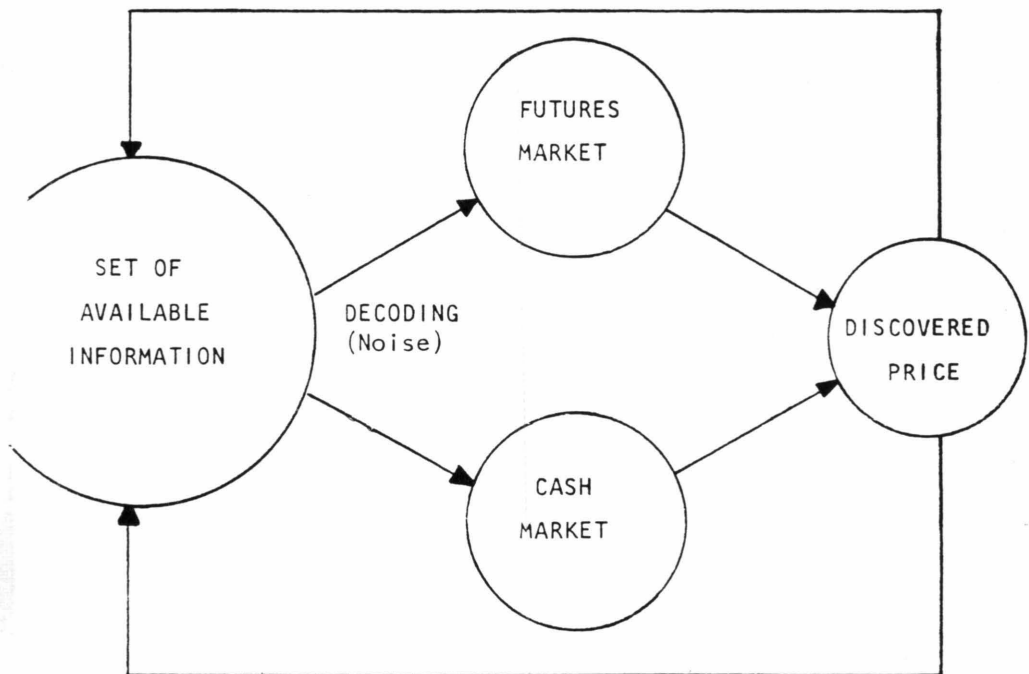


Price Discovery Processes in the Cattle Complex: Investigation of Cash-Futures Price Interaction

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The Virginia Agricultural and Mechanical College came into being in 1872 upon acceptance by the Commonwealth of the provisions of the Morrill Act of 1862 "to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life." Research and investigations were first authorized at Virginia's land-grant college when the Virginia Agricultural Experiment Station was established by the Virginia General Assembly in 1886.

The Virginia Agricultural Experiment Station received its first allotment upon passage of the Hatch Act by the United States Congress in 1887. Other related Acts followed, and all were consolidated in 1955 under the Amended Hatch Act which states "It shall be the object and duty of the State agricultural experiment stations . . . to conduct original and other researches, investigations and experiments bearing directly on and contributing to the establishment and maintenance of a permanent and effective agricultural industry of the United States, including the researches basic to the problems of agriculture and its broadest aspects and such investigations as have for their purpose the development and improvement of the rural home and rural life and the maximum contributions by agriculture to the welfare of the consumer . . ."

In 1962, Congress passed the McIntire-Stennis Cooperative Forestry Research Act to encourage and assist the states in carrying on a program of forestry research, including reforestation, land management, watershed management, rangeland management, wildlife habitat improvement, outdoor recreation, harvesting and marketing of forest products, and "such other studies as may be necessary to obtain the fullest and most effective use of forest resources."

In 1966, the Virginia General Assembly "established within the Virginia Polytechnic Institute a division to be known as the Research Division . . . which shall encompass the now existing Virginia Agricultural Experiment Station . . ."

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AN INVESTIGATION OF CASH-FUTURES PRICE INTERACTION

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SUMMARY

Price discovery in the cattle complex was analyzed by examining price lead/lag relationships for live cattle futures and cash carcass beef, live cattle futures and cash slaughter steers, and cash carcass beef and cash slaughter steers. The live cattle futures market is important in the day-to-day price discovery processes for cash cattle and cash beef carcasses. The analysis indicates:

1. Live cattle futures are related to cash carcass beef prices via instantaneous (same day) causality and via a unidirectional flow (lag of one day or more) from futures prices to carcass beef prices.
2. Live cattle futures are instantaneously related to cash slaughter steer prices. There are also unidirectional flows from futures prices to cash steer prices and from cash steer prices to live cattle futures (a feedback relationship).
3. Cash carcass beef and cash slaughter steers are instantaneously related and possess strong feedback relationships, suggesting the two sectors continuously interact in price discovery.
4. The above relationships were confirmed by post-sample testing, particularly the causal flows from futures to carcass and from futures to cash slaughter cattle.
5. Live cattle futures play an important, but not dominant, role in price discovery for cash cattle and cash carcass beef. Evidence of interaction is strong and suggests all three markets react with relative efficiency to changes in information in seeking to discover the appropriate market clearing price. In the futures-carcass beef subsector, however, futures trade is the primary source of price discovery.

6. Of the three market sectors analyzed, the carcass market is the least important source of price discovery activity. The arguments presented across recent years on the implications of thin markets, the impact of formula pricing, the need for changes in reporting trade in carcass beef, etc., should be reexamined in light of the results of this research.

The identification and measurement of lead/lag relationships in the price discovery process for agricultural commodity markets has implications for agricultural policy workers, commodity exchanges, and producer and trade groups. The policy implications of the research include:

1. Price-related analyses of the beef complex which have a policy dimension should reflect the interaction of the live cattle futures market, the cash carcass beef market, and the cash slaughter steer market in discovery of price.
2. Regulatory efforts should focus on a system approach which recognizes the role of futures markets in the price discovery processes for cattle and beef. A regulatory emphasis in the carcass beef market, possibly important from an industry concentration viewpoint, may be relatively ineffective in changing pricing performance since the carcass market essentially reacts to or follows prices discovered in the futures and/or cash cattle markets.
3. Innovations in futures contracts and/or trading procedures should be considered as a policy and/or regulatory tool in the cattle and beef markets. The importance of live cattle futures in price discovery suggests policy and regulatory emphasis should be placed on this market. Further analysis of live cattle futures market should be encouraged. Every reasonable effort should be made to ensure that the price discovery processes in the live cattle futures market are based on the best possible information, evolve from an arena where buyers and sellers are well informed and are not subjected to restraints and/or influences which constrain their capacity to seek information, and reflect quickly and accurately that information in buying and selling activities.

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INTRODUCTION

Commodity futures are receiving increased attention. Trade in futures for storable commodities such as corn, soybeans, and cotton has been an important part of industry activity for decades. The perception that futures markets for nonstorable commodities would not be feasible delayed the development of futures trade in cattle, hogs, and other nonstorable commodities. In addition to the physical differences between storable and nonstorable agricultural commodities, there are price-related differences which merit investigation. The role and impact of the relatively young futures markets in cattle and hogs have often been questioned.¹ For storable commodities, the ability to store the product across production periods provides a strong conceptual link which allows the futures market to serve both an allocative and stabilizing role (Tomek and Gray, 1970). There is no universally accepted conceptual role for the futures markets for nonstorable commodities. Some producer groups have called for a ban of trade in live cattle futures (Fleming, 1977). The negative views are illustrated by the following passage:

Recently, I was in Sioux City, Iowa, with a group of about 75 cattle feeders. I asked how many of them felt the cattle market of the '70s was more volatile than the cattle market

¹ Futures trading in live cattle and hogs began in the mid 1960s, whereas futures trading in storable commodities, e.g., soybeans, wheat, and corn, dates back to the late 1800s.

in the '60s. Everyone put up their hands. I asked how many of them felt that this additional volatility in the cattle market in the '70s was caused by the futures market. Everyone put up their hands. Then I asked how many people felt that the grain markets have been more volatile in the '70s than in the '60s. Everyone put up their hands. Then I asked the obvious question --- how many people felt that this higher volatility is due to the grain futures market? No one raised a hand (Peter Stubben in Leuthold and Dixon, p. 161).

There is little research to describe and document the role of live cattle futures trading in the pricing of cash cattle and carcass beef. Examination of the limited information which is available suggests analysts are generally positive regarding the impact of futures trading in the various nonstorable commodities. Analysts who support trade in futures point to the research efforts of Working (1960), Gray (1963, 1972), Powers (1970), Taylor and Leuthold (1974), and Cox (1976) which demonstrate reduced variability in cash prices following the introduction of futures trading in onions, potatoes, and cattle. Little is known, however, about the role of futures trading in the price discovery process for nonstorable commodities.

The key issue in assessing the role of the futures market in the price discovery process and the impact of trade in futures on price for the cash product involves identification of the market which is most informationally efficient -- the market which registers new information most quickly. The market which registers information first will lead (in a time context) the other market(s) in discovering the market clearing price. Analysis of the temporal (lead/lag) relationships between cash and futures prices will contribute to a better understanding of the price discovery process in nonstorable commodity markets.

Miller and Kenyon (1980) analyzed the lead/lag relationships between cash and futures prices for hogs during 1976. The authors found a noninstantaneous unidirectional causality from live hog futures prices to cash prices. This result was interpreted as providing evidence that the live hog futures market was important in discovery of cash prices on a day-to-day basis.

Purcell, Flood, and Plaxico (1980) investigated daily lead/lag relationships for live cattle during 1976. Their finding of a bidirectional (feedback) relationship daily between cash and futures prices suggested that cash and futures prices interact and move together. The study further concluded that if a unidirectional flow existed, it was from past live cattle futures to current cash cattle prices, but statistical evidence in support of that inference was not strong. An examination of slaughter cattle-feeder cattle price relationships revealed statistically significant evidence of causality running from the quote on day t for distant live cattle futures to the cash price for feeder cattle on day $t+1$.

Weaver and Banerjee (1981, 1982a, 1982b) examined lead/lag relationships between cash and futures prices for live cattle. Employing a multivariate framework, the authors studied the price determination process for cash slaughter cattle prices. The authors found evidence of causal flows from live cattle futures to cash slaughter steer prices, confirming the hypothesis that futures prices lead cash prices.

THE PROBLEM

Minimal information is available on the exact nature of the relationships between cash and futures prices in cattle and beef markets. There is, at best, limited understanding of how the live cattle futures market affects the price discovery process for cash cattle and cash beef prices. Until these shortcomings in the body of knowledge are corrected, both policy decisions and the decisions of entrepreneurs in the private sector will be based on subjective judgements, biases, and innuendo.

Identification and analysis of cash-futures price relationships will increase understanding of price discovery processes in the markets for nonstorable agricultural commodities. A broader base of information will be of use to commodity exchanges, marketing economists, regulatory agencies, policy makers, and agricultural producers who are interested in or use the futures markets for nonstorable commodities. The specific ramifications include: (1) exchanges will be better able to propose and develop innovations in futures contracts for nonstorable commodities; (2) marketing economists will be able to develop better theories for price discovery; (3) policy makers will be able to develop more effective long term policies; and (4) producers will be better informed about the relationship between commodity futures prices and the cash prices they pay or receive.

There are a number of important policy dimensions to the problem. The limited knowledge of the role of trading in live cattle futures in the

price discovery process for cash cattle and carcass beef presents a dilemma to enforcement agencies such as the Packers and Stockyards Administration (PSA) of the United States Department of Agriculture. The PSA has a regulatory responsibility with regard to pricing activities in the cash market and must respond to groups or individuals calling for a ban of trading in live cattle futures. The lack of information regarding the impact of futures trading on cash prices makes the role of agencies such as the PSA more difficult.

The agencies which regulate futures trading, e.g., the Commodity Futures Trading Commission (CFTC), are also affected by the lack of information. The CFTC is also subject to public pressure from producer groups, trade groups, and interested individuals. Effective regulation of commodity exchanges, and the development of potentially productive new futures contracts for nonstorable commodities, can be thwarted by the lack of information about the impact of futures trading in nonstorable commodities.

Commodity exchanges are forced to make policy decisions regarding futures contracts for nonstorable commodities with limited knowledge of the full impacts of these decisions. Producer utilization of futures contracts, producer input to innovations in futures contracts, and progressive adjustments of operational procedures and policies are delayed or blocked by the lack of information.

OBJECTIVES

The primary objective of the analysis was to develop or adapt an appropriate method to isolate, describe, and measure lead/lag relationships for selected agricultural price series, including live cattle futures prices, cash cattle prices, and carcass beef prices. More specific objectives included:

1. To develop a conceptual framework to analyze the role of futures prices in the price discovery process for selected agricultural commodities including live cattle and carcass beef;
2. To investigate, describe, and evaluate alternative methods of analyzing lead/lag relationships in both storable and nonstorable commodities;
3. To describe and analyze the lead/lag relationships between or across combinations of live cattle futures, cash cattle prices, and carcass beef prices in terms of direction, magnitude, temporal distribution of causal influences, and statistical reliability of the measured relationships; and
5. To describe and infer the nature and relative importance of trade in live cattle futures in the price discovery process for slaughter steers and beef carcasses in the cash markets.

WORKING HYPOTHESIS

There exists an economically and statistically significant level of causal influence running from prices for live cattle futures to prices for slaughter cattle and/or carcass beef in the cash markets. Methods can be developed and/or adapted to identify and measure the lead/lag

relationships in these markets to provide insight into: (1) the role of futures trading in nonstorable commodities in the price discovery process; and (2) the impact of futures trading in nonstorable commodities on prices in the cash markets.

SPECIFIC HYPOTHESES

The specific hypotheses of the study were:

1. Tests for causal relationships between cash and futures prices in both storable and nonstorable commodity markets will provide results consistent with a priori theoretical relationships.
2. There exists a statistically significant level of causal influence running from Chicago Mercantile Exchange prices for live cattle futures to slaughter steer prices in the cash markets in the Amarillo, Texas, market news reporting area.
3. There exists a statistically significant level of causal influence running from Chicago Mercantile Exchange prices for live cattle futures to cash carcass beef prices in the Central or Midwest carcass beef market.

PRICE DISCOVERY: THEORETICAL DEVELOPMENT

Price Discovery versus Price Determination

Price discovery and price determination in agricultural commodity markets both involve the registration of available information to arrive at a consensus price which balances the physical supply and demand of the commodity. In this study, a distinction between the two concepts facilitates the analysis. Forker (1975) has suggested the following definitions(p. 4):

Price discovery refers to a process by which buyers and sellers arrive at a specific price. A buyer or seller may have no control, little control, or great control over the price arrived at, but in all cases the process will involve an attempt to discover the best price for the particular conditions, including those of place and time, under which the buyer and seller find themselves.

Price determination deals with the theory of pricing and the manner in which economic forces influence prices under various market structures and over various periods of time.

Following Forker, the concepts of price determination and price discovery can be characterized by their respective interactions with the set of available information. Price determination refers to the combining of the economic forces in the available information set and generating a market clearing price. Emphasis is on the price level generated, not the process of generation. Price discovery takes the information set or set of economic forces which influence price as given, and focuses on the process by which price is generated within a specific market (mechanism). An example will clarify the distinction.

Consider the live cattle market. Several factors are available at a given time, t , which affect live cattle prices. The factors include feeder cattle prices, corn prices, interest rates, and live hog prices. There are alternative markets for live cattle including the cash market, the futures market, and the carcass beef market.

Price determination focuses on the factors which affect live cattle prices and the net impact of these factors in generating a market clearing price. Price determination is largely irrespective of which market is examined. Price discovery, on the other hand, is concerned with the relative efficiency of the processes in cash, futures, and carcass markets in assembling the price-related information and arriving

at the market-clearing price.² The market which discovers price will lead the other markets in terms of direction of price adjustments.

The usefulness of the above distinction is in providing a framework for the analysis of the relative informational efficiency³ of cash and futures markets. Analysis of the price determination process requires a multivariate framework. The above distinction between price discovery and price determination suggests the use of a bivariate framework to examine the dynamics and timing of price discovery. In a bivariate context, if one market (market A) consistently leads a second market (market B) in registering the price impact of new information, then discussion and further analysis of price discovery should focus on market A.

Price Discovery in Agricultural Markets

Price discovery in agricultural commodity markets thus involves the interpretation and incorporation of information in seeking a price which balances supply and demand. The efficiency of alternative agricultural market mechanisms in the price discovery process is affected by the periodic release of information. Periodic reports result in an actual effect and an expectations effect on price. The actual effect arises

² The process of price discovery can be conveniently viewed in a signal-noise framework. The price related factors are the signals and the noise comes from trading in the specific market as market participants evaluate the information and arrive at the market clearing price. The market which is most efficient in receiving (registering) the signals will discover the market clearing price.

³ The phrase informational efficiency is used here to describe the speed with which alternative markets receive and evaluate information in registering a market clearing price. The market which is more informationally efficient will register the information more quickly and therefore discovers price before the other markets.

from the changes in supply and demand conditions reflected by the information being released. An expectations effect arises from the actions of producers in response to the report. The expectations effect is based on the initial price adjustment (the actual effect) and expectations of producers for future prices.

The expectations effect illustrates the importance of the identification of the market where price is discovered. Producer decision makers often react to new information by generating a supply response (e.g., increases in placement of cattle on feed in response to a report which prompts rising fed cattle prices). Producer awareness of which market institution or mechanism reacts most quickly to new information has the potential to improve the adjustment process of supply and/or demand.

Several issues regarding the timing of price quotes and the sampling interval for the analysis of price discovery are raised by the preceding discussion. Decision makers rely upon price quotes to reflect current and future (expected) supply and demand conditions. The timing of quotes from alternative markets must be carefully considered if analysis of the price discovery process is to be valid. In particular, a quote from one market taken prior to the release of periodic information should not be compared to a quote from a second market taken after the information is released.

A related issue in the analysis of price discovery is the selection of a sampling interval for prices used in the analysis. As noted above, the decisions, actions, and expectations of agricultural producers are influenced by the discovered price. Given the continuous nature of agricultural production, particularly livestock production, a relatively

short sampling interval is required. Analysis of price discovery processes relying on annual average prices or monthly average prices will be of little value. The possibility of a supply response and changes in producer expectations which could occur within such a time interval could markedly change the supply picture, distorting the observed lead/lag relationships. Similarly, weekly average data will not completely capture changing expectations and market information. Many decisions in the livestock sector, such as placements and hedging actions, are influenced by daily information.

Given these problems with annual, monthly, and weekly sampling intervals, a daily interval would seem to be more appropriate. Intraday data might provide even more insight into lead/lag relationships between alternative price series, but such an interval is too short for widespread use by many decision makers. The types of information which emerge within the day are not widely disseminated and producer decision makers, for example, will rely on the market to register the impact of such information at the end of the market day and utilize the interday quotes in the decision process.

A potential problem of the daily interval is the identification of lead/lag relationships consistent with simultaneous price discovery in the cash and futures markets. Simultaneous discovery of price means each market is registering a market clearing price each day. If analytical tools isolate only a simultaneous relationship, the results suggest the use of daily information still involves a sampling period which masks potential intraday time leads and lags. Confirmation of simultaneous price discovery, however, offers valuable insight into the process of price discovery. The decision maker who acts on this daily

information can use price quotes from either market if the two markets are equally efficient in registering information, and there are no lagged responses of at least one day in length.

Agricultural Policy Implications

Price discovery in agricultural markets has several implications for agricultural policy. The importance of information flows to the price discovery process was described in the previous section. From the viewpoint of market news agencies, the role of information in price discovery raises policy issues regarding the timing of publicly released information such as U.S. Department of Agriculture (USDA) reports, the quantity and quality of information contained in the reports, and the reporting requirements for producers.

Agricultural policies aimed at price stabilization are influenced by the process of price discovery in agricultural markets and, in turn, influence the price discovery process. Efforts by policy makers to ensure stable prices in one commodity area (such as feed grains) may lead to instability in other commodities (such as cattle), particularly if the price discovery process becomes distorted. A burden is placed on the market which is discovering price to register information quickly and effectively. Price stabilization programs place particular emphasis on the incorporation of the expectations effects discussed earlier. If a program designed to support the price of feed grains is successful, costs of feed grains may exceed earlier expectations and prompt a supply response in cattle and hogs.

The development of effective policies in the regulatory dimensions of agricultural policy is affected by the price discovery process. Policy

development should be influenced by the location of price discovery. A concern over the location of price discovery is particularly relevant in livestock markets.

In recent years, there has been much conversation and commentary on the effectiveness of beef pricing in United States markets. Concern reached a peak in the late 1970s with the appointment of a Meat Pricing Task Force (USDA, 1979). The Task Force report described the existing system and made recommendations based on the current pricing practices in the industry. The usefulness of the recommendations, however, was limited by the lack of complete knowledge of the price discovery process in cattle and beef markets. Specifically, before policy recommendations can be made and acted upon, it is necessary to locate the correct market to regulate. The longstanding concerns about the adequacy of the National Provisioner Yellow Sheet as a reporting mechanism and the related formula pricing arguments become somewhat less important if price is not being discovered in the carcass beef market.

Effective and well-placed regulation may enhance the process of price discovery. Ill-placed and ineffective regulation may lead to inefficiency in price discovery. For example, if the center of price discovery for live cattle is the futures market and regulatory efforts are aimed at the Yellow Sheet, the regulatory efforts will be largely ineffective.

The Role of Futures Markets

The role of futures trading in the price discovery process differs by commodity type. It is widely accepted that the long established

futures markets are the center for price discovery in storable grains and oilseeds.

The role of commodity futures markets in the price discovery process for nonstorable commodities is dependent upon producer expectations. When making production decisions, a producer can look backward to previous prices, look at current prices, or employ some form of expected prices. Prior to the emergence of futures trading, prices from previous years were widely used as expected output prices. The emergence of futures trading decreased producer reliance on previous prices and increased reliance on futures prices (Gray 1972; Peck 1973,1976; Gardner 1976). The role of futures prices as expected prices and in the formation of expectations of future prices affects the price discovery process in a number of ways. The basic impacts involve supply response.

The ability to store across crop years provides a conceptual link between futures prices for storable commodities. Regardless of the maturity date of the contract, the storable dimension of the product ensures the existence of certain price relationships between the futures contracts. Working (1948) suggested the notion of a carrying charge to reflect the differentials between futures contracts of differing maturities for storable commodities. The carrying charge may fully reflect the costs of carrying the commodity to the future time period, may less than fully reflect the carrying charge, or may become inverted and reflect a negative cost of carry. The existence of these carrying charge relationships rations storable commodity usage throughout the year and encourages/discourages producer storage depending upon the carrying charge.

In a price discovery context, storable commodity futures markets provide expectations of future prices in cash markets. Tomek and Gray (1970, p. 139) argue that "the springtime price of the harvesttime futures, is in such markets (for storable commodities) a reasonable forecast of the subsequent harvesttime price." As such, futures markets for storable commodities perform both an allocative and stabilizing role.

More recently, Garbade and Silber (1981) have examined the role of futures markets in the price discovery process for storable commodities. Assuming risk neutrality, the authors develop models to explain the changes in cash and futures prices for day t as a function of the differential between cash and futures prices from day $t-1$. They then develop a ratio to measure the relative importance of the futures market in the price discovery process based on the coefficients of the lagged price differentials in seemingly unrelated regression equations. The authors conclude that "more than 75% of the pricing of those grains (corn, wheat, oats) appears to occur in the futures markets" (1981, p. 16).

The role of futures trading in nonstorable commodities has been analyzed by Purcell, Flood, and Plaxico (1980); Miller and Kenyon (1980); and Weaver and Banerjee (1981, 1982a, 1982b). The results of these studies were discussed earlier. The hypothesis underlying the studies is that futures markets register information more quickly than cash markets and, therefore, are the center for price discovery in livestock markets.

The arguments against futures markets as the location of price discovery for nonstorable commodities are based primarily on the failure

of futures as forecasting mechanisms. Leuthold (1974), for example, investigating the forward-pricing role of live cattle futures, found that, prior to 16 weeks before maturity, current cash prices provided as good a forecast of subsequent cash prices as did the futures prices. However, the failure of futures prices to accurately forecast subsequent cash prices does not negate the price discovery role of futures markets for nonstorable commodities. As noted earlier, the ability of the market to incorporate information and to register actual and expectations effects quickly and effectively is the key in price discovery. Moreover, the possibility of an intra-year supply response suggests that the futures market can prove to be inaccurate as a predictor of subsequent cash prices at a later date precisely because the futures quotes, used by decision makers in forming expectations, prompts a supply response.

The key issue of the role of futures markets in the price discovery process for nonstorable commodities is therefore the impact of futures prices on decision makers and the related influence on supply response. The futures market provides price quotes for future time periods. Though the prices of these contracts may not provide accurate forecasts, the level at which they trade provides an expectation and a forward-pricing opportunity for use in producer decision-making. Distant prices for nonstorable commodity futures can register information effectively and transmit appropriate signals to decision makers, and it is in this context that the price discovery function must be considered.

PRICE DISCOVERY AND LEAD/LAG RELATIONSHIPS BETWEEN CASH AND FUTURES PRICES

Price discovery is a market-specific concept relating to the ability of the market to discover the market-clearing price from the available information set. The market which discovers price will lead, in a temporal context, the other market(s) in direction of price movements.

Price discovery is a process of information-mapping, by a specific market mechanism, of the economic factors which influence price. Analysis of the relative informational efficiency of cash and futures markets requires an examination of the lead/lag relationships between the two markets. There are three possible structures for the lead/lag relationships.

Figure 1 depicts the information mapping process of price discovery when futures prices lead cash prices, i.e., the futures market discovers the market clearing price. The solid lines in Figure 1

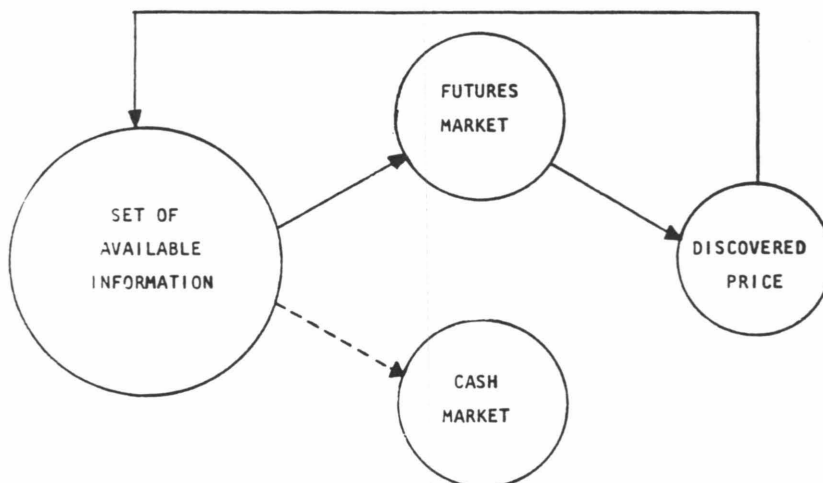


Figure 1. Information Mapping Processes of Price Discovery in Markets When Futures Prices Lead Cash Prices

represent flows of information which are contemporaneously related, a dashed line indicates a lagged flow of information, and arrows identify the direction of the information flow.

The set of available information in Figure 1 consists of all currently known information at time t which affects the price of the commodity. The process of price discovery is a decoding process of registering the information in the face of noise.⁴ In Figure 1, the futures market registers information more efficiently (quickly) than does the cash market. The discovered price is reflected in the available information which then flows to the cash market with a lag.

Figure 2 represents the case in which the cash market is the location of price discovery. Information is registered in the cash market, price is discovered and immediately reflected in the set of available information. The discovered price is reflected in the futures market with a time lag.

The case of simultaneous price discovery by the cash and futures markets is depicted in Figure 3. Available information is registered efficiently in both markets, and the price is discovered simultaneously. There is no perceptible lag in registration of the discovered price.

The cases depicted in Figures 1, 2, and 3 are a snapshot of a continuous process. In a more dynamic context, a feedback path would exist between the futures market and the cash market. Information flows along this feedback path would be bidirectional, reflecting the

⁴ The noise in the market refers to barriers to effective communication and arises from several sources, including the market mechanism itself, i.e., open outcry, auction, etc. Noise also arises in the market as participants with differing levels of information react with varying degrees of skill in evaluating the information.

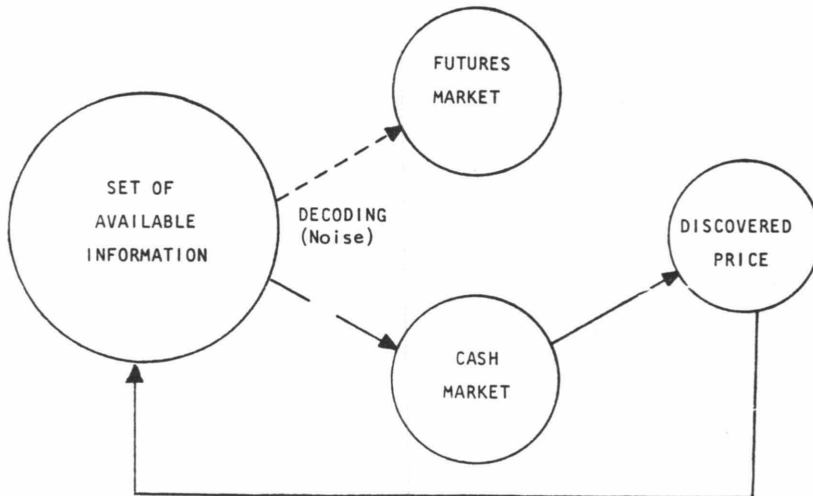


Figure 2. Information Mapping Processes of Price Discovery in Markets When Cash Prices Lead Futures Prices

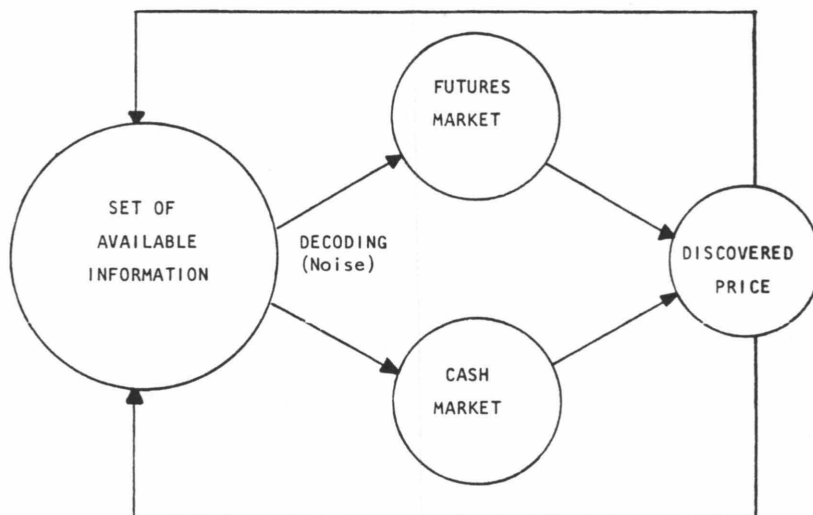


Figure 3. Information Mapping Processes of Price Discovery in Markets When Cash and Futures Markets Discover Price Simultaneously

fact that there is a continuous interaction between the markets within the day. Such a feedback path characterizes the simultaneous price discovery case of Figure 3 and relates to the earlier discussion of the timing dimensions of price discovery.

The information mapping process described above can be algebraically represented by:

$$(1) \quad FP_t = Q(CP_{t-1}, CP_{t-2}, CP_{t-3}, \dots, CP_{t-j}),$$

where FP_t is the futures price at time t , CP_{t-j} is the cash price at time $t-j$, $j = 1, 2, 3, \dots$, and Q is an arbitrary function.⁵ Equation (1) represents the case depicted in Figure 2 in which the cash market leads the futures market, i.e., the futures price today responds to cash prices in previous time periods. Similarly, the futures market leading the cash market (Figure 1) could be represented by:

$$(2) \quad CP_t = Q(FP_{t-1}, FP_{t-2}, FP_{t-3}, \dots, FP_{t-j}),$$

where CP_t is the cash price at time t , FP_{t-j} is the futures price at time $t-j$, $j = 1, 2, 3, \dots$, and Q is an arbitrary function.

The case where the cash and futures markets simultaneously discover price is more difficult to model algebraically, but a representation follows logically from (1) and (2):

$$(3) \quad CP_t = Q(FP_t, FP_{t-1}, FP_{t-2}, \dots, FP_{t-j}).$$

Equation (3) suggests that the cash price at time t responds to current and past futures prices. The simultaneous relationship in (3) could be

⁵ In the analysis of bivariate causal relationships, this function is typically assumed linear.

modeled equally well with the futures price as a function of the cash price.

A more general representation of the information mapping process would include past futures (cash) prices as influencing current futures (cash) prices. In the more general form, equations (1), (2), and (3) become:

$$(4) \quad FP_t = Q(FP_{t-1}, \dots, FP_{t-k}, CP_{t-1}, \dots, CP_{t-j}),$$

$$(5) \quad CP_t = Q(CP_{t-1}, \dots, CP_{t-k}, FP_{t-1}, \dots, FP_{t-j}), \text{ and}$$

$$(6) \quad CP_t = Q(CP_{t-1}, \dots, CP_{t-k}, FP_t, FP_{t-1}, \dots, FP_{t-j}).$$

ANALYSIS OF LEAD/LAG RELATIONSHIPS: THEORETICAL AND EMPIRICAL DIMENSIONS

Granger Causality

Granger's (1969) contribution of an operational definition of causality in a time series context stimulated much interest. The Granger definition of causality is widely used and has been shown to have appealing properties in the study of economic time series. Heuristically, Granger's notion of causality states that variable X causes variable Y, with respect to the information set including at least X and Y, if current values of Y can be better predicted using past values of X than by not doing so -- all other information (including past values of Y) being used in either case.

Sims (1972) demonstrated the equivalence between Granger causality and econometric exogeneity, so that unidirectional causality from the independent to the dependent variable is a necessary condition

for the consistent estimation of distributed lag models containing variables other than lagged dependent variables. Caves and Feige (1977) have demonstrated the equivalence of Granger causality and the concept of incremental efficiency, which has direct implications for testing the efficient markets hypothesis. Moreover, the Granger definition has given rise to testing procedures which overcome the problem of spurious regression described by Granger and Newbold (1974).

Definition: A formal definition of the concept of Granger causality requires agreement on what exactly is meant by the term causality.⁶ Granger (1980) discussed the definitional problems surrounding the concept, noting:

Attitudes toward causality differ widely, from the defeatist one that it is impossible to define causality, let alone test for it, to the populist viewpoint that everyone has their own personal definition and so it is unlikely that a generally acceptable definition exists.... unlike art, causality is a concept whose definition people know what they do not like but few know what they do like (p. 330).

Later, in the same paper, Granger adds a useful perspective to the concept of causality testing from a Bayesian viewpoint:

One way of viewing the test results is as an informal Bayesian. A person may start with a prior belief, or probability, that X causes Y, say, and then use the test results to alter his probability, if the test is viewed as

⁶ For purposes of the current discussion, the philosophical questions of defining causality will not be considered. The key philosophical issue is whether the relationships identified by Granger-type tests are truly "causal" in nature. In isolating lead/lag relationships which model the price discovery process for agricultural commodities, these concerns are less important than the ability of the test to identify the temporal interactions between prices in alternative markets.

being relevant. If the causality definition being invoked by the test is not liked, then the probability need not change. Once more, the purely personal aspect of the attitude towards causality is seen to be of real importance. For some cases, such as whether changes in animal behavior causes earthquakes, the prior probability will start at zero and will remain there despite any test results, so these changes will still be relevant leading indicators, but will not be thought of as causes. Surely no one believes that a lot of cows jumping up and down will trigger an earthquake. On the other hand, one may have a prior probability that smoking is a cause of heart failure, and, after an appropriate and well conducted test, this probability may be changed, depending on the results of the test (1980, p 343).

This comment illustrates the important aspect of forming these prior probabilities based on the availability of some convincing theory for the causal relationship being considered. Zellner (1979), in what Granger (1980, p. 343) calls "the only carefully thought out critical discussion to date" of Granger causality, strongly proposes that causality should be considered only in the context of some well accepted theory. He suggests that a more satisfactory definition of causality would be "in terms of predictability according to well thought out economic laws (p. 13)."

The viewpoint of Zellner is an econometrician's view of causality. The principles of econometrics require a specification of causal flows from the independent variables to the dependent variable. The concept of Granger causality, wherein the researcher is attempting to identify the direction of causality from alternative models, is contrary to the econometrician's paradigm. However, in the absence of clearly defined theoretical causal relationships, the tests of Granger causality provide empirical support for model building and verification of hypothesized theoretical relationships.

The Granger viewpoint of modeling is that of a statistician or time series analyst. The principles of time series analysis focus on the use of alternative lag structures in modeling the behavior of economic time series variables. The emphasis of such analysis is to first explain that part of the variable which can be explained by its own past and then to develop a model for the remaining variability using other (causally related) variables. Granger causality therefore provides a link between classical econometrics and time series analysis (see Granger and Newbold 1977 for a more complete discussion).

Four causal relationships may occur between economic time series (Granger, 1969): (1) causality; (2) feedback; (3) instantaneous causality; and (4) causality lag. The general Granger definitions follow from letting U_t represent all the information in the universe accumulated since time $t-1$ and letting $U_t - Y_t$ denote all this information apart from the specified series Y_t . We then have the following definitions.

Definition 1: Causality.

If $\sigma^2(X|U) < \sigma^2(X|U - Y)$, we say that Y is causing X , denoted by $Y_t \rightarrow X_t$. We say that Y_t is causing X_t if we are better able to predict X_t using all available information than if the information apart from Y_t had been used.

Definition 2: Feedback

If $\sigma^2(X|U) < \sigma^2(X|U - Y)$, $\sigma^2(Y:U) < \sigma^2(Y:U - X)$, we say that feedback is occurring, which is denoted $Y_t \leftrightarrow X_t$, i.e., feedback is said to occur when X_t is causing Y_t and also Y_t is causing X_t .

Definition 3: Instantaneous Causality.

If $\sigma^2(X|U, Y) < \sigma^2(X|U)$, we say that instantaneous causality $Y_t \rightarrow X_t$ is occurring. In other words, the current value of X_t is better "predicted" if the present value of Y_t is included in the "prediction" than if it is not.

Definition 4: Causality Lag.

If $Y_t \rightarrow X_t$, we define the (integer) causality lag m to be the least value of k such that $\sigma^2(X|U - Y(k)) < \sigma^2(X|U - Y(k+1))$. Thus, knowing values of Y_{t-j} , $j=0,1,\dots,m-1$, will be of no help in improving the prediction of X_t .

In the above definitions, X and Y are stationary time series,⁷ and $\sigma^2(X|U - Y)$ is the variance of the prediction errors in forecasting X based on the information set $U - Y$. For nonstationary X and Y series, $\sigma(X|U)$, etc., will depend on time t and the causal relationships may change over time. Operationalizing the above definitions requires the selection of a relevant subset of the universal information set U_t , as a majority of the information in the universe will be irrelevant in a causal sense. In particular, testing for causal relationships in the bivariate case assumes all information, other than the histories of the two variables, is either irrelevant or is incorporated in one of the included variables and therefore redundant.

Alternative Tests: A variety of testing procedures have evolved in applying the Granger definition to economic time series. Many economic time series possess time components which lead to serial correlation problems with regression and correlation tests. Because inferences based on such series can be misleading, the testing procedures generally involve the use of a filter to remove the systematic, time-related components from the data series prior to testing for causal

⁷ A time series is stationary if its mean and variance are independent of time.

relationships. Alternative tests of causality can be characterized by the filtering method employed.

The Granger definition was first operationalized by Sims (1972). Sims suggested the use of an autoregressive filter of the form $(1-\lambda L)^2$ to remove the time-related components from the data. Using natural logarithms of the filtered data, Sims suggested the use of ordinary least squares regression on the following equations:

$$(1) \quad Y_t = \alpha_{10} + \sum_{j=0}^q \beta_{1j} X_{t-j} + \varepsilon_{1t}, \text{ and}$$

$$(2) \quad Y_t = \alpha_{20} + \sum_{k=1}^m \delta_{2k} X_{t+k} + \sum_{j=0}^q \beta_{2j} X_{t-j} + \varepsilon_{2t}.$$

The Sims test involved the computation of two F-statistics from equations (1) and (2). The first was a test of the null hypothesis that:

$$\beta_{10} = \beta_{11} = \dots = \beta_{1q} = 0.$$

Rejection of the null hypothesis provided evidence that X causes Y, since current and past X's explain a significant amount of the variation in current Y. The second test statistic computed in the Sims' test was a test of the null hypothesis:

$$\delta_{21} = \delta_{22} = \dots = \delta_{2m} = 0.$$

Since the future cannot cause the past, significant values of the test statistic provide evidence of causality from Y to X. The procedure was then reversed to test for causality from X to Y. Significant flows in both directions suggested the existence of either feedback or instantaneous causality.

Sims examined causal relationships between money and income using a somewhat arbitrary version of the autoregressive filter. The filter, $(1-.75L)^2$, was claimed to "approximately flatten the spectral density of most economic time series" (Sims 1972, p. 545). The use of this arbitrary filter has been widely questioned and remains the major criticism of Sims' work. Another weakness of the Sims approach is the inclusion of the contemporaneous value of the independent variable in the first F-test. Computation of the test statistic in this manner precludes specific conclusions about either feedback or instantaneous causal relationships between the two series because the two relationships are inseparable.

Haugh (1972, 1976), and Pierce and Haugh (1977) suggested an alternative procedure for identifying causal relationships between economic time series. The authors suggested a two-step procedure. Each series is prefiltered using a univariate autoregressive integrated moving average (ARIMA) model. The residuals from the univariate models represent innovations in the series, i.e., that part of a series which cannot be predicted from its own past. The innovations are then cross-correlated with long lags. Pierce and Haugh demonstrate that X causes Y if the cross-correlations between the innovations series are nonzero at positive lags, indicating that current Y can be predicted by past X. Nonzero cross-correlations at both positive and negative lags indicate a feedback relationship between the two series. Instantaneous causality is present if there is a nonzero cross-correlation at lag zero.

A test for independence of the cross-correlations of the series innovations is suggested by Haugh (1972). The statistic is computed as:

$$U_m = n \sum_{k=1}^m r_k^2$$

where n refers to the number of observations on the innovations of X and Y , r_k^2 is the squared estimated cross-correlation at lag k , and m is an integer, greater than or equal to one, chosen large enough to include expected nonzero coefficients. The U_m statistic is distributed Chi-square with m degrees of freedom under the null hypothesis of series independence.

The Pierce-Haugh procedure has been criticized by Sims (1977). In assessing one-way causality, there is bias in the U_m statistic. Specifically, the significance of the hypothesis tests when one-way causality is present is underestimated if the tests are constructed under the assumption that the residuals are calculated from the true rather than estimated univariate models. Sims discusses the nature of the problem in more detail, noting that with two-sided filtering the distribution of the test statistic is unknown when feedback is present.

Ashley, Granger, and Schmalensee (1980) employ a two-step approach to identify causal relationships between economic time series. Univariate ARIMA models are estimated and used to filter each series, as in the Pierce-Haugh procedure. The residuals (innovations) from these models are then cross-correlated to identify the length and direction of lead/lag relationships between the two series. The innovations are then used to estimate bivariate transfer function models.⁸ Forecasts generated by the transfer function models are used

⁸ Bivariate transfer function models are an extension of the univariate ARIMA models to incorporate bivariate causal flows. Transfer function

to validate the causal relationship between the two series using out of sample data and a mean squared error criterion.

The Ashley, Granger, and Schmalensee procedure clearly provides a more direct test of the Granger definition, which requires evidence of forecast improvement, than either the Sims or the Pierce-Haugh procedures. The use of post sample evaluations provides an explicit examination of the forecast improvement required by the Granger definition. However, the procedure has not been widely used due in large part to the criticisms of the two-sided filtering approach. Further, the time series techniques, i.e., Box-Jenkins transfer function models, are less widely accepted than more standard regression techniques.

The common element of the above methods is the use of filters to remove the systematic, time-related components from the input series. However, there is no unanimity among researchers as to the appropriate filter to employ. Feige and Pierce (1979) have demonstrated that the choice of filter can lead to opposing results using a common data series. Moreover, many studies of causal relationships are an attempt to empirically identify relationships which are not clearly suggested by theory. The conflicting results that sometimes evolve from the use of different filters are not particularly helpful in advancing the state of the art in the causality area.

Geweke (1982) suggests a test of the Granger definition which uses ordinary least squares directly on the original levels of the

models utilize identified causal relationships to improve the forecast performance of a univariate ARIMA model by fitting a bivariate model to the data.

series.⁹ The Geweke test eliminates the arbitrary selection of a filter and the bias question of two-sided filtering. To test for causality from X to Y, Geweke suggests the following specifications:

$$(3) \quad Y(t) = \alpha_{10} + \sum_{j=1}^p \alpha_{1j} Y(t-j) + \varepsilon_{1t},$$

$$(4) \quad Y(t) = \alpha_{20} + \sum_{j=1}^p \alpha_{2j} Y(t-j) + \sum_{k=1}^q \beta_{2k} X(t-k) + \varepsilon_{2t},$$

where ε_{1t} and ε_{2t} are white noise residuals.¹⁰

The Geweke test based on (1) and (2) is equivalent to testing the following null hypothesis:

$$\beta_{21} = \beta_{22} = \dots = \beta_{2q} = 0,$$

which can be carried out using an F-test for equality between the two regressions. Large values of the statistic lead to the rejection of the null hypothesis that X does not cause Y.

The Geweke test for instantaneous causality is based on the residuals from equation (4) and those from:

$$(5) \quad Y(t) = \alpha_{30} + \sum_{j=1}^p \alpha_{3j} Y(t-j) + \sum_{k=0}^q \beta_{3k} X(t-k) + \varepsilon_{3t},$$

⁹ The test suggested by Geweke follows directly from Sargent (1976) and differs only in the use of an explicit test of instantaneous causality.

¹⁰ The term white noise is used to describe a purely random series, where all components are equally important, when measured in terms of their contribution to the variance of the series. The use of this term to describe a purely random sequence arose in connection with visual light. A light for which one component is more important than others will appear as a color, but light in which all color components are present in equal amounts appear white. The phrase white noise residuals refers to residuals which are not serially correlated; i.e., are random.

where ε_{3t} is white noise.

Estimation of equations (3), (4), and (5) requires that one either choose p and q large enough to remove substantial serial correlation from the residuals or apply generalized least squares. Selection of values for p and q must rely either on a priori knowledge of possible leads and lags, or on mechanical methods based on the final prediction (FPE) criterion or the prediction error sum of squares (PRESS) criterion (see Bessler and Binkley 1980).¹¹

Following the development of Geweke and using lagged dependent variables to correct for serial correlation in causality regressions, Geweke, Meese and Dent (1982) suggested a modified version of the Sims test. The modified Sims test is identical to the Sims test described above, with the addition of lagged dependent variables to the right-hand side to correct for serial correlation.

Recent Monte Carlo efforts of Nelson and Schwert (1982), and Geweke, Meese, and Dent (1982), have demonstrated that causality tests using lagged dependent variables outperform the alternatives in identifying known causal relationships between artificial data series. None of these efforts, however, examined the behavior of the Pierce-

¹¹ PRESS and FPE are alternative methods for selecting the appropriate lag length for autoregressive filters. The final prediction error criterion (FPE) is defined as the expected variance of the prediction error when an autoregressive model fitted to a series $y(t)$ is applied to another independent realization of the process. The prediction error sum of squares criterion (PRESS) is an alternative to the FPE criterion which employs ordinary least squares residuals to simulate prediction, i.e., the observation is not used to aid in the prediction of itself. Bessler and Binkley (1980) examined the procedures in filtering agricultural price series, concluding that "to explicitly guard against residual autocorrelations, we suspect FPE will be a preferred method" (Bessler and Binkley, p. 264).

Haugh test or the Ashley, Granger and Schmalensee (1980) procedure. Further, each of the Monte Carlo investigations employed stationary data series which will require less "filtering" than series with nonstationary components.

Limitations: As with any statistical testing technique, there are certain limitations to causality testing. The Sims (1972) procedure suffers from the use of an arbitrary prefilter. While a series-specific filter could be chosen, it seems an unnecessary step given the performance of the lagged dependent variable procedures which are computationally less burdensome, as they require fewer steps. Moreover, the inclusion of leads in the Sims procedure precludes the possibility of post-sample evaluation.

The Pierce-Haugh cross-correlation procedure has been criticized for the bias imposed by two-sided filtering. Nonetheless, the procedure may offer insight into the lead/lag relationships between series. Ashley, Granger, and Schmalensee (1980) employ the Pierce-Haugh procedure to specify unidirectional causal flows from which transfer function models are used to test beyond the sample period. The procedure is appealing in its direct test of the Granger criterion, though the use of transfer function models seems more art than science.

Lagged dependent variable tests, such as the Geweke and modified Sims approaches, have been demonstrated to perform well in identifying causal relationships (Hudson (1984b), Gamber and Hudson (1984), Geweke, Meese, and Dent (1982), and Nelson and Schwert (1982)). The selection of appropriate lag lengths for the dependent variable requires an additional computational step, although mechanical methods

such as final prediction error (FPE) and prediction error sum of squares (PRESS) are easily employed.

Finally, there is an important, though often overlooked, limiting dimension of causality testing. The timing interval of the data is critical to the direction of causality identified by any of the above tests. If the sampling interval is too long, then causal flows of a shorter duration will be masked. Similarly, too short an interval will lead to a failure to identify potentially important flows across longer intervals. To illustrate, suppose there is a unidirectional causal flow between two series which is reflected by a one-day lag. If the sampling interval is every two days, the two series will appear to be instantaneously related.

An issue related to the sampling interval is the timing of the information set upon which the causality test rests. The Granger definition requires that the information set containing the variables be timed at t . However, in analyzing price relationships for agricultural commodities, daily price quotes are often taken at different times during the day. If new information emerges between the two quotes, incorrect causal flows may be identified, as one market reacts and the other market's reaction cannot be registered until the next day.

The issues discussed here do not negate the value of causality testing, but rather serve to suggest the need for caution in interpreting the results of tests of Granger causality. The choice of analytical technique should depend on the available data and the goals of the analysis. Given the emerging emphasis on post-sample testing, a long data period will be needed for regression analyses to provide

subperiods for estimation of the FPE and/or PRESS criteria to select lag lengths and for post sample testing.

Causality and Price Discovery: Granger causality provides a technique for the analysis of lead/lag relationships between economic time series. Price discovery refers to the process by which price is generated in a specific market from the available price-related information. The analysis of price discovery is involved with the relative efficiency with which alternative market mechanisms assemble the relevant information and arrive at a market clearing price.

The accuracy of information registration in a market has a timing dimension and a market capacity dimension. If markets are temporally efficient in information registration, lead/lag relationships between price quotes provide insight into which market is first in discovering the market clearing price. A closely related dimension of the information registration process is the question of the capacity of alternative markets to register the available information in a market clearing price. A market which is incapable of assembling information and arriving at a market clearing price may lag other markets in registering the market clearing price -- price discovery takes place in the market which is capable of gathering the information.

It is plausible to assume that, given enough time, each market will arrive at the market clearing price. Therefore, the identification of lead/lag relationships between price quotes from alternative markets can be used to identify the market which discovers price. The presence of lead/lag relationships also provides insight into the informational capacity and the relative informational efficiency of the markets.

The distinction made earlier between price determination and price discovery is thus operationalized via Granger causality. Analysis of price discovery in cash and futures markets can be accomplished in a bivariate framework by analyzing the lead/lag relationships between the two price series. In contrast, analysis of the price determination process requires modeling the factors which affect price in a multivariate framework.

Stationarity, Serial Correlation, and Causality Testing

Tests for causal relationships rest on the ability to realize improved predictions by the inclusion of information not contained in the history of the variable to be predicted. The assumption of constancy of the relationship between the series is thus important in tests of causality. Covariance stationarity assures that the relationship between the series is independent of time, and stationarity is often assumed, if not explicitly examined, when testing for causal flows between economic time series.

A related problem which arises in causality testing is due to the strong temporal relationships between many economic time series. In regression analyses, such as the Geweke and modified Sims procedures above, computed F-statistics can be seriously overvalued if positive serial correlation is present in the regression residuals. The serial correlation problem can also lead to misleading conclusions in the Pierce-Haugh procedure.

The emergence of these two problem areas has led to virtually all of the discussion in the literature regarding causality tests. No clear

agreement exists among analysts as to the correct procedures to employ with regard to the problems of stationarity and serial correlation.

Stationarity-Inducing Transformations: Testing for causality requires that one assume the two series are covariance stationary. Prefilters, differencing, and logarithmic transformations are often employed to obtain stationary input series. The question of whether such transformations are necessary has been considered by numerous authors.

Granger and Newbold (1977b) argue that each series should be differenced to obtain stationarity prior to estimating a regression equation. Nerlove, Grether, and Carvalho (1979, p. 252) suggest letting the nonstationarity in one series explain the nonstationarity in the other series. Granger (1981) seems to support this latter view in suggesting that a regression equation will be consistent if a simulation of the explanatory side produces the major properties of the variable being explained.

With no real agreement on the question of transforming the data prior to the analysis to obtain stationarity, the researcher is left with a somewhat arbitrary decision. Following the ideas stated above, the best approach may be to examine each of the series for stationarity prior to analysis. If one series is stationary and the other nonstationary, then a transformation is definitely in order. If, on the other hand, both series are nonstationary, it may be useful to allow the nonstationarity in one series explain the nonstationarity in the other. This approach, however, requires that the relationship between the two series remain relatively constant over the sample period (Hudson, 1984b).

Correcting for Serial Correlation: Identification of causal relationships between two series relies heavily upon computed F-statistics which can be seriously overvalued if serial correlation is present (Granger and Newbold, 1977b). To correct for serial correlation, a variety of filtering methods are employed in causality tests. Available research suggests the following guidelines regarding the choice of an appropriate filter.

The use of arbitrary prefilters, such as the Sims filter, seems ill advised in most cases. Not only are the results sensitive to this filter but in some cases the filter fails to produce white noise residuals (Hudson, Purcell, and Toensmeyer, 1983). A better procedure would be to estimate a filter based on the nonwhite residuals from regressions on levels of the series and transform the data using this filter.

The use of separate ARIMA filters for each of the input series typically produces white noise residuals, and also guarantees that the input series are stationary, as they will be white noise. However, Sims (1977) has argued that this procedure introduces bias. To alleviate the bias problem, a common ARIMA filter may be used for both series. This approach is attractive if the nonstationarity in the two series is of a similar nature, so that both filtered series would be stationary.

Given the above problems of prefiltering, and the additional computational burden imposed by such procedures, it seems wise to rely on alternative methods. Regression tests which include lagged values of the dependent variable to correct for serial correlation have been shown to outperform available alternatives (Nelson and Schwert (1982) and Geweke, Meese and Dent (1982)). As for the question of the

impact of stationary input series on the outcome of causality tests, one should rely on alternative evaluation methods, such as out-of-sample tests, to verify identified causal relationships.

Causality Testing With Nonstationary Data

Nelson and Schwert (1982), and Geweke, Meese, and Dent (1982) conducted Monte Carlo studies to examine the behavior of alternative tests of Granger causality when known causal relationships are present in the data. In general, they concluded that tests of Granger causality which rely on lagged dependent variables to correct for serial correlation outperform the alternatives in the identification of causal flows. More recently, Zeimer and Collins (1983) examined relationships between five agricultural price series and three unrelated series, demonstrating that tests of Granger causality can identify causal relationships between series which are counter to theory. Bessler and Kling (1984) examined causal relationships between GNP and sunspots in demonstrating the need for post sample testing and input series which possess similar stationarity patterns. Specifically, Bessler and Kling showed that identified relationships between a stationary series (sunspots) and a nonstationary series (GNP) fail to hold outside the sample period.

The work of Zeimer and Collins (1983) and Bessler and Kling (1984) raised questions regarding the impact of nonstationarity on the outcome of causality tests. The Monte Carlo studies discussed earlier relied on stationary input series, yet there is a growing body of research (including Zeimer and Collins, 1983) which dismisses the stationarity issue by "letting the nonstationarity in one series explain

the nonstationarity in the other" (Nerlove, Grether, and Carvalho, 1979, p. 267). The empirical implications of this procedure were examined via a Monte Carlo study. Data series were constructed to possess known causal flows and known patterns of nonstationarity. Two tests for causality (the Geweke and modified Sims) were employed to examine causal relationships between raw data series and first-differenced data series with no time trends, common time trends, and different time trends in the X and Y series.

The Monte Carlo results suggest that the Geweke and modified Sims procedures perform well in identifying known causal flows when there is a small degree of contemporaneous error covariance between the series errors (Hudson, 1984b, pp. 53-75). Test performance declines as nonstationary components are introduced into the data series. Differencing the data prior to estimation provides mixed results. General conclusions suggested by the research include:

1. With regard to the arguments in the literature to let the nonstationarity in one series explain the nonstationarity in the other, the Monte Carlo analysis offers mixed support. When the nonstationary components in the two series are identical, i.e., common time trends, the percentages of correct identifications are slightly lowered when the data are differenced prior to estimation. The incidence of incorrect identification of instantaneous causality is unchanged when the data are differenced. If the nonstationarity in the two series is of different forms, i.e., different time trends, test performance is slightly improved by differencing. Instantaneous causality continues to be incorrectly identified when it is not present in the data. The decline of test performance in the cases where data are nonstationary and possess time trends compared to the case where the data possess no time trends suggest caution in interpreting the results of causality tests which employ nonstationary data.
2. The Geweke and modified Sims procedures perform equally well when there is a small degree of contemporaneous error covariance between the series errors. In some cases, the

modified Sims procedure provides somewhat misleading results when there is a high degree of error covariance. The general ability to test for the significance of future coefficients does provide a secondary check on the unidirectional test which could lead to correct conclusions with regard to causal flows. The performance of the modified Sims procedure suggests the test may be useful as a supplement to the Geweke procedure.

3. Investigation of collinearity diagnostics for preliminary experiments indicated an increased incidence of collinearity as the contemporaneous error covariance increases. The increased incidence suggested that poor test performance may be due in part to collinearity. The differenced regressions showed no evidence of collinearity; however, test performance did not improve. Inclusion of a time trend variable to account for nonstationarity components in the data intensified collinearity problems and did not improve test results (Gamber and Hudson, 1984).
4. The tests of Granger causality examined appear powerful for examining the lead/lag independence of economic time series. Lead/lag independence was correctly identified in over 80 percent of the cases. When data were nonstationary, however, the test for instantaneous causality incorrectly identifies contemporaneous independence in most cases, regardless of whether the data have been differenced.
5. The Monte Carlo investigation provided insight into the ability of the causality tests to identify unidirectional flows when data are nonstationary or possess varying degrees of error covariance. The results indicate that, although instantaneous causality was frequently identified when not constructed in the data series, the unidirectional tests remain powerful. The constructed unidirectional relationship was correctly identified in spite of the nonstationary components and the error covariances. Further, though instantaneous causality is frequently identified in series which were not constructed to contain an instantaneous relationship, both the nonstationary time trend components and the error covariances will build in a certain degree of instantaneous causality.

Guidelines for Causality Testing

Based on the preceding discussion, the following operational guidelines can be offered for a test of the Granger criterion:

1. The time series properties of the data series should be examined prior to estimation of causality regressions. This step will help the researcher determine the need for stationarity-inducing transformations. Allowing the nonstationarity in one series to explain the nonstationarity in the other should be avoided, unless there is evidence that the nonstationarity in the two series is of the same form.
2. Selection of lag lengths for the dependent variable in causality regressions should rely on mechanical methods, such as the final prediction error criterion or the prediction error sum of squares criterion. This procedure may arguably be referred to as "data dredging." However, since the goal of the inclusion of lagged dependent variables is to remove serial correlation from regression residuals, such procedures are dictated. The lag lengths for the independent variable should be selected based on theoretical constructs, allowing appropriate time intervals for reaction between the data series.
3. Interpretation of the results of causality tests relies on computed F-statistics which may be seriously overvalued if positive serial correlation is present. Therefore, it is important to calculate some measure of randomness of the residuals to allow identification of potential bias. Further, such measures may indicate inadequacy of the FPE or PRESS estimated filter and suggest appropriate correction (Hudson, Purcell, and Toensmeyer 1984b).
4. The results of the Monte Carlo investigation in the previous section indicate the importance of examining estimated causality regressions for collinearity. Collinearity problems will lead to unstable estimates, and identified causal flows may hold only for the sample period. Correction procedures for collinearity, such as ridge regression or principle components regression, could be applied, but there are no instances of the use of such correction procedures, when testing for causal relationships, known to the authors.
5. Post sample testing should be relied upon to verify identified causal relationships outside the data period of analysis. The use of post sample tests is particularly important in causality testing as the Granger definition requires evidence of improved forecasts.
6. Causality tests should be considered only in the context of some well-accepted theory. Tests of Granger causality are useful in identifying lead/lag relationships between economic time series which may then dictate directions for further analysis.

PRICE DISCOVERY IN GRAIN MARKETS

Analysis of price discovery between cash and futures markets for corn, wheat, and soybeans provided a set of markets where the theoretical tenets were sound and thus provided insight into the ability of the Geweke and modified Sims tests to identify relationships consistent with theory. The following conclusions are supported by the results:

1. Price discovery in grain markets involves interaction of the cash and futures markets for corn, wheat, and soybeans. Daily cash and futures prices are instantaneously related and also feature feedback relationships from cash to futures and futures to cash.
2. Instantaneous causality provides evidence of the relative informational efficiency of the cash and futures markets. The analysis supports the conclusion that if lead/lag relationships exist between cash and futures prices for grains, they are intraday in length (Hudson, 1984b, p. 150).

PRICE DISCOVERY IN AN INPUT/OUTPUT SETTING: LIVE CATTLE FUTURES AND FEEDER CATTLE FUTURES

Feeder cattle futures and live cattle futures provided a setting for the analysis of price discovery where an input/output relationship exists between the commodities. From derived demand theory, it was expected that changes in feeder cattle futures today would respond to changes in quotas for live cattle futures approximately five months in the future, where five months is roughly the length of an average feeding period. The relationships would be instantaneous in nature if the markets were efficient in incorporating and registering the impact of information. The results suggest:

1. The feeder cattle and live cattle futures markets exhibit intertemporal pricing efficiency. The two markets move in concert and behave according to theory. Prices in the feeder cattle and live cattle futures markets interact within the day and maintain price movements consistent with the underlying input/output relationship.
2. The relationship between feeder cattle futures and live cattle futures is sensitive to changes in corn prices. Feeder cattle futures may tend to react more quickly to extraordinary movements in corn prices than do live cattle futures. Unexpected causal flows, e.g., feeder cattle futures to live cattle futures, can be forced by extraordinary changes in corn prices. Such a result occurred in this analysis when tests were conducted using raw data, although the unexpected flow disappeared when daily price changes were employed in the analysis (Hudson, 1984b, p. 151).

The results of the above analyses demonstrate the ability of tests of Granger causality to identify relationships consistent with theoretical tenets. To assess the confidence in the results of the feeder cattle-live cattle and grain causality tests, the data series and identified relationships can be compared to the Monte Carlo results discussed above. The data series (first differences for grains and raw data for feeder cattle/live cattle) were stationary and possessed no time trends. The covariances between the series errors were examined and found to be less than .1 in all cases. The confidence in the results is, therefore, placed at over 90 percent given the results of the Monte Carlo investigation.

Based on the feeder cattle-live cattle results and the grains results, it was concluded that tests of Granger causality, in particular the Geweke test, provide a useful tool for analyzing the price discovery process in agricultural markets. The techniques were then applied to a set of markets where the theoretical tenets are less well established, the cattle complex.

PRICE DISCOVERY IN CATTLE AND BEEF MARKETS

Market Structure and Pricing Implications

Pricing issues have dominated the research literature regarding the cattle complex in recent years. Concerns over thin markets, formula pricing, and the impact of futures markets have been the major areas of debate. Trade and producer groups and politicians have expressed particular concern over the impact of futures trading in live cattle on the cash markets. Concern over the adequacy of pricing and price reporting in carcass beef carries the implicit hypothesis that the carcass beef market is the center of price discovery. Concern over the nature of futures trade and the impact of trade in live cattle futures carries the implicit hypothesis that the futures market is the center of price discovery.

The cattle industry can be characterized by the competitive structure at each level in the meat, cash cattle, and live cattle futures triangle. The cash cattle markets are characterized from the seller (producer) side as approaching pure competition. The buying side of the cash market is, however, an oligopoly, with few buyers in any given market. Much of the concern about thin markets emerges here. The carcass beef market is also an oligopoly, characterized by high concentration and potential pricing power with a competitive fringe of relatively small firms. The futures market is generally considered to be a competitive market.

The group which argues that the carcass beef market is the center of the price discovery process is concerned about the pricing power which firms in this oligopolistic industry may possess. An analysis by

the USDA Meat Pricing Task Force (1979) illustrates the nature of the concerns. The report indicated that over 70 percent of all carcasses were priced on a formula basis using Yellow Sheet published prices. The report goes on to illustrate widespread use of formula pricing for meat products by packers. The concern which arises here is rooted in awareness that less than 2 percent of total federally inspected steer and heifer slaughter provides the base for the Yellow Sheet quotes. Though the USDA analysis showed no tendency for the Yellow Sheet to inaccurately reflect negotiated prices, prices were quoted on days when no price ranges were provided by firms reporting market activities to the publication.

The concerns over the impact of the high levels of concentration in the packing industry and the use of formula prices which are not negotiated continue into the 1980's. If the Yellow Sheet is widely used and reports carcass and primal cut trade from a market sector which is the location of price discovery, then it is important that the price quotations accurately reflect the market clearing price. The attention of policymakers and regulatory agencies would rightly be focused on the carcass beef market.

Concern over the high concentration in the packing industry also contributes to the concern over the futures market. The USDA study noted above found that eight packers holding positions in 50 or more futures contracts accounted for 44 percent of total steer slaughter during 1977 and were the source of over 50 percent of the total sales information reported in the Yellow Sheet. However, concern over the futures market is not limited to the areas of high concentration and potentially thin markets.

The research literature contains numerous articles examining the efficiency of the live cattle futures market, including its forecasting ability (e.g., Leuthold, 1974), and analysis of the usefulness of live cattle futures as a hedging tool (e.g., Purcell, Hague, and Holland (1972); Leuthold and Mokler (1979); McCoy and Price (1975); Erickson (1978); Shafer, Griffin, and Johnston (1978); Caldwell, Copeland, and Hawkins (1982); and Peterson and Leuthold (1983). The live cattle futures market has been frequently attacked for failing to provide a useful tool for producer hedgers, especially small producers. The typical concern is that the market offers profitable forward prices only infrequently. Studies of market efficiency, in the Fama sense, have also suggested the live cattle futures market to be inefficient, i.e., there is evidence that day-to-day price changes are serially correlated (e.g., Purcell, Flood, and Plaxico, 1980).

The uncertainty regarding the role of live cattle futures in price discovery and its effect on cash prices has led to varying and often negative conclusions regarding the market. The live cattle futures market has replaced the thin cash markets, and the carcass market to an extent, as the whipping boy, taking the blame for low prices. The need for further research to clarify what goes on in the carcass, cash cattle, and futures markets and how they interact with each other prompted this research. The results should assist regulatory agencies, policy workers, commodity exchanges, and producers in working with the markets in the broad cattle complex.

The Possible Role of Live Cattle Futures in Price Discovery

The preceding discussion raises the issue of the role of futures trading in price discovery in the cash cattle and beef markets. The intense concerns over the Yellow Sheet and the pricing power of the packing industry are merited only if price is discovered in the carcass market. Similarly, strong concern over the futures market is merited only if price is discovered in the futures market. It is the market sector where price is discovered that merits close scrutiny and analysis. A policy prescription directed at the carcass beef market, for example, will not have much impact on price variability or other measures of pricing performance if carcass beef prices are generated in a lagged response to some other market sector.

The live cattle futures market approximates a perfectly competitive market with a large number of buyers and sellers, none of whom should be able to have a significant impact on price. In contrast to the cash or carcass markets, the futures market is geographically centralized, providing relatively low-cost access to information. The nature of the market encourages information gathering by creating a value for that information. For example, speculators seeking returns on investment capital are motivated to develop and/or seek information to guide their trading efforts.

These features of the live cattle futures markets suggest a possibly important role for the market in the process of price discovery. The futures market would be expected to perform the function of gathering and registering information in the form of a market clearing price which balances the physical supply and demand

forces of the market. The large number of well informed participants should create an evaluation process through which the market clearing price is discovered efficiently and effectively. The time required for information to be registered in the form of a price change or price response could be hypothesized to be shorter in the futures market due to the centralization of the futures market as compared to the more geographically dispersed cash and carcass markets.

Based on the argument presented above, it is plausible to hypothesize that the live cattle futures market is a primary force in the price discovery process in the beef sector. In the process, the futures market would be expected to receive and evaluate prices from the cash carcass and cash cattle markets in adjusting the discovered price. The specific nature of the interactions among the markets can be determined by examining lead/lag relationships between live cattle futures prices, cash carcass beef, and cash live cattle prices. If the futures market is in fact the most important force in the price discovery process and does interact closely with the cash markets, then statistically significant support for instantaneous and feedback relationships would be expected, with additional evidence of unidirectional flows suggesting that the futures market leads the cash markets.

Empirical Approach

Data for the analysis of lead/lag relationships between live cattle futures, cash carcass beef, and cash slaughter steer prices were collected for the period January 1, 1979 through May 28, 1982.¹² Live

¹² The selection of this period for analysis was based primarily on data

cattle futures prices were transcribed from the Chicago Mercantile Exchange Year Book and represent daily closing prices for the nearby contract. The truncation procedure employed to remove potential delivery month problems involved recording the nearby contract until the first day of the delivery month and then switching to the next nearby contract. For example, the April contract was used as the nearby contract during February and March, but on April 1, the June contract became the nearby.

The truncation procedure created problems with the first differenced series due to the price differentials between the "old nearby" contract and the "new nearby" contract. To alleviate this problem, the price differential of the new nearby contract was recorded on the day that the contracts changed. For the example above, the price change of the June contract would be recorded on April 1. This procedure controlled the range of price adjustments by preventing the "jumps" in the data when a price difference involves two different contracts.

The carcass beef series was recorded from the National Provisioner and represents the daily closing price for Choice steer carcasses, yield grade 3, 600 to 700 pounds, F.O.B. Midwest River Area. The cash slaughter steer price series was obtained directly from the Agricultural Marketing Service of the United States Department of Agriculture and represents the midpoint of the high/low range from the Amarillo, Texas

availability at the time the study was conducted. The Granger definition of causality employed in the study requires evidence of improved forecasts. A data period long enough to provide sufficient degrees of freedom, but short enough to ensure that relationships between the data series remained constant, was important. The data period selected satisfied these requirements.

reporting area, for Choice slaughter steers, yield grade 3, 900 to 1100 pounds.

Collection of daily cash slaughter steer prices and cash carcass beef prices was somewhat problematic due to missing quotations.¹³ For the carcass series, the problem was minor. There were a few days, however, when the Yellow Sheet published no quote. Missing data in the carcass beef series were replaced using a simple linear regression model to predict the National Provisioner quotation based on the Meat Sheet quotation for the same day. The model was fitted to the entire data period and replaces missing carcass observations according to:

$$\text{CARCASS} = .970082 + .988548 * \text{MEAT SHEET}.$$

The p-values (level of statistical significance) for the intercept and the MEAT SHEET coefficient were .0768 and .0001, respectively. There was evidence of first-order autocorrelation, indicated by the Durbin-Watson statistic equal to 1.34. The model explained 97 percent of the variability in the National Provisioner carcass quotes.

Cash cattle markets throughout the country are early week markets, i.e., there is little or no trading late in the week. The Amarillo cash market is typically a four-day-a-week market. Quotes for Friday were, therefore, generally unavailable throughout the data period. Occasionally, within-week data were also unavailable. To deal with this missing data problem, a simple linear regression model was

¹³ Due to the early week nature of the cash slaughter steer market, approximately 20 percent of the observations were missing. For the carcass beef series fewer than five percent of the observations were missing.

developed between the Meat Sheet carcass quotations and the Amarillo cash slaughter steer price. The fitted model:

$$\text{CASH STEERS} = 5.517851 + .607148 * \text{MEAT SHEET}$$

explained 78 percent of the variation in the cash slaughter steer price. Both the intercept and the MEAT SHEET coefficient were significant at the .0001 level of significance. There was evidence of first-order autocorrelation, indicated by the Durbin-Watson statistic equal to 0.91. Missing observations in the cash price series were replaced with values predicted by the above model. The approximation of missing quotations in this manner was deemed superior to interpolation or using the quotation from the previous day in spite of the serial correlation problems.¹⁴ There were, however, clearly procedural difficulties in analysis of daily prices from the cash market due to the lack of a consistent data series.

Prior to analysis of the lead/lag relationships between the series, the time series properties of the data were examined. Estimation of the autocorrelation functions and partial autocorrelation functions provided a check for series stationarity. The estimated autocorrelation functions for the raw data series all die out slowly, indicating nonstationary behavior. The estimated partial autocorrelation functions cut off after

¹⁴ The use of the previous days quotation when data were missing was implicitly employed by Purcell, Flood, and Plaxico (1980) and Weaver and Banerjee (1981, 1982a, 1982b). The Omaha cash price series used in these studies was recorded from the Wall Street Journal and repeats the Wednesday quotation for Thursday and Friday when market quotations are unavailable. Thus, the quotes for Wednesday, Thursday, and Friday were the same. When first-differencing procedures were employed, there were two zeros in the five observations for each week and the zeros created analytical problems.

short lags, indicating the series to be autoregressive in nature. The differenced data show estimated autocorrelation functions, which die out quickly, and estimated partial autocorrelation functions, which have no significant lags, indicating the series were stationary.

Estimation of the Geweke equations, presented and explained above, requires the selection of a lag length for the dependent variable which will produce white noise residuals. The final prediction error criterion was employed to identify the appropriate lag lengths for the dependent variable. The FPE criterion indicated lags of order 1 for both the futures price and futures price difference series. The FPE indicated a lag of order 3 for the carcass series and of order 5 for the differenced carcass series. Lags of order 6 and 7 were indicated for the cash slaughter steer and differenced cash slaughter steer series, respectively. The lag length for the independent variable was selected to be of order 10 to allow sufficient time for information transfer between the alternative markets.

Causality regressions were estimated for all combinations of the three series, using the Geweke procedure described earlier, for the period January 1, 1979 through December 31, 1981. The residuals from each of the estimated models were checked prior to computation of F-statistics, to determine if white noise residuals had been generated. The Q-statistic and the Fisher's Kappa statistic were both employed. Finally, the fitted models were used to generate one-step forecasts for the period January 1, 1982 through May 31, 1982. The mean squared forecast errors were computed and compared to the forecast errors of the FPE-implied autoregressive models. This procedure provided a

check to see if the identified causal flows persist beyond the sample period.

Empirical Results

Causality regressions between live cattle futures and cash carcass beef, live cattle futures and cash slaughter steers, and cash carcass beef and cash slaughter steers were estimated using the FPE-implied lag lengths for the dependent variable. The Q-statistic and the Fisher's Kappa statistic indicated the residuals from all equations to be white noise at the .05 level of significance.

The Geweke procedure suggests computation of test statistics from separate equations, i.e., the test for unidirectional causality is computed between the residuals from an autoregressive model and the residuals from a regression on lagged values of the dependent variable and lagged values of the independent variable. The test for contemporaneous causality is computed in a similar manner, employing the residuals of a regression containing lagged dependent and lagged independent variables and the same regression with the contemporaneous value included. Currently available software allows the computation of these same F-statistics from the estimation of a single equation containing lagged dependent variables, the contemporaneous independent variable, and lagged values of the independent variable. Selection between the two methods of statistic computation is a subjective matter, though the fit of the equations must be considered. If the single equation provides a significantly better fit, then the statistics should be computed from that equation. If there is no difference in the two

models, the method of statistical computation should not matter. The statistics for the estimated regressions were computed in both ways.

Table 1 presents the computed F-statistics for the live cattle futures and cash carcass beef regressions for raw and differenced data. The results of the raw and differenced data are similar, regardless of the computational method for the statistics. There is strong evidence

TABLE 1. F-STATISTICS FOR ALTERNATIVE SPECIFICATIONS OF CAUSALITY BETWEEN LIVE CATTLE FUTURES AND CASH CARCASS BEEF, JANUARY 1, 1979 TO DECEMBER 31, 1981.

Test Format ^a		Dependent Variable			
		Live Cattle		Carcass Beef	
		F-statistic	P-value	F-statistic	P-value
<u>Separate Equations:</u>					
Raw data	TEST2 ^b	40.66	.0001	38.62	.0001
	TEST3	0.88	.5328	9.17	.0001
Differences	TEST2	58.92	.0001	53.49	.0001
	TEST3	.78	.6496	11.01	.0001
<u>Single Equations:</u>					
Raw data	TEST2	40.66	.0001	38.62	.0001
	TEST3	4.86	.0001	7.24	.0001
Differences	TEST2	58.92	.0001	53.49	.0001
	TEST3	.65	.7728	11.08	.0001

^a The separate equations tests were computed between an equation containing only lagged values of the independent variable and an equation containing lagged and contemporaneous values. The single equation tests were computed from an equation containing both lagged and contemporaneous values of the independent variable. TEST3 is the same in either case.

^b TEST2 is a test for instantaneous causality and TEST3 is a test for unidirectional causality from the independent variable to the dependent variable.

of instantaneous causality between live cattle futures and cash carcass beef prices. The separate equation approach indicates unidirectional causality from live cattle futures to cash carcass beef for raw and differenced data. The single equation tests also identify strong unidirectional causality from futures to carcass. The single equation procedure also indicates a feedback relationship in the raw data since there is evidence (F-statistic of 4.86) of unidirectional causality from carcass to futures. If attention is restricted to the differenced data, the flow from carcass to futures disappears.

The results of the causality tests between live cattle futures and cash slaughter steers are presented in Table 2. Instantaneous causality is indicated between the two series in all cases. Strong unidirectional flows exist from live cattle futures to cash slaughter cattle. Unidirectional flows also exist, however, from cash slaughter steer prices to live cattle futures prices, although they are less strong (in a statistical context) than the cash to futures flows. These results indicate a feedback relationship between the two series. The two markets are both integrally involved in the price discovery process, interact with each other, and supplement each other, as evidenced by the feedback relationships. There is slight evidence (based on comparison of significance levels) the futures market is more efficient and incorporates the impact of new information more quickly than the cash market.

Table 3 presents the results of the Geweke causality tests between cash carcass beef and cash slaughter steers. Statistically significant instantaneous causal flows are indicated in all cases. Unidirectional flows are present from carcass to cash cattle and from cash cattle to

TABLE 2. F-STATISTICS FOR ALTERNATIVE SPECIFICATIONS OF CAUSALITY, LIVE CATTLE FUTURES AND CASH SLAUGHTER STEER PRICES, JANUARY 1, 1979 TO DECEMBER 31, 1981.

Test Format ^a		Dependent Variable			
		Live Cattle		Slaughter Steers	
		F-statistic	P-value	F-statistic	P-value
<u>Separate Equations:</u>					
Raw data	TEST2 ^b	60.25	.0001	57.50	.0001
	TEST3	2.55	.0135	12.51	.0001
Differences	TEST2	71.73	.0001	76.54	.0001
	TEST3	2.02	.0287	14.72	.0001
<u>Single Equations:</u>					
Raw data	TEST2	60.25	.0001	57.50	.0001
	TEST3	7.88	.0001	7.69	.0001
Differences	TEST2	71.73	.0001	76.54	.0001
	TEST3	3.64	.0001	16.76	.0001

^a The separate equations tests were computed between an equation containing only lagged values of the independent variable and an equation containing lagged and contemporaneous values. The single equation tests were computed from an equation containing both lagged and contemporaneous values of the independent variable. TEST3 is the same in either case.

^b TEST2 is a test for instantaneous causality and TEST3 is a test for unidirectional causality from the independent variable to the dependent variable.

TABLE 3. F-STATISTICS FOR ALTERNATIVE SPECIFICATIONS OF CAUSALITY, CASH CARCASS BEEF AND CASH SLAUGHTER STEERS, JANUARY 1, 1979 TO DECEMBER 31, 1982.

Test Format ^a		Dependent Variable			
		Carcass	Beef	Slaughter Steers	
		F-statistic	P-value	F-statistic	P-value
<u>Separate Equations:</u>					
Raw data	TEST2 ^b	134.81	.0001	142.14	.0001
	TEST3	6.74	.0001	3.31	.0003
Differences	TEST2	131.25	.0001	131.91	.0001
	TEST3	6.62	.0001	2.91	.0001
<u>Single Equations:</u>					
Raw data	TEST2	134.81	.0001	142.14	.0001
	TEST3	12.06	.0001	11.93	.0001
Differences	TEST2	131.25	.0001	131.91	.0001
	TEST3	8.66	.0001	4.86	.0001

^a The separate equations tests were computed between an equation containing only lagged values of the independent variable and an equation containing lagged and contemporaneous values. The single equation tests were computed from an equation containing both lagged and contemporaneous values of the independent variable. TEST3 is the same in either case.

^b TEST2 is a test for instantaneous causality and TEST3 is a test for unidirectional causality from the independent variable to the dependent variable.

carcass, with the latter being a bit stronger, particularly with the separate equation tests. For all practical purposes, these two markets are the "same" market and react to new information with similar levels of efficiency.

The results of the Geweke causality tests between live cattle futures, cash carcass beef, and cash slaughter steers are summarized in Table 4 for the separate equation tests. The results from the single equation test differ only in the identification of a unidirectional flow from carcass to futures for the raw data series. An asterisk in the table indicates the presence of the relationship and a dash indicates that the relationship is not present. All results are summarized for the .05 level of significance.¹⁵

The causal flows identified in Table 4 indicate the importance of the live cattle futures market in the day-to-day price discovery process. The instantaneous relationships between the three series suggest a high degree of efficiency in assembling and analyzing information in all the markets for cattle and beef. The strength of the unidirectional flows from futures to carcass and from futures to cash steers indicates that the futures market performs an important price discovery function because information is registered in the futures market and then reflected, with some time lag, to the carcass and cash markets. However, the interaction between the cash live cattle market and the futures market, (i.e., the unidirectional flow from cash steer to futures prices), indicates the futures market does receive "signals"

¹⁵ To verify the relationships in Table 4, the modified Sims test was estimated. The procedure indicated identical results, which are not presented here due to the inability to conduct post-sample tests with the procedure.

TABLE 4. SUMMARY OF IDENTIFIED CAUSAL FLOWS, GEWEKE PROCEDURE, LIVE CATTLE FUTURES, CASH CARCASS BEEF, AND CASH SLAUGHTER STEERS, JANUARY 1, 1979 TO DECEMBER 31, 1981, .05 LEVEL OF SIGNIFICANCE.

Model Specification ^a	Direction of Causal Flow ^b		
	F → C	C → F	F ↔ C
Live Cattle Futures vs Cash Carcass Beef:			
Raw data	*	-	*
Differenced Data	*	-	*
Live Cattle Futures vs Cash Slaughter Steers:			
Raw data	*	*	*
Differenced Data	*	*	*
Cash Carcass Beef vs Cash Slaughter Steers:			
Raw data	*	*	*
Differenced Data	*	*	*

^a The results summarized in the table are for the separate equation tests reported in Tables 1, 2, and 3.

^b C = cash market, F = futures market, and the arrow indicates the direction of causal flow.

^c CB = cash carcass beef, CS = cash slaughter steers, and the arrow indicates the direction of causal flow.

or information from the cash market. This evidence of interaction suggests the futures market does not dominate the price discovery process for live cattle. Prices are not "discovered" in the futures market with no attention paid to what is happening in the cash market. Activities in the cash market do exert an important influence in price discovery. This result contrasts with the futures and carcass beef interaction where the futures market is the dominant market and there is statistical evidence of influence from carcass to futures only for the raw data series. The statistical significance (p -values of .0001 in most cases) of the instantaneous and feedback relationships between carcass and cash steers suggests informational flows between these markets which are relatively efficient.

Post-Sample Evaluation: To examine the identified causal relationships beyond the sample period for which they were identified, one-step ahead post-sample forecasts were computed using the estimated causal models. If the causal flows identified during the sample period hold up in the out-of-sample period, the mean squared forecast error will be smaller for models which include the identified causal flows than for simple autoregressive models. Post-sample testing is, therefore, a direct measure for evaluation of the Granger definition that X_t causes Y_t if you can better predict X_{t+1} using Y_{t-j} , $j = 0, 1, 2, \dots$, than by using only X_{t-j} .

The mean squared forecast errors for alternative causal models between live cattle futures, cash carcass beef, and cash slaughter steers are presented in Table 5. Model 1 in the table refers to the autoregressive model suggested by the final prediction error criterion.

TABLE 5. MEAN SQUARED FORECAST ERROR FOR CAUSAL MODELS, LIVE CATTLE FUTURES, CASH CARCASS BEEF, AND CASH SLAUGHTER STEERS, JANUARY 1, 1982 TO MAY 31, 1982.

Model Specification ^a	Model 1 ^b	Model 2	Model 3
Live Cattle Futures vs Carcass Beef:			
Raw Futures	0.4464	0.4802	0.3868
Differenced Futures	0.4649	0.4819	0.3992
Raw Carcass	1.2224	1.3155	1.1143
Differenced Carcass	1.1365	1.1251	0.9392
Live Cattle Futures vs Cash Slaughter Steers:			
Raw Futures	0.4464	0.4791	0.6182
Differenced Futures	0.4649	0.5021	0.6452
Raw Cash	1.1965	1.1514	1.1462
Differenced Cash	1.2099	1.1451	1.1662
Carcass Beef vs Cash Slaughter Steers:			
Raw Carcass	1.2224	1.4918	1.5873
Differenced Carcass	1.1365	1.3503	1.5023
Raw Cash	1.1965	1.1627	1.0904
Differenced Cash	1.2099	1.2217	1.1346

^a The model specifications between live cattle futures prices, cash carcass beef prices, and cash slaughter steer prices are referred to by the dependent variable in the equations used to compute the mean squared forecast errors.

^b Model 1 is a simple autoregressive model suggested by the final prediction error criterion. Model 2 is the autoregressive model with lagged values of the independent variable. Model 3 adds the contemporaneous value of the independent variable to Model 2.

Model 2 contains the lagged dependent variables from Model 1 plus lagged independent variables. The third model, Model 3, is the same as Model 2, but includes the contemporaneous value of the independent variable. The mean squared forecast errors (MSE) for Model 3 confirm the strength of the instantaneous relationship between live cattle futures and cash carcass beef. There is a reduction in MSE for all versions of the model. The size of the MSE for Model 2 in the futures-dependent variable cases confirms the lack of a strong unidirectional relationship from carcass to futures. For the raw series, the MSE is larger (0.4802 vs. 0.4464). The reduction in MSE for the carcass-dependent, differenced series indicates that the unidirectional flow from futures to carcass holds up beyond the sample period.¹⁶

For the live cattle futures and cash slaughter steers case, the instantaneous flows hold outside the original sample only for the cash dependent equations. For the cash slaughter steer-dependent equations, the two flows fail to hold for the differenced series, though both hold for the raw data cash-dependent equations. These results tend to confirm the unidirectional flow from futures to cash steers, but dampen any conclusions about the importance of flows from cash cattle to futures.

The cash carcass beef and cash slaughter steer equations indicate similar results. The instantaneous and unidirectional flows fail to hold for the carcass dependent equations. These results tend to confirm that the carcass market is not an important seat of price discovery.

¹⁶ The comparison of mean squared errors is based solely on magnitude. If Model 2 or Model 3 features a smaller mean squared error than Model 1 during the post sample period, then the identified causal relationship is supported. This procedure is a direct analogue to the Granger definition of improved forecasts.

Further Investigation: The results presented above regarding lead/lag relationships between live cattle futures, cash carcass beef and cash slaughter steers raised concern with regard to their seeming contradiction of theoretical norms. From the theory of derived demand, it would be expected that prices would be discovered in the carcass beef market and reflected in the futures and slaughter cattle markets. Although consistent with the conceptual arguments made earlier, the results in Table 4 do not support the derived demand notion. Moreover, there was some concern over the "lack of circularity" in the results. The identification of a causal flow from carcass beef to slaughter steers and from slaughter steers to futures seemed to suggest a flow from carcass beef to futures. Since the replacement procedure for missing cash quotes involved the use of a carcass series, further analysis was deemed necessary to verify the identified flows.

The lead/lag relationships between live cattle futures, cash slaughter steers, and cash carcass beef were further examined using a truncated data series which included only prices for Monday, Tuesday, and Wednesday. By truncating the data series in this manner, the problems of missing observations were virtually eliminated. The Geweke procedure was then employed to estimate causality tests for raw with one and two day lags and for differenced data with one day lags (since one observation is lost in the differencing process). The results from these truncated series are identical to those summarized in Table 4. Live cattle futures are instantaneously related to cash carcass beef and there is evidence of unidirectional causality from futures to carcass. The test for unidirectional causality from carcass beef to live cattle futures is not significant at the .05 level. For the one-day lag, tests

using differenced data did suggest a stronger flow from carcass to futures than in the results summarized in Table 4. The implication of this stronger flow may be that the interaction between the two markets is stronger early in the week, and that later in the week, the carcass market relies more heavily upon the futures market to gather and register information.

The identification of instantaneous causality between live cattle futures and cash carcass beef suggested that the two markets interact within the day. In an effort to further describe the within-day interaction between the futures and carcass beef markets, an intraday data series was gathered from October 1, 1983, through January 31, 1984. Live cattle futures prices were recorded at 11:30 a.m. and 12:30 CST p.m. and matched with carcass beef quotes from the National Provisioner's midday and closing wire, released at 12 noon and 4 p.m., respectively. Investigation of lead/lag relationships between these quotes provided further support for the flows from futures to carcass beef at the .05 level of significance. There were no significant unidirectional flows from carcass to futures in the intraday data series.

Implications

The causal flows identified by the Geweke procedure between live cattle futures and cash carcass beef, live cattle futures and cash slaughter steers, and cash slaughter steers and cash carcass beef clarify the price discovery processes in the markets for cattle and beef. It is clear that the live cattle futures contract is important in the day-to-day price discovery process for cash carcass and slaughter steer prices. The markets move together and interact within the day, but

the futures market tends to register information more quickly, especially when compared to the carcass market. The results support the following conclusions:

1. Any arguments that the live cattle futures market dominates the market are incorrect. Live cattle futures are important to the price discovery process for cash cattle and carcass beef. Information is sometimes registered first by the futures market and subsequently reflected in the cash markets, especially the carcass market. But there is also significant statistical evidence of interaction between the cash and futures markets during the day, thus suggesting prompt registration of supply and/or demand information in and across the alternative markets. Live cattle futures markets do not dominate but interact with cash slaughter cattle markets. Live cattle futures markets do not dominate but clearly do strongly influence the carcass beef markets.
2. Concerns over the structure of the industry and the related pricing dimensions, such as formula pricing, the Yellow Sheet, and excessive pricing power, may be overstated in terms of their importance and impact in the process of price discovery. The analysis suggests that price is not discovered in the "thin" carcass market, but that information flows between the markets which interact in price discovery. Of the three market sectors analyzed, the carcass beef market appears to be the least important in terms of contribution to price discovery processes.
3. Prices in the cash slaughter steer markets respond to and contribute to changes in futures prices, indicating that the cash markets both rely on futures prices to reflect the broad supply and/or demand conditions and contribute significantly to that process. This interaction suggests an important role for futures prices in producer decision making, both with regard to production and marketing decisions.
4. There is a high degree of interaction between the cash slaughter steer markets and the cash carcass beef market. The markets tend to move together within the day and information feedback occurs over longer time intervals. Price in the carcass markets, therefore, reflects cash live cattle prices and vice versa.
5. Regulatory efforts intended to influence the process of price discovery in the markets for cattle and beef must consider the role and importance of the live cattle futures market. Response to concerns over the impact of Yellow Sheet pricing must be addressed in light of the findings that the live

cattle futures prices are reflected with a time lag of one day or more in carcass prices. The interaction between the carcass market and the cash slaughter steer market must also be considered. In short, regulatory efforts which focus on the carcass market, while they may be successful in addressing the market structure issues, will not necessarily lead to improved efficiency of price discovery. Policy prescriptions and regulatory efforts should focus on the system within which price is discovered and the role each market plays in that system.

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- 2 — Steeles Tavern
Shenandoah Valley Research Station
Beef, Sheep, Fruit, Forages, Insects
- 3 — Orange
Piedmont Research Station
Small Grains, Corn, Alfalfa, Crops
- 4 — Winchester
Winchester Fruit Research Laboratory
Fruit, Insect Control
- 5 — Middleburg
Virginia Forage Research Station
Forages, Beef
- 6 — Warsaw
Eastern Virginia Research Station
Field Crops
- 7 — Suffolk
Tidewater Research and Continuing Education Center
Peanuts, Swine, Soybeans, Corn, Small Grains
- 8 — Blackstone
Southern Piedmont Research and Continuing Education Center
Tobacco, Horticulture Crops, Turfgrass, Small Grains, Forages
- 9 — Critz
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