors. He examines how economic arguments regarding the role of information may be tested using observations on futures market behavior. Similarly, any analysis of a specific activity, such as the hedging imbalances of private firms, is necessarily incomplete, since it is part of a broader market system with a number of highly correlated endogenous variables.

The focus of agricultural economics on operating markets has led to the explicit incorporation of time in theoretical and empirical research. Agricultural economists were early users of dynamic programming to model individuals' production and marketing decisions, as well as market outcomes [Rausser and Hochman (1979) summarize this work]. This focus led to important developments of the theory of rational expectations applied to storable commodities, as detailed in Wright (2001) (Chapter 14, this Handbook).

Storage allows consumption to be protected from production fluctuations. The benefits of the resulting social stability have prompted governments throughout history to create public stocks. In the United States in this century, this logic took a new twist. The government developed public buffer stocks to protect farmers from price variation, rather than to protect farmers and consumers from yield variation. The need to evaluate

the effects of these policies provided an impetus for economists to develop and refine the necessary economic frameworks.

Early economic analyses of the effect of government storage and price support programs for the major grains neglected the responses of rational private individuals to such policy initiatives. The close relationships among industry, policymakers, and economists in agriculture facilitated feedback to the discipline regarding the shortcoming of existing economic models. Agricultural economists analyzing commodity policy recognized long before the Lucas critique appeared that rational economic agents anticipate government policy and adjust their decisions accordingly. Beginning with Gustafson (1958a), the storage model of agricultural economics illustrates how markets behave when agents have rational expectations. This fundamental insight was established before rational expectations entered the language and analysis of macroeconomists following Muth's (1961) paper. Direct and indirect empirical tests of the agricultural storage model are consistent with its predictions. Since the model is based on rational expectation, this in turn provides indirect evidence in addition to that provided by Nerlove and Bessler that rational expectations is consistent with observed behavior.

Agricultural economics has generated a rich stream of industrial organization literature. Many early industrial organization studies were done within agriculture, such as Cassel's (1933) study utilizing structure-conduct-performance analysis and Nicholls' (1941) study. In the fifties, sixties, and seventies agricultural economists conducted detailed studies of specific industries. In addition to the increased understanding of a specific industry, these studies sometimes resulted in contributions to analytical methods. This is certainly true for the dynamic stability analysis conducted for the potato industry [Zusman (1962)] and the orange industry [Rausser (1971)]. These empirical analyses are representative of a number of specific industry studies that have been conducted that are rich in institutional detail, reflecting the economic roles of cooperatives, marketing orders, as well as coordination mechanisms, among various components of the vertical value chain in most agricultural commodity systems.

Chapter 15, by Sexton and Lavoie (2001), provides a comprehensive overview of the agricultural marketing and distribution literature. This chapter focuses on the industrial organization approach to market analysis, in contrast to the following two chapters, which address topics of particular interest to agriculture. Farmgate agricultural commodity markets are the classic introductory microeconomics example of perfect competition. In truth, these markets are characterized by increasing concentration and attempts to gain market power through product differentiation. Further, government-sanctioned cartels are a feature of many markets. These and other characteristics lead to a multitude of questions regarding the effects of these institutional features on market performance.

Agricultural industry studies tend to have a different flavor than those outside agriculture. In keeping with the distinguishing characteristics of agricultural economics, these studies emphasize the importance of institutions, such as marketing orders and cooperatives. In many cases, these studies are intended to be the factual foundation for the policy-making process (see the second volume of this Handbook). Another difference is the emphasis on the supply chain as a whole. Rather than focusing on one level of the

production chain, or perhaps the relationship between two levels, many of these studies follow production from before the farm to the final consumer [Rausser (1971)].

This supply chain focus is reflected in a subcategory of the industrial organization literature that is unique to agricultural economics: the margins literature [Wohlgenant (2001), Chapter 16, this Handbook]. The marketing margin is defined as the difference between the value of the product when it leaves the farmgate and the retail price of the product. While the marketing margin literature is quite similar to the literature on value-added functions in manufacturing, its focus is on the farm share of the food dollar.

The share of each food dollar that accrues to the farmer has been a question of historical significance. It is closely related to the concept of parity, which refers to the amount of non-agricultural products that can be purchased for the market value of a given amount of a farmgate commodity, such as a bushel of wheat. Farmer purchasing power parity has declined over the past century. Over this time period, the marketing margin has increased its share of the food dollar, and the farmer's share has decreased. This has led to the political and social question of whether parity should be preserved, and the related question of whether the marketing margin is too large.

The marketing margin is an equilibrium concept derived from the retail and farm prices. Empirical assessments of the marketing margin must begin by characterizing these prices and the price formation process. In practice, much of the recent work in this literature has focused on testing for the presence of market power. Results are indeterminate, due in part to the likely presence of scale economies and economies of scope.

Much like storage, spatial price relationships have been an active area of agricultural economic research due to the characteristics of commodity markets. Fackler and Goodwin (2001) (Chapter 17, this Handbook) present a comprehensive development of spatial price modeling research. A focal point of this work has been testing whether the Law of One Price holds: whether or not the same product sells for the same price in the same market at the same time. The authors develop and discuss definitions of spatial market integration and spatial market efficiency. In practice, empirical tests of the Law of One Price are often tests of integration or efficiency. The chapter discusses a number of methodologies that have been developed for this test. A common weakness is that transaction costs are not included. This is an important consideration for market integration tests. Generally, the null hypothesis is a joint null: markets are efficient and perfectly integrated. A rejection of the null may be due to a significant amount of market efficiency-reducing friction rather than to a lack of integration. The authors conclude with a caution regarding the interpretation of any test results: in order to minimize mistaken interpretations, it is essential to understand the institutions of the market in question.

An emerging body of agricultural economics literature addresses agricultural contracts. In this volume, Vercammen and Schmitz summarize much of the recent descriptive work (Chapter 20). Agricultural contracts have a number of features that are interesting due to the predictions of economic theory regarding their effects, and the effect of these features on the parties who enter these contracts. Most broiler chicken contracts, for example, contain relative performance compensation provisions. Under these

provisions, a grower's compensation depends on how many pounds of chicken he produces using the chicks and feed supplied by the processor *relative* to other growers who deliver flocks in the same one- to two-week time period. In some hog contracts, a grower's compensation depends on his performance relative to an absolute performance standard. In processing tomatoes, some contracts include price incentives for higher tomato quality. In fresh strawberries, growers contract with shippers to market their production. Shippers receive a fixed fee per unit, and growers receive the residual returns. Under sharecropping contracts, the grower and landowner share revenues and sometimes share variable costs. Such features provide a number of opportunities for testing economic theory. Further, the variety of contractual provisions observed supports the perspective that good agricultural economic analysis of these contracts will exhibit the distinguishing characteristics described earlier: analysis within the larger social-economic system, integration with scientific knowledge, an emphasis on the role of time and space, an identification of any inflexibilities of factors of production or economic agents, and attention to the role of institutions.

To date, relatively little analytical research has been conducted regarding these contracts (see chapters by Chavas, Vercammen and Schmitz, and Sexton and Lavoie in this Handbook). Explanatory research tends to use either transaction cost explanations [Knoeber (1989)] or contract theory explanations [Goodhue (1997); Tsoulouhas and Vukina (1999); Hueth and Ligon (1999)]. One difficulty with this explanatory research is that it generates very few testable predictions that distinguish one explanation from another. This is particularly true in cases for which an actual contract is the only form of available empirical evidence.

Goodhue (1999) demonstrates this problem in a discussion of a specific contract provision. Many agricultural contracts contain clauses that require the producer to use specified inputs. Some produce contracts, for example, restrict chemical use to those listed as approved by the contractor. Sometimes, the contractor controls the actual timing and amount of the input. Broiler chicken contracts are an extreme example of this observation. The broiler processor chooses the size and timing of flock placements with each grower. Chicks are an essential input for chicken production. Economic theory provides a number of explanations for contractor input control, all of which would result in the same contract provision. The contractor may control inputs in order to aid the planning of his own production process, particularly if timing is important. The contractor may wish to control the intellectual property embodied in an input, such as a proprietary plant variety. Even without intellectual property considerations, the contractor may specify certain inputs in order to guarantee greater consistency in the final product. For example, hog feeding contracts may specify the genetic stock of the hogs fed. The contractor may control a non-labor input in order to reduce the scope for potential moral hazard in the production of output or of output quality. The contractor may control a non-labor input in order to reduce the cost of adverse selection. An adverse selection problem may exist in terms of production costs or in terms of quality production costs.

The empirical research that evaluates these contracts is in its infancy. In part, this is due to the difficulty of obtaining proprietary data on performance outcomes under

contracts. Another reason relatively little empirical work has been done is the nature of the theoretical work on contracts. The theoretical literature from general economics results in very few testable predictions that are not observationally equivalent to simpler, alternative explanations, particularly in an agricultural context. Similarly, theoretical predictions are dependent upon a number of jointly imposed theoretical assumptions involving relative risk preferences, and cost structures.

There are a few analyses of contract outcomes in the literature. Knoeber and Thurman (1994) utilize data on performance outcomes for broiler growers under contract to a single processor to test predictions from labor economics regarding the effects of tournament compensation. Their results largely conform to theoretical predictions. Using the same data set, they evaluate the per flock risk transfers of the contract. They find that it transfers the majority of risk from growers to the processor, relative to a spot market transaction [Knoeber and Thurman (1995)]. The relative performance provision in the contract transfers additional risk to the processor. Martin (1997) finds similar results for hog contracts. Goodhue, Rausser, and Simon (2000) use the Knoeber and Thurman data set to test predictions regarding processor behavior and grower heterogeneity. They find strong support for the hypothesis that the processor assigns larger flocks to higher ability growers, and significant evidence that growers are heterogeneous in terms of performance. This hypothesis is consistent with symmetric or asymmetric information regarding grower ability. They find weaker support for a prediction that is dependent on initial asymmetric information regarding grower ability. In another context, Allen and Lueck (1999) use a data set on crop share and cash rent contracts for grain farms to test whether or not ratcheting effects are present in land tenure decisions.

Contracts between farmers and others in the production and marketing chain are an area of concern for policymakers and producers. In order to contribute effectively to this debate, agricultural economists need to be able to distinguish among theoretical explanations with different practical and policy implications. Mere consistency is inadequate [Rausser and Just (1981)]. For example, contractual price incentives based on delivered commodity quality may be designed to deal with a moral hazard problem, or may maximize profit for the contractor even when quality is completely random. Alexander, Goodhue, and Rausser (1999) examine whether growers respond to price quality incentives in processing tomato contracts in order to differentiate between random and non-random tomato quality. They find that growers do indeed respond to quality incentives. While theoretical constructs may be provided for either situation, the costs and benefits of the pricing provisions will differ for growers and contractors. The close relationship between participants in the agricultural sector and agricultural economics requires that this distinction must be made empirically, rather than assumed. Stakeholders are interested in applicability, rather than analytical neatness. In turn, this distinguishing characteristic of agricultural economics suggests that research on agricultural contracts has the potential to contribute to the economic literature on mechanism design by using the theory to generate and test observationally distinctive predictions.

Agricultural economists have conducted a substantial amount of work regarding demand theory and the demand for food and other agricultural products. This work has in

general been closely aligned with the demand work done in general economics. Agricultural economists initiated work in analyzing demand systems concurrently with the work of Frisch (1959) in general economics. [See, for example, Nordin et al. (1954), Wetmore et al. (1959), and Brandow (1961).] Food demand estimation is the only area of economic research that has carefully and consistently applied Frisch's analytical insights. The crucial reference in this field is George and King (1971). Their systematic estimates of demand elasticities still stand as an important contribution to applied demand analysis.

Agricultural economists' work in food demand has continued to lead in tests and applications of economic theory. Agricultural economists have conducted substantial research regarding the estimation of demand systems, especially work regarding flexible forms, non-parametric approaches, and separability of demand systems. Chalfant and Alston (1988) utilized the revealed preference approach to develop and perform a nonparametric test of structural change in meat demand. They find that changes in meat consumption in the United States and Australia can be explained in terms of changes in relative prices and income alone. This result contradicted previous research, based on functional form estimation of meat demand. Chalfant and Alston then demonstrated that only the use of specific functional forms could reverse their result. This finding suggested that specification errors were an important concern in demand analysis, and parametric estimation may be problematic in many cases. However, an offsetting consideration is that the power of nonparametric tests is relatively low.

Another important area of research has been in separability of demand systems. This work illustrates the symbiotic relationship between theory and practice that characterizes good agricultural economic research. Moschini, Moro, and Green (1994), for example, derive a general representation of the necessary and sufficient conditions for direct weak separability of the utility function. They then derive the parameter restrictions that are required to use their theoretical result for common demand systems, and apply their findings to food demand. Green, Holt, and LaFrance (forthcoming) provide an in-depth treatment of demand theory and applications.

In Chapter 18, LaFrance (2001) develops an approach to demand analysis that is based on duality theory for the household, generalizing the approach elucidated in [Deaton and Muellbauer (1980)]. His framework includes consumer preferences, household production and nonmarket goods, and quality characteristics of food and other goods. He pays particular attention to the dynamic problem, and the resulting analytical difficulties. Based on his approach, he identifies problems with existing empirical treatments of consumption habits and durable goods in the demand analysis. In particular, these treatments are only consistent with myopic expectations.

While LaFrance provides a road map for future work in demand analysis, Antle (2001) (Chapter 19, this Handbook) focuses on applying a number of different economic tools to an emerging issue in demand: food safety. The market for food safety is characterized by heterogeneity in consumers and producers, technology choices, and imperfect information. In some products, imperfect competition is an important consideration. Numerous regulations provide various participants with largely unanalyzed incentives.

Analytical approaches to food safety are drawn from elsewhere in economics, such as using the contingent valuation approach to value safer foods. Similarly, benefit-cost analysis of food safety regulations is not unique to food safety. Research in this area is a recent illustration of the interaction between stakeholders and agricultural economists that results in economic techniques applied to pressing empirical questions. Food safety research illustrates some of the distinguishing characteristics of agricultural economics, particularly the integration of economics and science and an emphasis on the critical role of institutions.

The commodity promotion literature is another area that displays the distinguishing characteristics of agricultural economics. This literature emerged in response to an actual problem: marketing orders and other industry groups engaged in promotion activities funded by mandatory assessments. An economic evaluation of the benefits and costs of these programs was needed in order to justify these assessments. Rather than relying on existing economic tools, agricultural economists incorporated marketing approaches into their methodology to provide factual information on program efficacy. Nerlove and Waugh (1961) presented the first empirical assessment of the effect of advertising on demand. The significance of the findings of these studies has encouraged a continual re-evaluation of the accuracy of the underlying theoretical and econometric assumptions. Currently, commodity promotion analysis is perhaps the most active applied area of advertising research within economics. This is due to the close relationship of agricultural economics with industry stakeholders; there is a demand for this analysis, and there is the willingness to cooperate with providing data and institutional information necessary for the analysis.

Vercammen and Schmitz (2001) synthesize the agricultural marketing literature in Chapter 20. They begin with an overview of the basic structure and observed variations of the marketing chain in North America, focusing on the comparison of agricultural marketing with the marketing of other types of products. They evaluate the different reduced form and structural models that have been used for price analysis, providing a summary of the pricing efficiency assessments discussed in previous chapters. [See Rausser et al. (1987), for a discussion of the usefulness of such measures.] They address three emerging topics on marketing: the role of information, the effect of changing consumer tastes, and increased vertical integration. Case studies of the Canadian Wheat Board and the Mexico–U.S. tomato dispute are presented to illustrate international marketing analysis. The main point that emerges from their chapter is that the distinguishing characteristics of agricultural economics must be used to define and conduct research on emerging empirical questions in these industries. For example, any analysis of the Canadian Wheat Board must account for its specific institutional features and for the specific institutional features of the markets in which it operates.

4. Future of agricultural economics

The future of agricultural economics is tied to the future of economics and the future of agriculture. Throughout the twentieth century, agricultural economics has grown

and evolved with agriculture. Analytical methods have increased in sophistication as agricultural markets have increased in complexity. Today, information technology and biotechnology are redefining agriculture and agricultural markets. Information technology is facilitating new coordination arrangements among various components in the production and marketing chain. Combined with the information technology revolution, advances in plant, animal, and nutritional genomics provide the foundation for pursuing enhanced human and environmental well-being. In order to remain relevant, agricultural economics must continue to evolve in order to address these developments through integrating advances in economic and scientific thought into its analyses.

The challenge for agricultural economics is to integrate new advances in economic theory with relevant empirical questions. The shift in the focus of economics makes this challenge increasingly difficult, as more and more economic theory is developed without attention to applicability or testability. Guided by its own distinct research philosophy, agricultural economics has not experienced this division to nearly the same degree; however, it is increasingly present.

The profession can learn as much from its mistakes as from its successes. As suggested by Just and Pope and by Mundlak in this volume, agricultural economics has been least successful when it has been simply applied theoretical economics using agriculture as another data source. Experience suggests that agricultural economics will make its most important contributions to economics and to agriculture when it seeks to answer real world questions in ways marked by the five distinguishing characteristics presented here. The agricultural economics research philosophy will promote the development of careful empirical tests that critically examine economic theory and practice.

Appeals to historical accomplishments are easy to make. The relevance of such appeals for the future depends on the sustainability of the distinguishing characteristics of agricultural economics. We argue that it is possible to nurture and enhance the distinctive character of agricultural economics, but doing so will require intensive effort from individuals, various organizations, and the profession as a whole. The distinguishing characteristics of agricultural economics are dependent on the maintenance of a distinctive research culture.

Defining a research culture is a difficult exercise. Many authors have tried to define agricultural economics, or differentiate its research culture from general economics [see, for example, Leontief (1971), Castle (1977), McCloskey (1990), and Galbraith (1993)]. We define the agricultural economics research culture as a dual standard of top quality economic research and empirical relevance. When research favors one of these goals over the other, the quality of the research suffers, as does its uniqueness.

An overemphasis on empirical relevance results in inattention to economic principles. Often, such work moves into the category of agribusiness management, or farm management. Work that is purely descriptive, or that closely resembles accounting or business management, is effectively lost to the discipline. Careful readers will notice that very little of such work is mentioned in this Handbook.

An overemphasis on economic methodologies poses another set of problems. As research loses its link to the real world, researchers are no longer using economics to

address empirical problems. Instead, they are applying economics to agricultural and agribusiness data. Analysis that demonstrates technique is less likely to result in innovations that aid economists in analyzing actual problems, compared to analysis that utilizes technique to address actual problems. While it is essential to maintain high professional standards, an overemphasis on technique will result in economists applying duality (or time series econometrics or mechanism design) to agricultural or agribusiness data. In contrast, we suggest that the profession will be sustained by agricultural economists who study production, marketing, nutrition, natural resources, the environment, and agricultural households using duality or time series econometrics or mechanism design.

Agricultural economists must maintain a firm grasp on economic methodology and technique in order to evaluate these problems with the best approaches the discipline has to offer. Agricultural economics will be most likely to contribute to the discipline when practitioners understand both techniques and problems. Without understanding both, it is difficult to know when the techniques are inadequate. In order to sustain the field of agricultural economics and maintain its distinct character, we must continue to balance the requirements of theory and practice.

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