Regional Fed Cattle Price Dynamics

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The lead-lag relationships present in the regional price discovery process are important indicators of market performance. Differences across markets in the speed of adjustment to evolving information may have implications for pricing efficiency within these markets. This study estimates intertemporal price relationships among 11 regional slaughter cattle markets. Larger volume markets, located in the major cattle feeding regions, were the dominant price discovery locations. Price adjustments across markets were completed in one to two weeks in the large volume markets located relatively close to each other and in two to three weeks in the more remote, smaller volume markets.

Key words: cattle prices, price dynamics, cattle markets.

Commodity price at a particular location is determined by local supply and demand conditions. Spatial arbitrage should force the differences in prices across locations to be no greater than transportation costs. Thus, with efficient arbitrage activities, market prices will approach a unique spatial equilibrium. However, spatial arbitrage may not be instantaneous. This is, the physical arbitrage process may take time to complete, and it may take time for arbitragers to recognize that an arbitrage opportunity is present. Thus, commodity prices may be slow to adjust to changes in supply and demand. The purpose of this study is to determine the dynamic price relationships among regional slaughter cattle markets.

Price discovery is the process by which buyers and sellers arrive at specific transaction prices through negotiation, bidding, formula, or public establishment (Tomek and Robinson). Price discovery is primarily "concerned with the actions of buyers and sellers as they interact in the market place on the basis of something less than perfect information concerning the level of supply and demand" (Purcell, p. 107). The level of information originating in a particular market together with the time required to move cattle from one market's region to another contribute to lags in price adjustments across geographically separated slaughter cattle markets.[1]

The lead-lag relationships present across regional prices are important indicators of market performance. Differences across markets in the speed of adjustment to evolving information may have implications for pricing efficiency within these markets. Garbade and Silber called the case of prices in one market leading those of another market a dominant-satellite relationship. In particular, if prices in a certain market usually adjust to those in another market with some time delay, the leading market is labeled the dominant market, and the lagging market is a satellite of the dominant market.

If a dominant-satellite relationship exists, the satellite markets may be responding less efficiently to evolving information. Alternatively, some markets may be "sources" of significant amounts of evolving market information, whereas other markets may have insufficient activity to generate much new information. Fama defined an efficient market as one that fully reflects all available infor-

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[1] Price discovery is composed of temporal and spatial considerations. The existence of a well-organized futures market facilitates temporal price discovery at an aggregate level but has less impact on short-run spatial price linkages across regional markets. The findings of Koontz, Garcia, and Hudson support this claim.

mation. If certain markets systematically lead others in price adjustments to new information, they may be more efficient at reflecting new information than the lagging markets. The speed of price adjustment provides an indication of the integration of the markets and may help define relevant market areas. Research on this issue should improve knowledge of geographic price relationships and provide data useful to producers, traders, and policy makers.

Limited research has addressed the intertemporal nature of regional slaughter cattle prices. Bailey and Brorsen used multivariate autoregressive models to examine the dynamics of weekly slaughter steer prices from 1 January 1978 through 4 June 1983 in the regions of Utah-Eastern Nevada-Southern Idaho; Colorado-Kansas; the Texas Panhandle; and Omaha, Nebraska. They found that Texas Panhandle prices led prices in the other three regions but that there was feedback from the Omaha market. They surmised that Texas prices were generating the clearest signals of market conditions. Koontz, Garcia, and Hudson performed pairwise Granger causality tests on eight weekly regional slaughter cattle markets over the 1973 through 1984 period. They concluded that, in general, the Nebraska direct market reacted the fastest to evolving market information, though some markets exerted feedback to it.

These previous studies provide evidence that certain markets react more rapidly to new information than others. However, they also raise several questions. First, Bailey and Brorsen concluded that Texas Panhandle prices were a leading source of price information. However, the findings of Koontz, Garcia, and Hudson suggest that the Nebraska price leads the Texas Panhandle region price. Thus, although the two studies differed in several ways,[2] there is evidence that the Texas Panhandle may not be the dominant market when compared with markets in the western Corn Belt. However, the conclusions reached by Koontz, Garcia, and Hudson may be dependent upon the pairwise nature of their tests, as opposed to examining a complete multivariate system. The multivariate approach of Bailey and Brorsen accounts for the joint effects of all regions being examined.

This study expands upon and extends the work of these earlier studies in several important manners. First, more market regions (11) are examined than in the Bailey and Brorsen (four) or Koontz, Garcia, and Hudson (eight) research. Second, a multivariate vector autoregressive (VAR) empirical model (similar to what Bailey and Brorsen utilized) is employed to examine the temporal market price linkages. The multivariate VAR is a tool that allows for a dynamic analysis of the entire set of prices in a complete system. Third, the period examined is more recent and includes prices through 1987, allowing us to investigate whether the continuing regional shifts in cattle feeding have affected the relative importance of different regions in the price discovery process. Fourth, we explicitly compare several centralized terminal markets and noncentralized direct trade markets (as did Koontz, Garcia, and Hudson) to test for general differences in their influence on the price discovery process (Buccola). Finally, the results of the VAR model are used (in a similar manner to the analyses conducted by Bedrossian and Moschos and by Brorsen, Chavas, and Grant) to explicitly test how market type (direct vs. terminal), distance between markets, and volume of cattle marketing in the region affect the lead-lag relationships.

Model Specification and Procedures

The procedure used to examine the dynamic nature of regional fed cattle markets utilized a multivariate VAR system. A VAR system is often specified by modeling each variable as a function of all variables in the system in a distributed lag framework. This specification reduces spurious a priori restrictions on the dynamic relations (Sims). The VAR system is:

$$(1) \quad Y(t) = \sum_{k=1}^{K} \begin{bmatrix} a_{11}(k) & \cdots & a_{1n}(k) \\ \vdots & & \vdots \\ a_{n1}(k) & \cdots & a_{nn}(k) \end{bmatrix} Y(t-k) + E(t),$$

[2] The two studies differ in three important ways: (*a*) different time periods are analyzed (Bailey and Brorsen examined the 1978 to mid-1983 period; Koontz, Garcia, and Hudson examined the 1973–84 period); (*b*) the empirical techniques differ (Bailey and Brorsen used a multivariate autoregressive model; Koontz, Garcia, and Hudson used pairwise Granger causality models); and (*c*) the markets examined differ (Bailey and Brorsen examined four market regions and Koontz, Garcia, and Hudson examined eight regions; the only markets common to the two studies were Omaha and the Texas Panhandle).

where t refers to time ($t = 1, 2, \ldots, T$); $Y(t)$ is an $n \times 1$ vector of prices; n is the number of markets in the system; K is the number of lags in the system; $a_{ij}(k)$ are parameters to be estimated ($i, j = 1, \ldots, n$); and $E(t)$ is a vector of random errors. VAR systems have had widespread use in examination of dynamic systems in economic analyses (see for example, Bessler; Bessler and Brandt; Featherstone and Baker; Sims).

To estimate the system, the lag length (K) (i.e., the order of the VAR system) must be selected. The order of the VAR system was determined using the modified log-likelihood ratio test (Sims).[3] This test was performed on the system of equations for increasing lags; the lag length selected was the largest for which the null hypothesis was rejected (Nickelsburg). The same number of lags was used for each variable in all equations. The Ljung-Box Q-statistic was used to test for significant serial correlation among the residuals of the estimated models. In the estimation reported, all price data were first-differenced.[4]

Causal flows in price adjustments across regional markets were tested using the standard Granger F-tests.[5] This procedure involves testing the null hypothesis for the parameters in equation (1) that $a_{12}(1) = a_{12}(2) = , \ldots, = a_{12}(K) = 0$. If the null is rejected, then discovery of variable 2 leads discovery of variable 1. Following the terminology of Garbade and Silber, if price changes in market 2 are found to lead price changes in market 1 with no significant feedback, then market 2 will be referred to as dominant to market 1 and market 1 as a satellite of market 2.

To test the influence of market volume, distance between markets, and type of market (direct vs. terminal) on price dynamics, the following regression model was estimated:

$$F_{ij} = b_0 + b_1\, Distance_{ij} + b_2\, Type_{ij} + b_3\, Volume_{ij} + e_{ij} \qquad i, j = 1, \ldots, 11; \quad i \neq j, \tag{2}$$

where F_{ij} is the F-statistic testing the blockwise significance of the lagged prices from market i in the VAR equation, with the price in market j as the dependent variable; $Distance_{ij}$ is the logarithm of the approximate road miles between markets; $Type_{ij}$ is a dummy variable equal to one if market i is a direct market and equal to zero if it is a terminal market; and $Volume_{ij}$ is the average annual finished cattle slaughter over the period of analysis in the state in which market i is located relative to the state in which market j is located. Because F_{ij} is a generated regressand from an F-distribution, the error term, e_{ij}, cannot be assumed to be normally distributed, as is required for exact hypothesis testing of small-sample OLS estimates. Thus, equation (2) was estimated using bootstrapping methods (Efron). Bootstrapping is a nonparametric procedure, which simply requires that the e_{ij}s are independently and identically distributed, without any assumptions regarding their distribution (Prescott and Stengos).

The distance between markets is expected to have a negative influence on the F-statistic. That is, as the distance between markets increases, the degree of feedback in price is expected to decline because of reduced opportunities for direct arbitrage between these markets. Also, direct markets are expected to have a stronger tendency to lead prices at terminal markets than vice versa. Though certainly subject to empirical testing, it would seem reasonable that given the declining importance of terminal markets in slaughter cattle trade (Paul), terminal markets likely would be less significant in affecting prices in direct markets than the reverse. Thus, the sign of the coefficient on market type is expected to be positive. $Volume_{ij}$ in equation (2) is measured as the ratio of the average annual statewide cattle slaughter between market i and market j. In this manner, volume is a measure of the relative slaughter volume of cattle in the approximate geographic market area. If price

[3] The order of the VAR models was also tested using the AIC statistic of Akaike. This statistic yielded orders consistent with the likelihood ratio tests.

[4] The data were differenced due to the fact that all series were determined to be nonstationary over each of the three periods at the .05 level using the Dickey-Fuller unit-root test. The models also were estimated using price levels in order to examine whether the results were sensitive to the differencing. The price-level models, however, were found to be nearly unstable, using the test proposed by Sargent (p. 273). That is, some eigenvalues were very near one in absolute value. As a result of these problems, the price-level models resulted in impulse responses that were very slow to dampen over time. Thus, only the results using first-differences are reported and discussed.

[5] In the strictest sense, Granger causality refers to out-of-sample forecasting. Some studies have found differences between in-sample and out-of-sample causality test results (Bessler and Kling). Our results utilize in-sample analyses and, thus, may be subject to this bias. However, the consistency of our results across three periods suggests that these biases likely are not significant. In addition, Bessler and Kling found that by paying close attention to the autoregressive properties of the data and applying differencing transformations where nonstationarity is evidenced, within-sample causality results are consistent with a priori beliefs (p. 335).

leadership and generation of new price information tend to be present more in the concentrated feeding areas (where a large proportion of the total volume of cattle are being marketed) so that price changes in these areas contain most of the available new information (Garbade and Silber), then $Volume_{ij}$ is expected to have a positive influence on F_{ij}.

The results of the estimated VAR were further analyzed by converting the system to a moving-average representation using Choleski factorization. This conversion allows us to use the VAR to forecast the time path response of the system to exogenous shocks to any one of the variables (Hakkio and Morris). These time path responses (referred to as impulse responses) were used to examine the adjustments across different markets to an unanticipated price shock in any one market. The standard errors of the impulse responses were calculated using the Monte Carlo integration technique outlined in Doan and Litterman.

The conversion of the VAR to a moving-average representation also allowed us to examine the forecast error decomposition. This decomposition explores the degree of exogeneity of a set of variables relative to another set of variables by computing the percentage of the expected k-steps-ahead squared prediction error of a variable produced by an innovation in another variable (Hakkio and Morris). In the problem at hand, the error decomposition allowed us to examine which, and to what extent, regional cattle markets are exogenous or endogenous relative to each other in the short run. Standard errors of the forecast error decompositions were calculated using the bootstrapping technique described in Runkle.[6]

Data

Weekly average price data (midpoint of daily range) for 900- to 1,100-pound, Choice, Yield Grade 2–4, slaughter steers were collected for 11 U.S. regional markets over the 1976 through 1987 period from the Chicago Mercantile Exchange and from summaries of the U.S. Department of Agriculture's *Livestock, Meat, and Wool Market News*. Price data were assembled for the direct trade cattle markets of California, Colorado, Illinois, Iowa-Southern Minnesota, Western Kansas, Eastern Nebraska, and the Texas Panhandle. Price data also were obtained for the terminal markets of Lancaster, Pennsylvania; Omaha, Nebraska; South St. Paul, Minnesota; and Sioux City, Iowa. The markets were selected to represent a geographic dispersion of locations that included the primary markets in the largest volume cattle feeding areas, as well as some smaller volume market regions. Price data for both direct and terminal markets were collected (some covering the same general trade areas) to allow us to examine differences in the price discovery process between these two marketing methods. Some of the price series had a small number of missing observations. The total number of missing prices was 28, which is less than .5% of the total data points.[7] Proxies for the missing prices were determined by the predicted values from a regression of each series on the 1,100- to 1,300-pound steer price at the same location during the same week.

Results and Discussion

To examine whether regional price relationships have changed over time, given the shifts in regional cattle production and slaughter and the increases in beef packing and slaughtering industry concentration (Ward), the data were arbitrarily split into three equal-length subperiods. Period I covered 1976 through 1979, period II covered 1980 through 1983, and period III covered 1984 through 1987. The changing patterns in market volume that occurred over these periods are reported in table 1. The markets that increased in total and relative cattle volume over the three periods included the direct markets of Colorado, Western Kansas, Eastern Nebraska, and the Texas Panhandle. These four markets accounted for 57.4% of the cattle sold in the 11 markets examined in the 1976–79 period, and they increased to represent 74.6% of the cattle volume in these markets in 1984–87. This suggests that significant movements of cattle feeding from the Corn Belt markets to the Plains and southwest Plains occurred during this period. All of

[6] In his analysis Runkle used 1,000 replications of the bootstrapping to estimate confidence intervals of the error decompositions. We used 500 replications in this analysis.

[7] The missing prices appeared to be random with no seasonal pattern. The Lancaster market had the largest number of missing prices (14) of the 11 markets over the 12-year period.

Table 1. Summary of Average Annual Cattle Volumes at Selected Markets over Three Subperiods, 1976 through 1987

	1976–79[a]		1980–83		1984–87	
Market	Average Annual Volume (1,000 head)	Percent of 11 Markets (%)	Average Annual Volume (1,000 head)	Percent of 11 Markets (%)	Average Annual Volume (1,000 head)	Percent of 11 Markets (%)
California Direct	688.2	5.5	456.9	3.9	519.0	4.2
Colorado Direct	761.9	6.1	703.2	5.9	1,014.9	8.3
Illinois Direct	693.2	5.5	550.9	4.6	391.0	3.2
Iowa-So. Minn. Direct	1,413.7	11.3	1,975.8	16.7	1,050.8	8.6
Western Kansas Direct	2,221.7	17.7	2,170.8	18.3	2,863.1	23.3
Lancaster Terminal	142.5	1.1	113.9	1.0	104.0	0.8
Eastern Nebraska Direct	1,116.6	8.9	1,131.7	9.5	1,342.5	10.9
Omaha Terminal	831.4	6.6	659.0	5.6	360.2	2.9
South St. Paul Terminal	828.4	6.6	569.9	4.8	401.3	3.3
Sioux City Terminal[b]	737.5	5.9	494.1	4.2	281.1	2.3
Texas Panhandle Direct[c]	3,093.3	24.7	3,040.5	25.6	3,938.1	32.1

[a] Direct markets include 1977–79.
[b] Includes both cattle and calves.
[c] Includes New Mexico, Texas, and Oklahoma Panhandle.
Source: U.S. Department of Agriculture, Agricultural Marketing Service, *Livestock, Meat, and Wool Market News, Weekly Summary and Statistics*, various issues.

the terminal markets examined declined in volume over the 1976–87 period. This trend is consistent with more general findings by Paul that terminal markets have declined from handling saleable receipts for nearly one-third of all U.S. commercial cattle slaughtered during 1975–79 to handling less than 20% of commercial cattle slaughtered during 1985–87.

The VAR systems were estimated using OLS. The adjusted R-square values for the models ranged from .35 for the Iowa-Southern Minnesota market to .55 for the South St. Paul market in period I, from .18 for the California market to .38 for the Colorado market in period II, and from .22 for the Eastern Nebraska market to .40 for the Texas Panhandle market in period III.

The estimated VAR systems had similar structures for the three periods examined. The 1976–79 and 1980–83 models were both third order (three lags of each variable) and the 1984–87 model was a second-order model. These lag lengths are longer than the one-week lags found by Bailey and Brorsen. Koontz, Garcia, and Hudson settled upon two-week lags in their bivariate models, which is consistent with the most recent period of our analysis.

The Ljung-Box Q-statistics indicated that no significant residual autocorrelation was present in any of the equations of the models. The contemporaneous correlations of the residuals of the models are reported in table 2. All contemporaneous correlations were significant at the 1% level, indicating that generally a large portion of information is reflected in price adjustments between markets within the week. The cross-correlations ranged from a low of .40 to a high of .96, with most being in the .75 to .90 range. The magnitudes of the correlations appeared to be related to the relative volumes of markets and the distance between regions. Relatively close market regions with high volume (e.g., Texas Panhandle and Western Kansas) had relatively large instantaneous correlations, whereas low volume, geographically dispersed markets (e.g., California and Lancaster) had small correlations.

To identify the dominant-satellite market relationships, Granger causality F-tests were performed on the estimated equations of the VAR systems. The summary F-statistics are reported in table 3. Three markets, Iowa-Southern Minnesota direct, Eastern Nebraska direct, and the Omaha terminal, appeared to be dominant markets in the price discovery process throughout the three periods. This result is consistent with Koontz, Garcia, and Hudson.

In recent years (1984–87), the Western Kansas direct market has become more dominant in the price discovery process, which may be due to its large increase in relative volume

Table 2. Correlations for Residuals of VAR Systems, 1976 through 1987[a]

Market	Period[b]	California Direct	Colorado Direct	Illinois Direct	Iowa-So. Minn. Direct	Western Kansas Direct	Lancaster Terminal	Eastern Nebraska Direct	Omaha Terminal	South St. Paul Terminal	Sioux City Terminal	Texas Panhandle Direct
California	I	1.00	0.83	0.78	0.75	0.83	0.60	0.75	0.79	0.41	0.77	0.83
Direct	II	1.00	0.79	0.74	0.74	0.77	0.51	0.74	0.72	0.68	0.73	0.78
	III	1.00	0.74	0.73	0.76	0.77	0.49	0.65	0.72	0.72	0.71	0.78
Colorado	I		1.00	0.86	0.56	0.91	0.66	0.84	0.87	0.45	0.84	0.90
Direct	II		1.00	0.82	0.88	0.90	0.54	0.81	0.84	0.79	0.84	0.91
	III		1.00	0.84	0.86	0.92	0.54	0.79	0.82	0.79	0.83	0.92
Illinois	I			1.00	0.91	0.87	0.77	0.85	0.90	0.57	0.89	0.85
Direct	II			1.00	0.87	0.80	0.58	0.77	0.82	0.80	0.84	0.81
	III			1.00	0.89	0.86	0.65	0.77	0.86	0.85	0.82	0.87
Iowa-	I				1.00	0.88	0.72	0.89	0.91	0.54	0.89	0.86
So. Minn.	II				1.00	0.86	0.55	0.84	0.84	0.83	0.85	0.87
Direct	III				1.00	0.89	0.59	0.83	0.86	0.87	0.83	0.89
Western	I					1.00	0.64	0.89	0.87	0.47	0.85	0.94
Kansas	II					1.00	0.51	0.81	0.79	0.75	0.80	0.92
Direct	III					1.00	0.55	0.80	0.83	0.82	0.81	0.96
Lancaster	I						1.00	0.61	0.71	0.40	0.69	0.62
Terminal	II						1.00	0.50	0.59	0.53	0.58	0.51
	III						1.00	0.50	0.61	0.58	0.56	0.54
Eastern	I							1.00	0.87	0.47	0.86	0.88
Nebraska	II							1.00	0.78	0.76	0.78	0.80
Direct	III							1.00	0.79	0.77	0.73	0.79
Omaha	I								1.00	0.52	0.94	0.85
Terminal	II								1.00	0.81	0.89	0.82
	III								1.00	0.87	0.87	0.84
South	I									1.00	0.54	0.43
St. Paul	II									1.00	0.85	0.78
Terminal	III									1.00	0.85	0.84
Sioux	I										1.00	0.83
City	II										1.00	0.80
Terminal	III										1.00	0.84
Texas	I											1.00
Panhandle	II											1.00
Direct	III											1.00

[a] All correlations are significantly different from zero at the .01 level.
[b] Roman numerals denote periods, I is 1976–79, II is 1980–83, and III is 1984–87.

during this period (table 1). This result seems reasonable, given the westward shifts in regional cattle feeding. In 1975, Kansas accounted for approximately 12.4% of the fed cattle marketed in the 13 largest volume cattle feeding states, but by 1986 it accounted for more than 18%. The increase in relative volume of cattle feeding (and slaughtering) in this region may mean that more market information is originating there and contributing to this region's importance in the regional slaughter cattle price discovery process.

Several market regions had little influence on any of the other markets. California, Colorado, Illinois, Lancaster, and South St. Paul all appeared to have limited influence on the prices in subsequent weeks at other regions. These low volume markets include those on the fringes of concentrated cattle feeding areas and also those located the farthest from the majority of larger volume markets. Thus, these markets appear to react as satellites to the western Corn Belt and western Plains markets.

The estimates of equation (2) are reported in table 4. As expected, the distance between markets had a negative and statistically significant influence on the summary F-statistics. This implies that the farther apart the markets are, the less direct influence they have on each other. Market type was found to have a positive and at least marginally significant impact on the F-statistic (being significant at the .05

Table 3. Summary *F*-Statistics for Causal Flows between Selected U.S. Slaughter Steer Weekly Cash Market Prices, 1976 through 1987

		Lagged Independent Variables[a]										
Dependent Variable	Period[b]	California Direct	Colorado Direct	Illinois Direct	Iowa-So. Minn. Direct	Western Kansas Direct	Lancaster Terminal	Eastern Nebraska Direct	Omaha Terminal	South St. Paul Terminal	Sioux City Terminal	Texas Panhandle Direct
California Direct	I	0.47	1.28	1.83	3.89*	0.49	4.90**	5.54**	4.04**	0.02	1.86	3.77*
	II	0.27	0.48	0.94	4.47**	0.26	0.60	2.62	4.59**	0.84	0.85	0.22
	III	1.63	2.21	5.10**	6.30**	4.99**	2.71	1.80	9.23**	2.08	0.54	1.99
Colorado Direct	I	1.13	5.73**	1.20	4.52**	0.83	2.70*	9.33**	4.27**	0.49	1.93	6.37**
	II	0.37	3.37*	1.71	4.25**	3.87*	0.14	9.47**	9.47**	0.52	1.49	1.93
	III	0.42	4.31*	4.21	8.53**	11.05**	1.74	5.62**	11.61**	2.38	1.20	2.25
Illinois Direct	I	2.20	2.31	0.40	7.25**	1.60	1.22	9.30**	3.37*	0.99	3.60*	2.12
	II	0.82	1.53	2.16	8.46**	2.14	0.17	7.21**	6.24**	1.00	1.65	0.90
	III	0.44	2.39	6.73**	12.71**	2.98	3.95*	5.29**	11.81**	2.90	1.06	1.65
Iowa-So. Minn. Direct	I	1.55	2.63	1.22	1.80	2.39	1.53	7.00**	3.51*	1.22	2.21	2.12
	II	0.45	2.23	1.33	2.31	2.18	0.34	6.45**	7.94**	1.37	0.90	0.86
	III	0.29	1.78	3.01	2.72	2.28	1.56	6.07**	8.52**	1.43	0.39	1.13
Western Kansas Direct	I	1.32	2.05	2.47	5.71**	1.74	1.44	8.25**	4.39**	1.04	2.15	6.02**
	II	0.42	1.84	0.89	2.69*	3.50*	0.15	6.18**	7.04**	0.47	2.61	1.97
	III	0.03	0.82	4.27*	9.40**	4.26*	1.80	3.53*	9.53**	2.47	1.40	2.11
Lancaster Terminal	I	0.19	2.13	1.82	8.11**	2.57	7.88**	3.73**	3.40*	0.23	3.12*	0.93
	II	0.41	0.31	0.62	1.87	0.41	4.53**	4.56**	3.95**	0.04	1.80	0.78
	III	0.39	1.40	0.64	6.16**	1.77	9.76**	3.83*	8.75**	1.25	1.99	1.69
Eastern Nebraska Direct	I	2.70*	2.30	1.12	4.21**	1.96	1.61	3.41*	2.81*	0.95	2.53	2.75
	II	0.56	2.11	1.30	2.39	2.01	0.37	5.38**	4.56**	0.70	1.54	0.77
	III	0.84	0.54	3.29*	10.00**	1.06	0.69	1.91	8.60**	2.63	0.74	3.33*
Omaha Terminal	I	1.30	4.31**	0.95	7.32**	2.42	1.78	11.58**	9.59**	1.10	3.19*	3.96**
	II	0.79	1.58	0.51	4.43**	1.00	0.27	7.91**	10.10**	0.53	2.67*	1.31
	III	0.37	1.47	2.44	8.44**	4.85**	1.20	5.19**	15.32**	2.85	0.66	2.75
South St. Paul Terminal	I	0.79	0.47	0.61	1.33	0.95	0.70	5.67**	0.67	4.79**	0.68	0.92
	II	1.17	1.84	0.35	5.72**	0.83	0.27	6.69**	7.63**	0.52	1.36	0.85
	III	1.22	1.77	4.07*	10.30**	4.40*	1.68	8.43**	13.91**	3.76*	0.86	3.46*
Sioux City Terminal	I	0.76	2.73*	0.81	5.60**	2.45	2.37	7.30**	3.64*	0.94	6.95**	2.75*
	II	0.82	3.09*	0.28	3.16*	3.15*	0.36	5.68**	7.86**	0.77	4.15**	0.92
	III	0.02	1.10	1.71	10.55**	6.46**	1.56	5.71**	10.77**	2.05	2.52	2.33
Texas Panhandle Direct	I	1.10	1.25	2.26	5.37**	1.14	1.43	7.80**	3.15*	0.92	3.24*	3.03*
	II	0.06	2.00	1.45	4.15**	3.72*	0.11	7.53**	8.27**	0.66	2.42	0.89
	III	0.10	0.80	4.60*	8.77**	13.21**	1.16	4.13*	9.43**	2.74	1.38	6.71**

[a] System lag lengths were selected using the modified likelihood ratio test and were three weeks, three weeks, and two weeks for periods I, II, and III, respectively.
[b] Roman numerals denote periods, I is 1976–79, II is 1980–83, and III is 1984–87.
Note: Numbers reported are *F*-statistics for H_0: all coefficients associated with the respective market jointly equal zero. A significant *F*-statistic indicates that changes in the independent market's price lead changes in the dependent market's price. Single asterisk indicates significantly different from zero at the .05 level, double asterisk indicates significantly different from zero at the .01 level.

Table 4. Estimated Coefficients for Regressions of *F*-Statistics

Independent Variable[a]	Period I 1976–79	Period II 1980–83	Period II 1984–87
Intercept	8.267**	11.025**	13.909**
	(5.30)	(7.71)	(6.32)
Distance	−1.046**	−1.604**	−1.845**
	(−4.37)	(−7.33)	(−5.39)
Type	0.821**	0.991**	0.925*
	(1.79)	(2.51)	(1.51)
Volume	0.538**	0.644**	0.745**
	(3.21)	(5.40)	(4.05)
R-Squared	0.21	0.41	0.28
Observations	110	110	110

[a] *Distance* = the logarithm of the approximate road miles between markets; *Type* = an indicator of a direct or terminal market; *Volume* = the average annual finished cattle slaughter over the period of analysis in the state in which market *i* is located relative to the state in which market *j* is located.
Note: Values reported in parentheses are *t*-statistics; single and double asterisks indicate significantly different from zero at the .10 and .05 levels, respectively, using a one-tailed *t*-test.

level in the 1976–79 and 1980–83 periods and at the .10 level in the 1984–87 period). Thus, it appears as though direct markets have a stronger influence on terminal market prices than vice versa. Finally, as expected, relative volume had a significant positive impact on the *F*-statistics. Thus, markets located in the concentrated cattle feeding and slaughtering regions had a greater influence on the markets located in the smaller volume regions than vice versa, as measured by the *F*-statistics. This result is similar to what has been found in regional grain markets (Brorsen et al.).

The response of the prices in the system to innovations in each of the variables (one at a time) allows us to examine the dynamic adjustment process in the system. The impulse response shows the price reaction paths over time, following a one-standard deviation increase in one of the variables. The one-standard deviation shocks are to the structural disturbance of a given variable, which implies, through transforming the error covariance matrix into an orthogonal form, simultaneous shocks to all of the reduced-form disturbances that are lower in the ordering of variables (see Orden and Fackler for further discussion of this process). To accomplish this, the system was triangularized, and the market prices were ordered as Eastern Nebraska, Iowa-Southern Minnesota, Omaha, Western Kansas, Texas Panhandle, Illinois, Colorado, Sioux City, South St. Paul, California, and Lancaster for the 1976–79 and 1980–83 periods. For 1984–87, three different orderings were examined (as discussed below). The ordering implies causality from the first through the last variable contemporaneously but not vice versa.

Selection of the market orderings was based upon the Granger causality results. The specific orderings among some markets were arbitrary due to the lack of any strong evidence regarding the precise rank ordering among them. Because several of the markets appeared to be jointly leading the price discovery process, and several others seemed to be responding to price changes in these leading markets, alternative orderings were examined. Similar implications resulted, although relative price responses were different. Three different orderings of the impulse responses and their associated standard errors for the 1984–87 period are available from the authors upon request.[8]

The impulse responses for selected markets are reported in figures 1, 2, and 3 for the 1976–79, 1980–83, and 1984–87 periods, respectively. Figures 1 and 2 illustrate the responses of the Iowa-Southern Minnesota, Texas Panhandle, South St. Paul, and Lancaster prices to a one-standard deviation shock in the Eastern Nebraska market. Figure 3 shows the responses of the Eastern Nebraska, Texas Panhandle, South St. Paul, and Lancaster prices to a one-standard deviation increase in the Iowa-Southern Minnesota price. The market responses reported in the graphs were selected to include representative larger volume (direct) markets (Iowa-Southern Minnesota, Tex-

[8] The data used in this analysis are available from the authors.

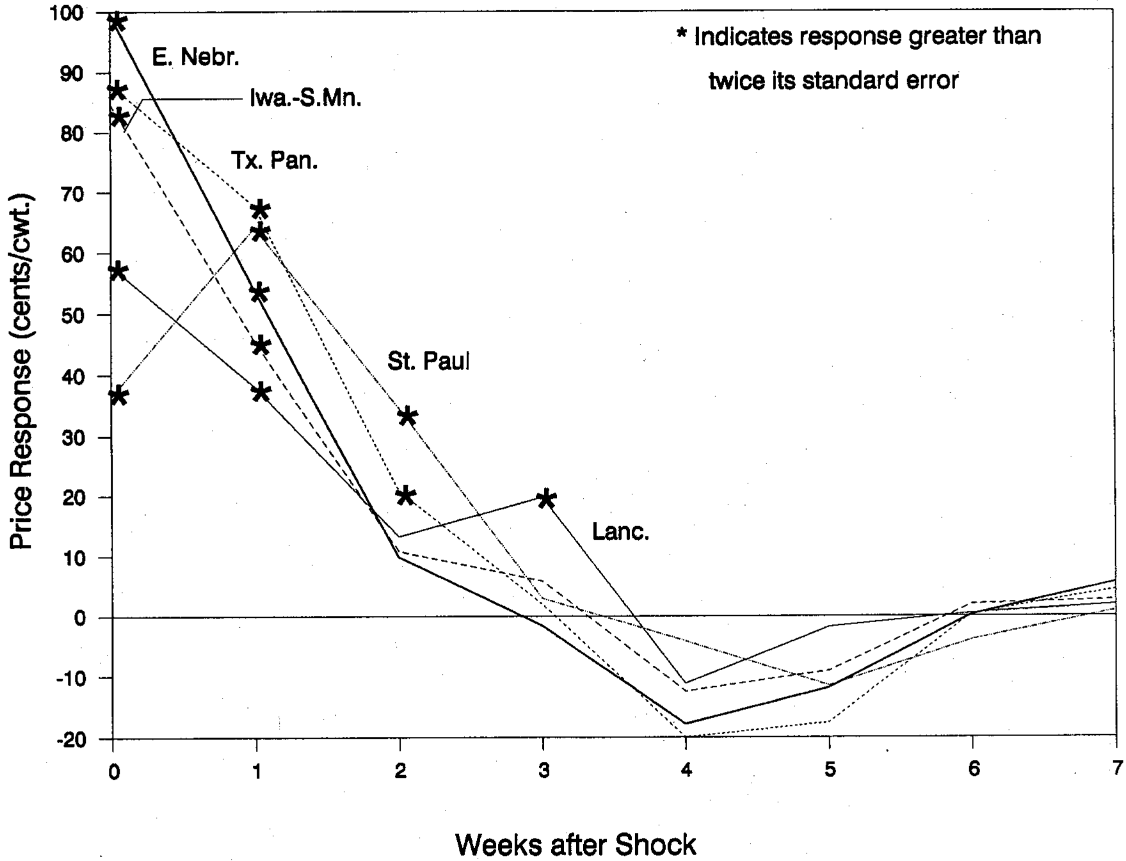

Figure 1. Price responses of selected markets following a one-standard deviation shock in the Eastern Nebraska direct price, 1976–79

as Panhandle, and Eastern Nebraska) and smaller volume (terminal) markets (South St. Paul and Lancaster). The remaining markets' responses followed patterns similar to those illustrated, with the magnitudes of the impulse responses falling between those of the large volume and small volume markets in the figures.

The larger volume markets generally had larger immediate responses to the price shocks than did the smaller volume markets. In most instances, the larger volume markets responded with instantaneous (same-week) reactions, which were 80% to 90% of the magnitude of the initial shock. The smaller volume markets, on the other hand, responded with instantaneous price adjustments of generally less than 70% (and as low as 40%) of the initial shock. The smaller volume markets typically had significant price adjustments occurring for one to two weeks longer than the larger volume markets. In most cases, the larger volume markets had significant price adjustments occurring for one to two weeks after the initial shock, whereas the smaller volume markets took two to three weeks to fully respond. For example, in two of the three orderings of the markets analyzed for the 1984–87 period, the Lancaster and South St. Paul markets had significant impulse responses through the second week after the shock, whereas the majority of the other markets had significant responses for only one week following the shock. Thus, it appears as though the larger volume markets adjust more rapidly and with a larger initial adjustment to evolving market information than the smaller volume markets.

Forecast error decompositions for 1984–87 also were estimated for three selected market orderings (these results are available from the authors upon request). The within-sample forecast error decompositions were essentially unchanged beyond five weeks. Truly exogenous variables would explain 100% of their

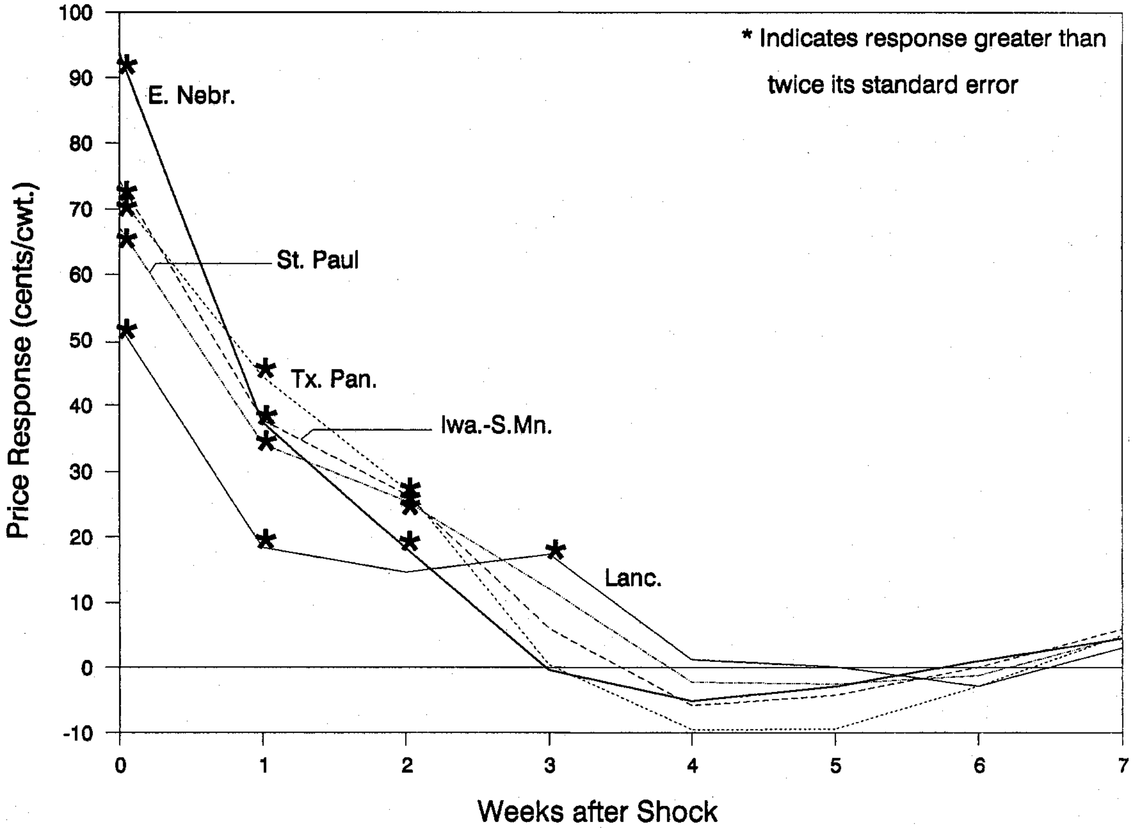

Figure 2. Price responses of selected markets following a one-standard deviation shock in the Eastern Nebraska direct price, 1980–83

own k-step-ahead forecast error variance. For the three selected orderings of the markets, the first market in the ordering (Iowa-Southern Minnesota, Eastern Nebraska, and Western Kansas, respectively) had in excess of 80% of the variance in five-weeks-ahead forecast error because of innovations in its own price. The majority of the remaining markets generally explained less than 30% of their five-weeks-ahead forecast error variances. An interesting exception was the Lancaster market, which had greater than 44% of its five-weeks-ahead forecast error variance explained by innovations in its own price series. This seems to imply that, given its location and small market volume, the Lancaster market reacts more to its own price movements over time than do many of the other markets, and it is not highly integrated with the remaining markets.

Conclusions

The intertemporal price relationships among 11 regional slaughter cattle markets were examined in this study. Three vector autoregressive systems were estimated, Granger causality tests were performed, and impulse response functions and forecast error decompositions were used to identify the dominant markets. The leading price discovery locations, none of which clearly dominated the others, were Iowa-Southern Minnesota, Eastern Nebraska, and Omaha. The Western Kansas market has become more important in slaughter cattle price discovery in recent years, reflecting the shifts that have occurred in regional cattle feeding and slaughtering from the Corn Belt to the southwestern Plains.

In the 11 markets examined in this study, regional price adjustments took from one to three weeks to complete. The larger volume markets, located near concentrated cattle feeding and slaughtering regions, fully reacted to price changes at the other major markets usually within one or two weeks. However, the smaller volume markets, located on the fringes of the major cattle feeding regions, took two to three weeks to fully respond to price changes

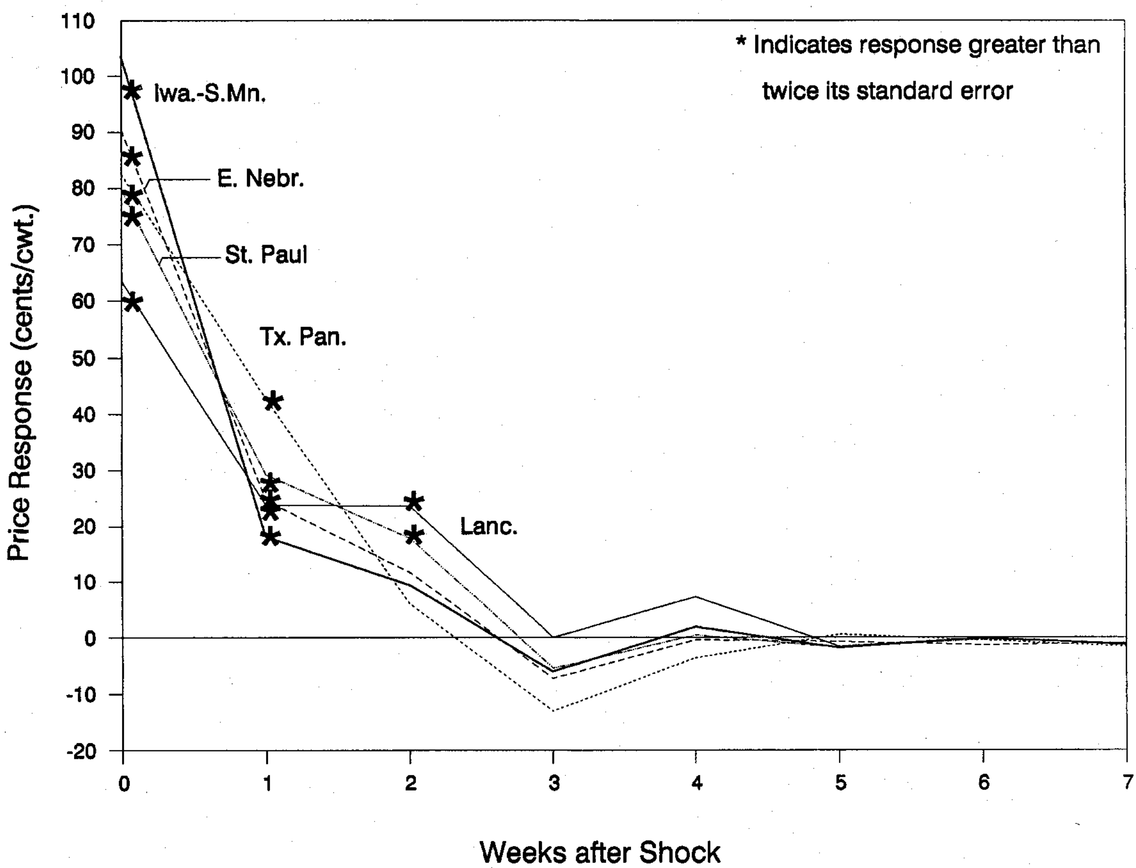

Figure 3. Price responses of selected markets following a one-standard deviation shock in the Iowa-Southern Minnesota direct price, 1984-87

in the larger markets. Thus, the larger volume markets appear to be dominant in the short-term pricing process, with the smaller volume markets reacting as satellites to price changes in the larger markets.

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