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A PRICE DISCOVERY PROCESS IN THE HOG-PORK COMPLEX

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I. Introduction

The study of price discovery among farm level, wholesale and futures prices of a livestock commodity is of importance to producers, wholesalers, packers, and retailers since the pork belly contract in 1961 and the live hog contract in 1966 had been introduced by the Chicago Mercantile Exchange(CME). Livestock futures trading has been the subject of continual debate as to whether or not futures trading can play a role in price stability with quality differences. Such a study provides information on pricing efficiency to each economic agent engaged in the livestock.

The major part of this study includes examining the price discovery process among the live hog and pork belly futures prices, cash slaughter hog prices, and wholesale pork prices for loins, hams, and bellies. There is little research to describe and document the role of both live hog and pork belly futures, and wholesale pork trading in the pricing of cash slaughter hogs. Due to a special relation between hog and pork, a price discovery process generated from hog and its futures prices or pork and its futures prices may respond to a limited information. Because all price series generated in different markets are based on similar characteristics of the commodities, a price discovery for hogs must take into account prices in all three separate markets. That is, considering more relevant information on a price discovery process will bring better pricing efficiency, in the sense of

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Fama(1970)'s efficient prices.'

In general, price discovery has the same function as price determination in terms of pricing efficiency because both use relevant information to achieve the prices which equalize supply and demand for the commodity. However, the former deals with a process to achieve at any satisfactory price for both buyers and sellers, whereas the latter refers to the whole range of relevant market structures and economic factors. According to Hudson(1984), price discovering is concerned with the relative efficiency of the process in cash, wholesale, and futures markets in arriving at the market clearing price using relevant information. But price discovery does not focus on the clearing condition as does price determination. Therefore, price discovery can be defined as a process of finding relevant information in order to reach the true price which possibly exists under market clearing conditions.

Information is costly. One concern, then, is which markets have the lowest cost for gathering new supply and demand information? Markets which have the lowest cost for gathering new market information will be price discovery leaders. Newly discovered prices then become public goods because prices are publicly reported and are reflected in other markets. Hence, other markets become price discovery followers. Sometimes, different markets gather different information efficiently, which implies feedback.

Most previous price discovery studies conclude that there is strong evidence of existing relationship between futures and spot prices of a commodity. Due to limited information, however, a number of problems are presented. Among cash, wholesale and futures markets, which contributes most to price discovery of slaughter hogs? Which market plays the most important role in pricing each wholesale product? Or, is it possible to observe feedback relationships among them? For the above questions, has price discovery changed over time? In sum, are futures market prices centers of pricing in cash and wholesale markets, as is generally expected? Similarly, are futures market prices more efficient than cash hog market prices or wholesale pork prices?

The overall objective is to analyze the price discovery process and determine which markets provide more information to each marketing agent in cash hog and/or pork markets.

Tracing the price discovery process is accomplished by utilizing cointegrating theory for each bivariate system. Results from error correction models (ECMs) are sources of interpreting the Granger- or the Hicks-type causality. Moreover, those results are compared and confirmed by results from the out-of-sample tests.

II. Concept of Causality

Some portion of economic benefits to be realized in the future may already have been determined by plans of the individual decision-making units who consider factors concerned with the future and the present as well as the past. The relations between each time period could be explained by the concept of causality.

Causality can be defined conceptually and operationally. Granger(1969) defined it for an operational purpose to be applied in economics. Subsequently, Sims(1972) demonstrated a two-sided distributed lag method, whereas Sargent(1976) formalized a one-sided distributed lag approach implied by Granger. In 1979, Hicks defined it as the relationship between cause and effect, which is thought to be the business of philosophers.

According to Granger, relations between variables of the past, the present and the future are defined by causality, feedback, instantaneous causality and causality lag, assuming that those variables must result from stochastic processes but not deterministic processes; the variables are stationary; and the futures cannot predict the past (for more information, see Granger(1969)). The use of Granger causality in analyzing the price discovery process can indicate the presence of lead and lag relationships, feedback, or no relationships between any two economic time series.

Even though Granger's definition of causality is doubted by philosophers, it is operational and practical in an economic time series context. Whether the Granger-type causality tests are truly causal in nature can be shed light on by the Hicks' definitions of causality. Hicks defined it as weak and strong causation. Weak causation is again divided into separable causation, including additive, sole, negative, ultimate and overlapping ones, and sequential causation. If an event (say X) is one of the causes of another event (say Y), the relation is defined as weak causation. Strong causation in that case implies that an event X is the sole cause of another event Y.

Separable causation assumes that there are several events, e.g., X_1 and X_2, where $X \in (X_1, X_2)$: An additional cause means that the effect Y will not appear unless both causes X_1 and X_2 are present; sole cause implies that either X_1 and X_2 causes Y. But in case X_1 causes Y solely, X_2 must be assumed not to be present, and vice versa; overlapping cause is when Y occurs if either X_1 or X_2 is present; and assumed that there exists another effect X_3 to explain negative and ultimate cause. Assume a case where the effect Y would have happened if neither X_1 nor X_2 was present but X_3 was present, and also happened when X_1, X_2 and X_3 were all present. If X_1 alone was not present, Y would not have happened. Then X_2 is called a negative cause; If X_2 acted alone, it would offset the effect of X_3. In this case, X_3 is called an ultimate cause.

Hicks' explanation of the theory of separable causation is led by Hume's philosophy that cause precedes effect. He explains non-separable cause based on Kant's critique of Hume's principle that an event X precedes another event Y, and, also, event Y precedes event X. This kind of causal relation is usually called contemporaneous cause like Keynes' explanation of the relation between the money supply and interest rate.

Another important explanation of causality by Hicks is sequential causality which refers to the relationship between lags and reserves. It is sometimes called a causal chain. Sequential causality implies that X was a cause of X_1, X_1 was a cause of X_2, X_2 of X_3, and so on, and finally that X_n was a cause of Y.

Economics is concerned with decisions, and decision-makers sometimes must decide something in the intermediate stage of such a causality chain. Price discovery may be closely related to sequential causality. The price discovery study might pose an intermediate stage of variously changeable economic circumstances, excluding that there are various other situations. Therefore, even though the relations between each price series of hog and pork complex is distinguished based on the Granger's causality concept, because the Granger causality provides a convenient technique which can be used to analyze the lead or lag relationships between two price series, interpreting the relations could follow the Hicks' theory of causality for more excisable explanation.

III. Previous Studies and Models

There is little research to describe the role of live hog futures or pork belly futures trading in the pricing of cash slaughter hogs and wholesale loins, hams, and bellies. Previous live stock futures research on risk transfer and price discovery used six models; cross-spectral analysis, univariate residual cross-correlation approach, simultaneously dynamic analysis, vector autoregressive representation (VAR), out-of-sample performance, and test for cointegration between price series.

Rausser and Cargill(1970) used spectral analysis to determine whether any signified lead-lag relationships exist along the time series data which normally are employed to illustrate cycles in broiler. Barksdale, Hilliard and Ahlund(1975) studied beef prices at different market levels. They reported the lead-lag relations among beef prices at levels of feeder, live cattle, wholesale and retail markets. Miller(1980) applied univariate residual crosscorrelation analysis to pork prices at the retail, wholesale and farm levels. He found that, in the pork markets, farm level prices lead wholesale prices by up to 2-3 weeks and wholesale prices lead retail prices by 2-3 weeks. Garbade and Silber(1983) specified and estimated a simultaneous dynamic model which describes the interrelationship between cash and futures prices for storable commodities. Oellerman and Farris(1985) investigated the lead-lag relationship between changes in futures and cash prices for live cattle using dynamic analysis. Price discovery analyses using VAR are varied. Bessler and Brandt(1982) and Hudson(1984) used Geweke's causality test to search for lead-lag relationships in the various live stock prices. Bessler and Brandt`s research has a specific feature that confirms causal relationships using out-of-sample forecasting method.

Spectral methods do not require specification of the model. The estimation procedure is independent of the form of the model (i.e., a non-parametric procedure). However, it brings unfamiliar concepts and presents difficulties in interpretation. The application of univariate residual cross-correlation analysis in assessing economic lead-lag relationships between price series is not complicated but parametric. However, it gives some disadvantages: If time-ordered data series do not have reasonable parameters, this approach is implausible; and since residuals generated from each ARIMA type model of series are pre-verified to be white noise series, individually estimated cross-correlations can be misleading(Pierce 1977). A complete dynamic simultaneous equation model requires adequately generating economic time series, and it cannot be modeled with a single equation. In the analysis of price discovery using vector autoregressive representations, data differencing could result in a loss of information, which is included in the original data series being studied.

Another popular method is tests for cointegration among price series in order to identify the relationship of futures market to the cash market. Bessler and Covey(1991) used cointegration as well as out-of-sample tests. Schroeder and Goodwin(1991) analyzed the price discovery role of live hog futures prices in cash market prices using the concept of cointegration. The authors found that causality exists from the futures to the cash market, that the two futures price series operate independently, and that the long-term basis is nonstationary. The out-of-sample test suggested by Ashley, Granger, and Schmalensee(AGS, 1980) used univariate cross-correlation at first, and its defects have been pointed out.

This study utilizes test for cointegration suggested by Engle and Granger(1987) as well as the out-of-sample tests developed by Bessler and Kling (BK,1984).

A VAR analysis with data differences will be misspecified if the variables are cointegrated. Most earlier time-series approaches ignore the fact that it is possible to generate a model misspecification by neglecting some missing information due to differencing. However, cointegration provides some evidence to include the missing information by recognizing that two variables are of the same order (p) of cointegration, and that a linear relation of two variables is cointegrated of order p-1.

Consider that there are two variables X and Y. A series is said to be $I(0)$ if it is stationary, where 'I' implies integration, and '0' in parenthesis indicates the number of order differenced to obtain a stationary series. Before differencing the data series being considered, each series is checked of its stationarity. Then for nonstationary data series, the lag length is determined using Schwarz's Bayesian Information Criterion(SBC) and/or the Akaike Information Criterion (AIC). After the lag length is determined, a unit root test by the Dickey-Fuller and/or the augmented Dickey-Fuller(ADF) test methods is accomplished. If a series has a unit root, it can be first-order differenced.

If two series are both $I(1)$, frequently called 'vector-integrated', then any linear combination of $X + AY$, where 'A' is a coefficient, will also be $I(1)$ in general. However, if the linear relationship represents $I(0)$, both X and Y are said to be cointegrated. For two series defined by the cointegrated relationship, an error correction process is generated so as to set up an error correction model(ECM). A cointegration regression model will be built as :

$$X_t = \mathrm{a} + \mathrm{b}Y_t + u_t \qquad (1)$$

Residual estimated from the cointegrating regression, say $\hat{u}_t$, reintroduced and applied for processes from checking stationarity to a unit root test so that it can provide a corrected error to ECM.

First-differencing data series results in the loss of information with regard to the long-run relationship between pairs or series. First-order differencing potentially has long run variability. However, if two series are cointegrated, the pairs of series will be adjusted to an equilibrium constraint. The long-run trends of series are integrated as an equilibrium state. If a portion of the disequilibrium moves away from such equilibrium, that is, the characteristic of short run dynamics of each series exists, it may be adjusted by the corrected error.

Using the corrected error, the ECMs are built to test causal relationship between two series such as :

$$\Delta X_t = \alpha_0 + \alpha_1\hat{u}_{t-1} + \sum_{i=1}^{p} \beta_i \Delta X_{t-i} + \sum_{j=1}^{q} \gamma_j \Delta Y_{t-j} + \varepsilon_t, \text{ and} \qquad (2)$$

$$\Delta Y_t = \phi_0 + \phi_1\hat{u}_{t-1} + \sum_{k=1}^{p} \varphi_k \Delta X_{t-k} + \sum_{m=1}^{q} \delta_m \Delta Y_{t-m} + \eta_t \qquad (3)$$

Equation (2) shows that the one period lagged correction error is an independent vector variable in the restricted VAR representation. In both ECMs, (2) and (3), 'Δ' implies the change of variables, ε_t and η_t are jointly white noise residuals, respectively, and at least one of α_1 and ϕ_1 is non-zero.

The null hypotheses for causality test are (i) $\alpha_1 = 0$ and $\gamma_j = 0$, for all j, in equation (2), which means Y does not Granger-cause X, and (ii) $\phi_1 = 0$, and $\delta_m = 0$, for all m, meaning that X does not Granger-cause Y.

The out-of-sample test expanded by BK supplements some drawbacks of one suggested by AGS. It uses the augmented unrestricted VAR representation modeled by expressions (2) and (3) except that there is no corrected error term instead of univariate residual cross-correlation.

BK's out-of-sample tests begin with dividing the appropriately differenced data series into two categories; within- and post-samples. It utilizes vector autoregressive properties of the series. AGS generates a problem that results from within-sample tests with differenced data which have different properties from those derived from undifferenced out-of-sample data. Undifferenced data cannot be compared with the same property of causality which within-sample data has.

Then, nonstationary within-sample series are differenced and modeled as autoregressive representation(AR):

$$X_t = \alpha + \sum_{i=1}^{p} \beta_i X_{t-i} + \upsilon_t \tag{4}$$

Using both within-sample series, a bivariate model based on the number of lags for each variable is set up such as follows:

$$X_t = \gamma + \sum_{i=1}^{p} \eta_i X_{t-i} + \sum_{j=1}^{q} \phi_j Y_{t-j} + u_t \tag{5}$$

Both (4) and (5) are estimated by ordinary least square regression, and mean square error(MSE) for each equation are solved by MSE(X)and MSE(X, Y), respectively.

Comparisons between MSE(X) and MSE(X, Y) evaluated from within-sample data will provide *the a priori belief* that either X or Y causes either Y or X series. A priori belief can also be estimated by comparing F-statistics calculated from (4) and (5). This is simply the general procedure of the VAR tests with within-sample data. Then the procedure where all coefficient parameters are estimated from (4) and (5) should apply to the remaining post-sample observations to produce a linear combination of the coefficients and the differenced out-of-sample data with the same order as the differenced within-sample data.

Assume that the estimated parameters from (4) and (5) are denoted by $\hat{\alpha}$, $\hat{\beta}_i$, $\hat{\gamma}$, $\hat{\eta}_i$ and $\hat{\phi}_j$, and out-of-sample series are represented by $\overline{X}$ and $\overline{Y}$ Combined linear regression models are as below:

$$\overline{X}_t = \hat{\alpha} + \sum_{i=1}^{p} \hat{\beta}_i X_{t-i}, \text{ and} \tag{6}$$

$$\overline{X}_t = \hat{\gamma} + \sum_{i=1}^{p} \hat{\eta}_i \overline{X}_{t-i} + \sum_{j=1}^{q} \hat{\phi}_j Y_{t-j} \tag{7}$$

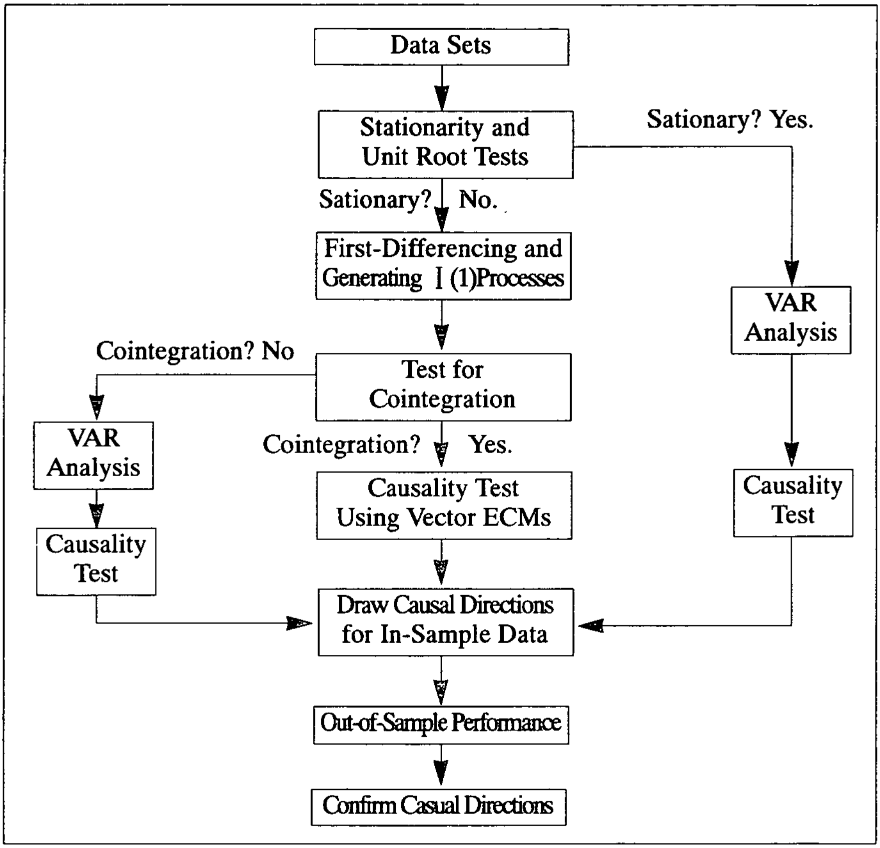
From (6) and (7), out-of-sample mean-squared errors, MSE $(\overline{X})$ and MSE $(\overline{X}, \overline{Y})$ can be estimated. If the estimated MSE $(\overline{X}, \overline{Y})$ is smaller than the estimated MSE $(\overline{X})$, then it can be said that there exists a causal relationship which runs from the Y to X series. If a priori belief about causal relationship between two series obtained from within-sample are the same as the results from out-of-sample tests, evidence about the causal relationships is provided. Otherwise, causal relationships provided by within-sample are to be suspected.

IV. Procedures and the Data

The general procedure for applying tests of cointegration, ECMs and out-of-sample tests to causality tests is shown in Figure 1.

First, all data sets will be collected and futures price series will be generated as a continuous-type data series. Checking stationarity is a next important step. If series are stationary before differencing, the VAR tests are performed. Otherwise, tests for cointegration is

FIGURE 1 Procedure for Causality Tests



achieved after appropriately differencing the data series. If the series cointegrate with each other, causal relationships between bivariate series are tested using vector ECMs. Otherwise, VAR tests will also be accomplished. Then, causal directions *of the a priori beliefs* are summarized.

The out-of-sample tests are performed after getting a priori belief because these tests will confirm the causal relationship. Finally, all relationships between two series are summarized.

All the variables used in this study are daily series collected from 1987 to 1991 which in general have more information on changes and trends about the original series than weekly, monthly, or quarterly series.

The daily spot price series for live hogs and for wholesale pork (loins, hams, and bellies) used in this study are collected by U.S.D.A. The daily price series for live hogs are for hogs categorized as U.S.D.A. grade 1-2 and weighing 210-240 pounds in Iowa and Southern Minnesota. Wholesale pork prices are collected in Omaha. The weight of fresh wholesale pork products are 14-18 pounds for loins, 20-26 pounds for hams, and 14-16 pounds for bellies, respectively. The daily closing futures price series for pork belly and live hog futures prices are collected from the CME.

In this research, continuous futures prices for both series are constructed in order to avoid the jumps and falls which occur when maturity months are changed. The procedures to smoothen the series follow Djunaidi et al.(1992): (i) All price series for each contract are first-order differenced. $\Delta FUT_{t,h} = FUT_{t,h} - FUT_{t-1,h}$, where *t* is data and h is contract; (ii) ΔFUT to a new contract month is switched on the last day of the month prior to contract maturity. Since the procedure (ii) generates a continuous series of first-order differenced nearby futures contract, it can be used to construct a continuous futures price series. Let's assume that the first observation of each futures price series is its actual futures price. (iii) Then, the modified continuous futures price series(MFUT) at period *t* are created as $MFUT_t = MFUT_{t-1} + \Delta FUT_t$. The overall data period used is January 5, 1987 to December 27, 1991. The number of observations in each series is 1272. A few missing values, which were found by 15 out of 1272 on the average in each series, are replaced by the price of the previous day.

Continuous futures prices for both pork bellies and live hogs for each year are yearly segments from the entire continuous data series.

V. Empirical Results

1. Results For 1987-1991

There are eleven combinations or pairs of series which will be modeled as single linear regression models. The tests for cointegration is a procedure for relationships between two variables. For the price series which are cointegrated, it is stated that these markets are operating efficiently. Cointegration between two prices is a necessary condition for market efficiency. Based on cointegrating relationship between two series, one price series (dependent variable in cointegrating regression) can consistently predict the other price series (independent variable). All pairs, except for live hogs(LH) vs. pork belly futures(FPB), live hogs vs. live hog futures(FLH), and wholesale pork bellies(WB) vs. either of the futures market prices, are cointegrated. Thus, for the series which are not cointegrated, it can be said that at least one market is not efficiently operating. In other words, information about a certain price series cannot be used in predicting the other price series.

An ECM for two cointegrated variables was applied to examine the price discovery process. An error correction model is used to eliminate or correct the equilibrium error. If some pairs of series are not to be cointegrated but have the properties of a vector autoregressive process, then they are analyzed with an equation for the augmented unrestricted VAR.

Overall results of the ECM and VAR analysis are given in Table 1.

One can infer the following from the results. First, pork belly prices cause live slaughter hog prices, and only wholesale belly prices of the wholesale meat prices and the two futures contract prices provide information for predicting cash hog prices. There is no domination between wholesale loin prices and live hog prices because of their feedback relationship. Second, the prediction of ham prices in wholesale pork markets can be enhanced by either pork belly or live hog futures market prices. However, wholesale loin prices and either of the futures contract prices cause each other. Third, it is concluded that the changes in wholesale ham prices are well explained by the corrected error from the cointegrating regression model, the changes in the lagged pork belly futures prices or live hog futures prices, and the changes in the lagged wholesale ham prices. Fourth, the results show that changes in the lagged live hog futures prices do not effectively and consistently influence changes in the live hog prices in one direction. Similarly, wholesale pork belly prices are not influenced by pork belly futures prices. In other words, futures market prices for live hog or wholesale pork bellies are, respectively, not the

TABLE 1 Causal Relationships

Model	X_t	T_t	F_1	F_2	Causal Direction
ECM	WL	FPB	5.38(0.005) [2,1234]	1.91(0.012) [18,1234]	WL↔FPB
ECM	WL	FLH	11.58(0.0001) [2,1234]	1.68(0.037) [18,1234]	WL↔FPB
ECM	WH	FPB	6.12(0.002) [2,1242]	1.38(0.155) [14,1242]	FPB↔WH
ECM	WH	ELH	15.5(0.001) [18,1230]	1.34(0.179) [14,1242]	FLH↔WH
ECM	LH	WL	3.48(0.0001) [18,1230]	8.4(0.0001) [6,1230]	LH↔WL
ECM	LH	WB	5.08(0.0001) [5,1255]	2.11(0.049) [6,1266]	LH↔WB
VAR	LH	FPB	90.83(0.001)	0.81(0.543)	LH↔FPB
VAR	LH	FLH	315.45(0.0001)	5.23(0.001)	LH↔FLH
VAR	WB	FPB	19.07(0.001)	0.96(0.427)	WB↔FPB
VAR	WB	FLH	81.80(0.0001)	2.93(0.02)	WB↔FLH
VAR	LH	WH	5.23(0.0001)	5.6(0.0002)	LH↔WH

Note that values in parenthesis indicate the p-value, and ones in [ ] mean the degree of freedom.

center of price discovery for them.

Fifth, the role of futures markets in providing price information to wholesale pork belly prices seemingly exists. Price changes in pork belly futures lead price changes in the live hog cash market, not the reverse. The price discovery function of the live hog futures market to cash hog markets is not clear, but feedback exists. Finally, pork belly futures market prices strongly lead pricing in wholesale pork belly prices. There is no dominant market in pricing between the wholesale belly market and the hog futures market. Their relationship is bidirectional. Also, a strong feedback relationship exists between cash hog and wholesale ham prices.

In sum, causal directions may not agree with the common view that live hog futures market prices are expected to lead cash hog market prices. However, for pork belly prices, futures market prices strongly cause wholesale pork belly prices.

2. Year by Year Trend in Causality

A general view about causal directions can be checked with determining whether such relationships have changed over time. Observing the existence of a general trend in hog and pork market pricing, ECMs and/or VAR were again used. All yearly data series were proven to be integrated of order one after their original series had not been found to be stationary. Similarly, for pairs of series which are cointegrated, causality tests were conducted on the error correction models. Otherwise, the augmented unrestricted VAR test was conducted.

Results of causal direction are reported in Table 2, which shows the tendency toward causal relationships over time. First, both live hog and wholesale loins or hams are bidirectionally causing each other in general except for the 1991 series. During 1991, wholesale prices led live hog prices. Second, it can be said in general that wholesale belly prices cause cash hog prices. Third, there is no clear change of causality between live hog and its futures prices. Both have a bidirectional causal relationship in each year except in 1991. Thus, there are mainly bidirectional causal relationships between live hog and live hog futures market prices over time. However, pork belly

TABLE 2 Causality Test Results for Yearly Data

		X_t																			
		LH					WL					WH					WB				
Yr.		87	88	89	90	91	87	88	89	90	91	87	88	89	90	91	87	88	89	90	91
Y_t	WL	B	B	B	B	YX															
	WH	B	B	B	B	YX															
	WB	YX	YX	B	B	YX															
	FLH	B	B	B	B	YX	B	NO	NO	B	NO	YX	B	NO	YX	YX	B	YX	B	YX	YX
	FPB	YX	B	YX	YX	YX	B	NO	YX	XY	NO	YX	YX	NO	NO	YX	B	B	B	B	B

Notion '*XY*' implies *X* series causes *Y* series, and '*YX*' means series *Y* causes series *X*. '*B*' denotes that *X* and *Y* are caused bidirectionally, and 'NO' represents there is no certain casual relationship between the two series.

futures prices led live hog prices with a change once in 1988.

Fourth, several changes occurred in relationships between wholesale pork prices and futures contract prices. There is no certain causal relationship between wholesale loin and live hog futures contract prices. But, it is concluded that live hog futures market prices are chiefly causing wholesale ham prices, even though there are sometimes exceptions. Furthermore, wholesale pork belly prices are mainly caused by live hog futures contract prices. Fifth, it cannot be concluded that there is clear causal relationship between wholesale loin and pork belly futures market prices. Additionally, pork belly futures contract prices mainly cause wholesale ham prices. Finally, there is only one pair of series which violates the normal viewpoint. In 1990, wholesale loin prices appear to affect pork belly futures. On the other hand, causal relationships do not exist for pairs of series for some years.

From the results of yearly data, it can be concluded that, even if it is not consistent, causal directions are actual from live hog futures to wholesale pork belly to live hog sequentially. It is interesting because, in general, beliefs for live hog futures contract prices causing cash hog prices are not accepted by the results. It is also summarized that wholesale loin, ham, and live hog futures contract prices are not the center for pricing live hogs.

Year by year causal relationships, in general, correspond to causal directions for all observations in this study. Wholesale pork belly and pork belly futures contract prices are more important to price live hogs in the futures spot market rather than live hog futures market prices.

3. Out-Of-Sample Tests

For 4 year data from 1987 to 1990, the within-sample tests were given similarly to the results of the entire period data series and the year by year series. Based on the causal results from them, the out-of-sample tests were performed. Table 3 reports the results of the test.

Since, by construction, $MSE(\overline{X}) > MSE(\overline{X}, \overline{Y})$ is defined by 'a series *Y* causes *X*,' every pair of series seems to have a unidirectional causal relationship. However, the changes of $MSE(\overline{X})$ to $MSE(\overline{X}, \overline{Y})$ are not much higher so as to conclude that *Y* causes *X* except for the

TABLE 3 Out-of-Sample Causality Test

$\overline{X}_t$	$\overline{Y}_t$	MSE($\overline{X}$)	MSE($\overline{X}$, $\overline{Y}$)	Δ (%)	Casual Direction
LH	FPB	0.4340	0.4197	3.40	FPB→LH
LH	FLH	0.4340	0.4094	5.93	FLH→LH
WL	FPB	8.2745	8.2636	0.13	FPB→WL
WL	FLH	8.2745	8.2524	0.27	FLH→WL
WH	FPB	4.2131	4.1963	0.40	FPB→WH
WH	FLH	4.2131	4.2063	0.16	FLH→WH
WB	FPB	2.4218	2.1362	13.37	FPB→WB
WB	FLH	2.4218	2.3405	0.03	FLH→WB
LH	WL	0.4340	0.4306	0.79	WL→LH
LH	WH	0.4340	0.4268	1.69	WH→LH
LH	WB	0.4340	0.4335	0.12	WB→LH

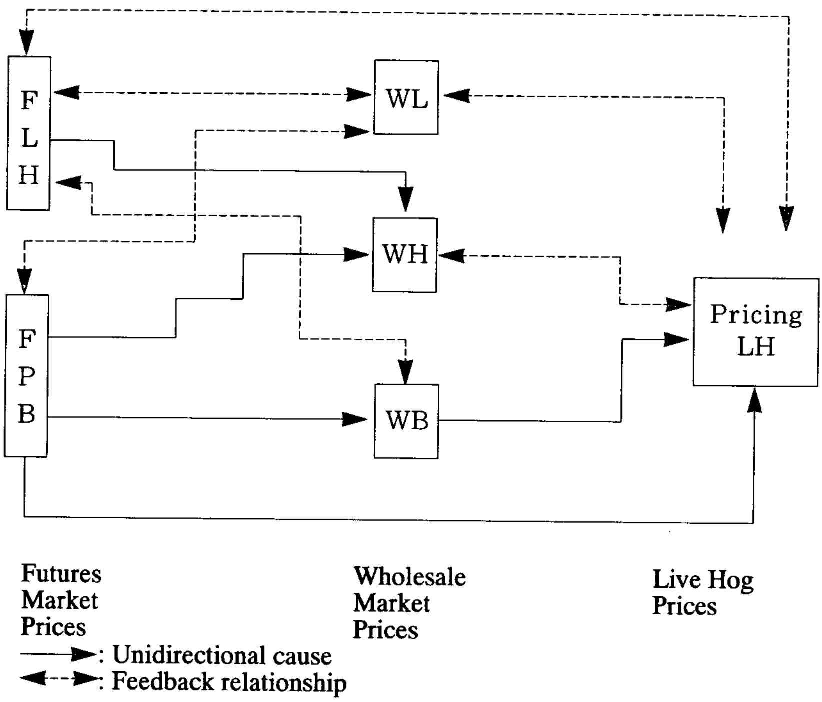
If MSE($\overline{X}$) is greater than MSE($\overline{X}$, $\overline{Y}$), then MSE($\overline{Y}$) causes $\overline{X}$. It is not clear that a series causes the other series using these MSEs, because there is little change in MSEs between uni- and bi- variate models. Δ implies the change of MSE($\overline{X}$) to MSE($\overline{X}$, $\overline{Y}$).

relation between wholesale pork bellies and pork belly futures prices. Therefore, the role in pricing live hogs of any other products may be weak. Its weakness implies that results from the year by year analysis for the same period are revealed to be more powerful than those out-of-sample tests to document causal directions.

VI. Conclusions and Implications

This study examined the dynamic relationships between cash slaughter hog prices, wholesale pork prices for hams, loins, and bellies, and futures market prices for live hogs and pork bellies. Daily price data covering the period from 1987 to 1991 was analyzed. Each series was collected from different markets and locations. Accepted tests for stationarity, cointegration, and causality were employed. Causality inferences from the sample were compared with post-

FIGURE 2 A Diagram of Causal Direction



sample predictions. Using the concept of Granger-type of causality, ECM, VAR, and post-sample tests, an outline of the price discovery process of hog-pork complex is drawn in Figure 2.

The figure describes that sequential causal chain in the sense of Hicks is found. That is, sequential causal directions from pork belly futures to wholesale pork belly, and wholesale pork belly to live hog appear dominantly. Moreover, pork belly futures prices are most important in pricing live hog rather than live hog futures and wholesale loin and ham prices. A sequential causal chain is also verified by the year by year analysis.

Overall results from this study can be summarized as follows:

1) Cointegration was found between the following pairs of price

series: live hog futures - wholesale loins; live hog futures - wholesale hams; pork belly futures - wholesale loins; slaughter hogs - wholesale bellies; and the three wholesale price series (loins, hams, and bellies). The cointegration results indicate that these markets satisfy the necessary condition for efficiency.

2) Like other studies, the results show live hog futures are not cointegrated with cash slaughter hog prices. Unlike other studies, the results show live hog futures price are cointegrated with some wholesale pork prices. Past research has suggested that live hog futures contracts and cash slaughter hogs are different assets and, therefore, the absence of cointegration does not imply inefficiency. I found this argument difficult to make. This suggests there is some inefficiency in the cash or futures markets - most likely the cash market.

3) The following causality inferences were obtained from the EC and VAR models. Information feedback persists between all of the wholesale pork product prices. There is also information feedback between wholesale and slaughter hog prices. Live hog futures contract prices and pork belly futures contract prices lead cash slaughter hog prices and lead live hog futures contract prices. Lastly, there is a feedback between live hog futures contract prices and cash slaughter hog prices.

4) Causality inferences made based on the in-sample model results were verified with post-sample data as a whole.

In summary, the cointegration and causality test results suggest futures markets lead price discovery in the hog-pork complex. Wholesale pork markets are next in terms of their cointegration to price discovery, and the cash slaughter hog markets may be the least important. However, there is a large amount of information feedback between the futures, wholesale pork, and slaughter hog prices. None of the markets completely dominates the process. Ward(1988) describes that price discovery begins with a general price level and concludes with transaction prices. It is significantly important to know that pricing live hog follows wholesale pork belly and/or pork belly futures market prices within the description.

This study is accomplished only on bivariate model approaches. The order of causal strength can be derived from other methods like tri-variate models and so on. A price discovery study involves pricing efficiency. If more relevant variables are included, it would increase the efficiency of the results.

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