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Fed Cattle Spatial Transactions Price Relationships

Ted C. Schroeder

ABSTRACT

Delineation of geographic markets for fed cattle is essential in monitoring price behavior and determining geographic markets. This study uses transactions data from 28 U.S. fed cattle slaughter plants to determine the extent of the geographic market for fed cattle. Results indicate a national market for fed cattle with prices across most plants cointegrated. In addition, price discovery originates predominantly at plants located in Nebraska, and typically one-third of the total price adjustment to spatial integration occurs in one day.

Key Words: cattle prices, cointegration, relevant market, spatial prices.

Determining geographic markets for fed cattle is important for monitoring spatial price parity, and knowing the degree of spatial price integration across plants is essential in beef packer antitrust deliberations. Spatially integrated prices across plants do not diverge from each other. If plants' prices diverge, the plants do not compete strongly with each other (directly or indirectly through adjoining markets) for cattle purchases and they do not operate in the same geographic market. Rational choices by cattle feeders selling to the highest bidders and packers buying from willing sellers spatially link prices. Inadequate market information or barriers to cattle trade across locations reduce the strength of spatial price relationships. Spatial price differences may not be recognized instantaneously and they may take time to arbitrage. The speed of spatial price adjustment measures market participants' reaction time to new information.

This study examines daily transactions prices at 28 beef packing plants to determine spatial price relationships. To date, no previous published research has investigated fed cattle spatial price relationships using plant-level transactions data. Cointegration is used to determine long-run price relationships across plants. If prices across plants diverge from each other, to the extent that their prices are not cointegrated over time, the plants are not operating in a stable spatial price equilibrium—suggesting the plants are not in the same spatial market. Conversely, plants with cointegrated prices maintain a stable spatial equilibrium, indicating the plants are in the same geographic cattle procurement market.

Error correction models are estimated and used to determine speed of price adjustment to long-run spatial equilibrium. This provides information regarding how quickly plants change prices in response to price changes at other plants. Plants that respond quickly to price changes at other plants are more likely to be in the same spatial fed cattle procure-

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ment market than plants that respond slowly or not at all.

Previous Research

Several published studies have examined price leadership and cointegration in spatial fed cattle markets, and all have used publicly reported Agricultural Marketing Service (AMS) weekly or monthly prices. Bailey and Brorsen investigated the dynamics of weekly slaughter steer prices from January 1978 through June 1983 in four cattle feeding regions. They found that Texas Panhandle prices led prices in Utah-Eastern Nevada-Southern Idaho, Colorado-Kansas, and Omaha, Nebraska, but Omaha prices fed back to Texas. In their examination of Granger causality in eight weekly slaughter cattle markets from 1973 through 1984, Koontz, Garcia, and Hudson reported that the Nebraska direct market reacted fastest to evolving information, although some markets exerted feedback. Schroeder and Goodwin conducted a multivariate vector autoregression analysis of fed cattle prices from 11 regional direct and terminal markets using weekly data from 1976 through 1987. The results of their study showed that the leading price discovery locations were Iowa-Southern Minnesota, Eastern Nebraska, and Omaha, with the Western Kansas market becoming more dominant over the period. Regional price adjustments took from one to three weeks to complete. Larger volume markets, located near concentrated cattle slaughtering regions, fully reacted to price changes at other markets within two weeks. However, small-volume markets, located on the fringe of major feeding regions, took two to three weeks to fully respond.

In a subsequent study, Goodwin and Schroeder examined cointegration in 11 fed cattle markets using weekly price data from January 1980 through September 1987. They found that cointegration was somewhat limited, with about half of the tests indicating cointegrated markets. Spatial market cointegration increased over time, paralleling both information technology developments and increasing concentration in beef slaughtering. Markets separated by long distances had lower levels of cointegration than markets in close proximity.

The current study adds to previous research in several ways. Plant-level transactions prices from 28 plants located across the U.S. are analyzed. Transactions prices are aggregated into daily plant-level prices for analysis. This rich data set allows for investigation of daily pricing strategies and market dynamics across particular beef packing plants. No previous published research has examined the spatial price dynamics of such detailed and disaggregated slaughter cattle transactions prices. Furthermore, the most relevant prices in analysis of market performance are plant level, not aggregate AMS regional prices.

Empirical Models

When investigating spatial price relationships, either bivariate or multivariate time-series models could be used. The bivariate method involves examining price relationships across two plants, independent of prices at other plants. In bivariate modeling, it might be concluded that prices from two plants are related to each other directly when the relationship actually may be indirect through prices at plants located between these two plant sites (i.e., prices may be correlated in a multivariate fashion that may not surface in bivariate comparisons). In contrast, multivariate analysis accounts for the joint effects of all plants being studied. The problem encountered with multivariate analysis, however, is that if the plants' price series are highly correlated, degrading multicollinearity is problematic and little confidence can be placed in standard statistical tests.

The data set used for this analysis consists of daily prices from 28 plants. Because this large number of plants results in highly correlated daily prices, collinearity is a degrading problem when the multivariate time-series method is used. Thus, bivariate time-series models were chosen for this analysis.

Time-Series Model

If packing plants operate in the same geographic procurement markets, the respective prices they pay for fed cattle should not diverge from each other, suggesting that price series from competing plants are cointegrated. Consider two nonstationary series that require a single first difference to make them stationary. These price series are cointegrated if the residual term, e, in the following regression is stationary:

$$(1) \qquad Y_{1t} = \beta_0 + \beta_1 Y_2 + e_t\,.$$

The two series are said to be cointegrated of order (1,1) if e is stationary.[1]

Spatial market integration is brought about by arbitrage between markets or by sellers and buyers trading in overlapping regions. Delivery lags between spatial markets or other impediments to trade might result in short-run deviations from long-run spatial equilibrium. Assuming costs associated with spatial arbitrage (transportation, transactions, and risk) are stationary, spatial integration requires that the price series be cointegrated.

The procedure to test for cointegration, as suggested by Engle and Granger, is used here. The first step involves testing the stationarity of the individual price series using the augmented Dickey-Fuller (ADF) test (Engle and Granger). The ADF stationarity test for a particular series, y, is

$$(2) \qquad \Delta y_t = -\phi y_{t-1} + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \epsilon_t.$$

The null hypothesis is $\phi = 0$ that the series contains a unit root. Failure to reject the null suggests the series is nonstationary. The test statistic is ϕ divided by its standard error. Critical values are provided by Engle and Granger. Lag length is selected using the Schwartz-Bayesian criterion (Enders, p. 88).

Once nonstationarity of the prices in levels is established, and if their first differences are stationary, the parameters of the cointegrating regression are estimated using standard ordinary least squares (OLS) regression. Parameter estimates of the cointegrating regression are used to calculate estimates of the residual errors, $\hat{e}$, where

$$(3) \qquad \hat{e}_{1t} = Y_{1t} - \hat{\beta}_0 - \hat{\beta}_1 Y_{2t}.$$

Testing for cointegration involves testing stationarity of the residual series using the ADF test:

$$(4) \qquad \Delta \hat{e}_{1t} = -\phi \hat{e}_{1t-1} + \sum_{i=1}^{k} \beta_i \Delta \hat{e}_{1t-i} + \epsilon_t.$$

If there is a unit root, then the two series are not cointegrated. The null hypothesis of no cointegration is rejected (i.e., the series are cointegrated) if ϕ in (4) is significantly different from zero.

Vector autoregressive (VAR) models are used to determine price leadership and speed of price adjustment. If two series are cointegrated, then VAR models are estimated using an error correction model to avoid misspecification error (Enders), as follows:

$$(5) \qquad \Delta Y_{1t} = \alpha_1 + \alpha_{1y}\hat{e}_{1t-1} + \sum_{i=1}^{k} \alpha_{11}(i)\Delta Y_{1t-i} + \sum_{i=1}^{k} \alpha_{12}(i)\Delta Y_{2t-i} + \epsilon_{1t};$$

$$\Delta Y_{2t} = \alpha_2 + \alpha_{2y}\hat{e}_{1t-1} + \sum_{i=1}^{k} \alpha_{21}(i)\Delta Y_{1t-i} + \sum_{i=1}^{k} \alpha_{22}(i)\Delta Y_{2t-i} + \epsilon_{2t},$$

where the models in (5) are similar to standard VARs using differenced data, although the lagged error correction term [the error from cointegrating regression (3)] is added to the VAR. The α_{1y} and α_{2y} coefficients are speed-of-adjustment estimates. These parameters estimate how quickly prices at each plant respond to the previous day's deviations from long-run spatial equilibrium. A speed-of-adjustment parameter close to one in absolute

[1] A series is integrated of order (d) if it must be differenced d times to obtain stationarity. Two series are cointegrated of order (d, b) if the individual series are integrated of order (d) and their linear combination is integrated of order (d-b) (Engle and Granger).

value[2] indicates rapid adjustment to divergence from equilibrium, and a value close to zero suggests slow to no adjustment. The speed-of-adjustment parameter measures only the immediate response to a shock and, as such, does not indicate the entire adjustment (this is captured in the VAR estimates). If α_{1y} is zero and all $\alpha_{12}(i) = 0$, then Plant 2 price does not Granger cause Plant 1 price. Likewise, if α_{2y} is zero and all $\alpha_{21}(I) = 0$, then Plant 1 price does not Granger cause Plant 2 price.

Modeling Factors Related to Cointegration, Causality, and Speed of Adjustment

Degree of cointegration, level of causality, and speed of price adjustment to long-run equilibrium are continuous variables that provide means for economic analysis. Economic factors are expected to be related to these market conditions. To generalize requires conceptualizing factors affecting spatial price relationships. Following Goodwin and Schroeder, strength of cointegration can be measured by the magnitude of the ADF cointegration test statistic [the test of ϕ in (4)]. Larger ADF test statistics indicate higher levels of cointegration, suggesting the plants are in the same geographic market. Causality is also present to a degree. Plants that have large Granger causality F-statistics [equation (5)] have directional price causality (Schroeder and Goodwin). Also, the speed-of-adjustment parameter [the α_ys in equation (5)] indicates how rapidly prices at a plant adjust to price changes at another plant, with values close to 1.0 suggesting rapid reaction and parameters close to 0.0 reflecting slow reaction.

Cointegration, causality, and speed of price adjustment are all related to spatial price integration. As such, similar economic phenomena are expected to influence these integration measures. The strength of spatial price relationships is expected to be related to costs and risks associated with spatial arbitrage. An important factor likely to affect spatial price relationships is transportation costs which are related to the distance between plants (Tomek and Robinson). Plants located farther from each other would be expected to have weaker price relationships (Bressler and King). Also, plants that procure cattle from the same areas are expected to be more likely to compete directly with each other, which would influence their price relationships (Mulligan and Fik). Issues related to market structure of the plants may also influence spatial price relationships. Bedrossian and Moschos found that speed of short-run price adjustments was negatively related to industrial firm concentration. Although firm concentration did not change during the period of this study, structural components such as cattle procurement methods used, plant size, and plant ownership vary spatially and could influence price relationships.

From these concepts, the following models are posed to test relationships between these factors and the strength of cointegration, significance of causality, and speed of adjustment:

$$(6)\quad \begin{aligned} ADF_{ij} &= \beta_{10} + \beta_{11}Distance_{ij} + \beta_{12}Distance_{ij}^2 \\ &\quad + \beta_{13}Procurement\ Overlap_{ij} + \beta_{14}Cash \\ &\qquad Purchases_i + \beta_{15}Slaughter_i \\ &\quad + \beta_{16}Slaughter_i^2 + \beta_{17}Price\ Data_i \\ &\quad + \beta_{18}Same\ Firm_{ij} + \epsilon_{1ij}; \end{aligned}$$

$$(7)\quad \begin{aligned} FSTAT_{ij} &= \beta_{20} + \beta_{21}Distance_{ij} + \beta_{22}Distance_{ij}^2 \\ &\quad + \beta_{23}Procurement\ Overlap_{ij} + \beta_{24}Cash \\ &\qquad Purchases_i + \beta_{25}Slaughter_i \\ &\quad + \beta_{26}Slaughter_i^2 + \beta_{27}Price\ Data_i \\ &\quad + \beta_{28}Same\ Firm_{ij} + \epsilon_{2ij}; \end{aligned}$$

[2] If the series are cointegrated, one or both of the α_ys will be significantly different from zero. If both are statistically significant, one will be positive and the other negative.

$$(8)\quad SPEED_{ij} = \beta_{30} + \beta_{31}Distance_{ij} + \beta_{32}Distance^2_{ij} + \beta_{33}Procurement\ Overlap_{ij} + \beta_{34}Cash\ Purchases_i + \beta_{35}Slaughter_i + \beta_{36}Slaughter^2_i + \beta_{37}Price\ Data_i + \beta_{38}Same\ Firm_{ij} + \epsilon_{3ij},$$

where i refers to the dependent variable plant, j refers to the independent variable plant, *ADF* is the value of the augmented Dickey-Fuller cointegration test statistic, *FSTAT* is the significance of the Granger F-statistic from the error correction model, and *SPEED* is the estimated speed-of-adjustment parameter (α_y) from the error correction model. Independent variables are *Distance* (the number of miles between plant i and plant j), *Distance*^{2} (squared mileage), *Procurement Overlap* (the percentage of plant i's cattle purchased from a region overlapping with plant j's procurement area),[3] *Cash Purchases* (the percentage of cattle purchased in the cash market by the plant over the estimation time period), *Slaughter* (the number of cattle slaughtered by the plant during the time period), *Slaughter*^{2} (the slaughter variable squared), *Price Data* (the percentage of days over the period that daily price data were available—to be discussed later), and *Same Firm* (a binary variable equal to one if the two plants are owned by the same parent firm and equal to zero otherwise).

Distance between plants is used as a proxy for transportation costs across locations. As distance between plants increases, strength of spatial price relationships is expected to decline (Mulligan and Fik). Therefore, *Distance* is expected to be negatively related to the ADF cointegration test statistic. As distance increases, speed of price adjustment to spatial equilibrium is expected to decline, implying *Distance* should be negatively related to the speed-of-adjustment parameter (*SPEED*). The significance level of the Granger F-statistic (*FSTAT*) is expected to be inversely related to the other two dependent variables. Therefore, as the ADF and speed-of-adjustment parameter increase, the significance level of the Granger F-statistic is expected to decline (i.e., increased significance implies reduced significance level value). Thus, the F-statistic significance level is expected to be positively related to *Distance*. Distance was allowed to have a nonlinear effect by including a squared term.

Procurement Overlap is expected to have an effect similar to that of *Distance*. Plants in close proximity to each other are expected to have large procurement overlaps. However, *Procurement Overlap* measures actual trade activity, whereas *Distance* measures potential trade activity. *Distance* is not a complete measure of costs of spatial trade because road quality and differences in spatial market environments alter costs or risks of spatial trade.

The *Cash Purchases* variable was included to determine whether the packer's procurement method was related to spatial cash price differences. The sign of this variable could be either positive or negative. If the plant predominantly uses the cash market, this could imply that local cash price is more liquid, and therefore the local market has more opportunity for spatial arbitrage. This suggests a positive sign for the *ADF* and *SPEED* equations, and a negative sign for the *FSTAT* equation. Alternatively, if the plant uses the spot market less, relying more on other means of cattle procurement, then the cash market may be of less direct importance to the plant. This could mean that spot market prices are cheaper to formula price based upon another market than to discover locally—implying a negative relation between *Cash Purchases* and *ADF* and *SPEED*, and a positive relation with *FSTAT*.

The *Slaughter* variable captures the relation between plant size and spatial market integration and is expected to be negatively related to strength of spatial price relationships. If larger plants discover price somewhat independently, then prices at larger plants would be less cointegrated, slower to respond to, and

[3] *Procurement Overlap* is precisely defined as the percentage of cattle purchased by the particular plant representing sets of counties from which the plant purchased at least 10% of its cattle and from which the other plant purchased at least one pen of cattle during the one-year study period. (See Hayenga, Jiang, and Hook for additional details regarding this variable.)

less influenced by prices at other locations. This suggests negative signs in the *ADF* and *SPEED* equations and a positive sign in the *FSTAT* equation. Goodwin and Schroeder found large-volume markets were less cointegrated with small-volume markets. Similarly, Schroeder and Goodwin found large-volume markets were more likely to cause prices at smaller volume markets than the reverse. The effect of plant size is allowed to be nonlinear by including a squared term.

Price Data was included to adjust for statistical effects of having to replace missing daily price data (i.e., days no cattle were purchased by a particular plant). Missing price data were estimated by using the predicted values of a regression of the plant's daily prices on contemporaneous, single-day lagged, and two-day lagged overall plant average prices. This smooths the individual plant price series when there are more occurrences of missing data. This suggests that the more missing data (smaller *Price Data*), the more likely the plant price series is cointegrated, the faster the price will react to other plants' prices, and the greater the *FSTAT* significance. Larger plants have fewer missing prices; therefore, *Price Data* is negatively correlated with *Slaughter* since both variables relate to plant size.

Same Firm was used to capture different spatial price adjustments associated with plants owned by the same firm relative to those owned by different firms. Plants owned by the same firm have lower costs and risks associated with spatial arbitrage than plants owned by different firms. In addition, plants owned by the same firm share information and rely on each other to schedule cattle procurement. Thus, this variable is expected to positively affect *ADF* and *SPEED,* and to negatively affect *FSTAT.*

Data

Plant-level transactions data were obtained from the Grain Inspection, Packers, and Stockyards Administration (GIPSA). Transactions data provide a rich data set for analyses and help ensure that results reflect plant-level market behavior. However, primary data also present problems. The original data set consisted of transactions data procured from 23 March 1992 through 3 April 1993, for fed cattle slaughtered in 43 U.S. plants. This time period was selected by GIPSA and corresponded to an approximate one-year period beginning just prior to initiation of the data collection effort. Dressed fed cattle prices started this period at about \$125/cwt, trended downward to \$115/cwt, and then trended upward over the last seven-month period to about \$135/cwt.

As a result of missing data, irreconcilable differences in data, data incompatibilities across plants, or obvious errors, the data set was condensed to 28 plants. The final data set for this analysis was comprised of a total of 103,442 pens of cattle slaughtered, or 12.3 million head, which represented 52% of the total transactions data collected. Plants were represented from the states of Texas, Kansas, Colorado, Nebraska, Iowa, Minnesota, northwestern states, and eastern states.[4] Only pens of steers, heifers, fed Holsteins, or mixed sexes, with 35 or more head (the minimum number for which GIPSA collected data), purchased in the cash (spot) market, with average carcass weights, and yield and quality grades recorded were used.

Numerous plants did not maintain consistent records of transactions data pertaining to cattle purchase dates, cattle quality, or yield grades. Without such records, price comparisons across plants are problematic. When working with such data, an obvious tradeoff exists between observations and data comparability. For comparison of prices across plants, our general rule was to use data that had "standard" industry specifications. As rules are relaxed, the size of the data set increases, but the confidence associated with comparing increasingly heterogeneous prices rapidly becomes suspect.

Daily Plant Prices

A necessary step for conducting the time-series analysis is to obtain a daily price series

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[4] To maintain plant confidentiality, the northwestern and eastern states are not identified.

for each plant. The daily price series must be quality-adjusted to be comparable over time and across plants. Therefore, transactions prices needed to be converted to a quality-adjusted daily price for each plant. This involved estimating a hedonic price model using cash market transactions data for each plant over all observations. These plant-specific models were used to estimate the plant-specific price expected each day for a pen of cattle possessing a particular set of quality traits.

The specification of the hedonic model is based upon previous research on fed cattle pricing (Ward 1992; Schroeder et al.; Jones et al.) and data availability. The model is:

$$\begin{aligned}(9)\quad & \textit{Price} \\ & = \beta_0 + \beta_1 \textit{Heifer} + \beta_2 \textit{Holstein} + \beta_3 \textit{Mixed} \\ & \quad + \beta_4 \textit{Yield Grade } 3 + \beta_5 \textit{Pen Size} \\ & \quad + \beta_6 \textit{Pen Size}^2 + \beta_7 \textit{Average Hot} \\ & \qquad \textit{Weight} + \beta_8 \textit{Average Hot Weight}^2 \\ & \quad + \beta_9 \textit{Purchase to Kill Days} \\ & \quad + \beta_{10} \textit{Wholesale Value} \\ & \quad + \beta_{11} \textit{Average Plant Price} + \epsilon.\end{aligned}$$

Variables are defined in table 1. Perfect collinearity required a default pen be specified that consisted of steers. Pens of heifers, fed Holsteins, or mixed sexes were each expected to receive lower prices than steers. The percentage of cattle that were graded yield grade 3 or better was expected to positively influence price. Price was expected to increase with increasing pen size, but at a declining rate. Price was expected to increase, then decline, with increasing average carcass weight. The number of days between purchase and kill dates could be either positive or negative, depending upon how this variable influences packer pricing (Schroeder et al.; Ward 1992). Wholesale value was expected to be positively related to price. *Average Plant Price* was included to adjust for changing price levels over the study period. Summary statistics of the data across all plants and over time are reported in table 1.

The empirical model described in equation (9) is estimated separately for each plant and for all plants combined. The parameter estimates for combined data from all 28 plants are reported in table 2. The model explains 89% of the variability in transactions price. All parameter estimates are significant at the 0.001 level and have the expected signs. The estimated price impacts associated with the two nonlinear variables (*Pen Size* and *Average Hot Weight*) are difficult to casually interpret. The premium for *Pen Size* increases at a declining rate, with a maximum price at about 300 head where the premium is about \$0.40/cwt relative to a pen containing 40 head. Fed cattle price declines at an increasing rate as carcass weight increases, with an 800-pound carcass receiving a discount of just under \$1/cwt relative to a 525-pound carcass. Premiums and discounts reported in table 2 are comparable with previous work (Ward 1992; Schroeder et al.; and Jones et al.).

To conserve space and to maintain required confidentiality, parameter estimates from the 28 plant-specific models are not reported. The R^2s of the plant-specific models range from 0.71 to 0.97, with most between 0.85 and 0.95. The RMSEs range from \$1.10/cwt to \$3.40/cwt, or from about 1% to about 2.8% of the mean price. These values are important because accuracy of predicted daily plant prices is contingent on the explanatory power of these models.

The plant-specific models were used to estimate a daily carcass beef price at each plant. The following are the selected standard pen characteristics to which each daily price was adjusted: a 150-head pen of steers, graded 60% Choice or better, 95% yield grade 1–3, average carcass weight of 730 pounds, and purchased seven days prior to slaughter. For each day cattle were purchased in the cash market, price paid for each pen was adjusted for quality differentials typically paid by the plant. The average quality-adjusted prices were used as the plant price for that day.

On any day that a plant did not purchase cattle in the cash market, a price needed to be approximated to estimate the time-series models. The total number of days having at least one plant with at least one transaction was 364. The number of days plants had at least

Table 1. Definitions of Variables from Hedonic Model and Summary Statistics of Data Across All Plants and Over Time

Variable	Variable Description	Mean (Std. Dev.)	Min.	Max.
Price	Hot carcass price paid for cattle, including transportation and commission to packing plant ($/cwt)	121.61 (6.05)	91.47	148.58
Steer	Binary variable equal to 1 if pen is steers; equal to 0 otherwise	0.56	0	1
Heifer	Binary variable equal to 1 if pen is heifers; equal to 0 otherwise	0.36	0	1
Holstein	Binary variable equal to 1 if pen is holsteins; equal to 0 otherwise	0.01	0	1
Mixed	Binary variable equal to 1 if pen is mixed; equal to 0 otherwise	0.07	0	1
Yield Grade 3	Percentage of cattle in the pen that are graded yield grade 1 to 3 (%)	95.55 (5.84)	0	100
Pen Size	Number of head in the transaction (head)	118.55 (94.04)	35	1,055
Pen Size^2	The pen size variable squared	—	—	—
Average Hot Weight	Average hot carcass weight of cattle in the pen (lbs.)	733.37 (61.02)	441.97	1,021.57
Average Hot Weight^2	The average hot weight variable squared	—	—	—
Purchase to Kill Days	Number of days between cattle purchase and plant delivery (days)	5.84 (3.08)	0	30
Wholesale Value	Wholesale value of cattle, calculated as the USDA Choice carcass cutout price × the percentage of pen grading Choice or higher + the USDA Select carcass cutout price × the percentage of pen grading Select or lower ($/cwt)	115.86 (4.57)	107.10	128.69
Average Plant Price	Average price paid for cattle across all plants in the study on that day ($/cwt)	121.61 (5.62)	112.64	138.50

one transaction ranged from 84 to 314 (23% to 86% of the 364 days).

Missing daily prices were estimated by regressing the average quality-adjusted daily plant prices on the current, single-day lagged, and two-day lagged *Average Plant Price* variable. Predicted values from these plant-specific regressions were used as daily prices when a plant did not have cash cattle purchases. This resulted in 28 plants having 364 days with quality-adjusted comparable carcass prices.

Because time-series models cannot be estimated without complete time-series data, determining the precise impact on results of replacing missing data is not possible. One method to determine potential impacts of replacing missing data is to examine pairwise price correlations across plants with and without missing data replacements. All plant price series have high contemporaneous correlations, with most being 0.95 to 0.99. In addition, correlations for the original series and for the series with missing data replaced are essentially the same, with most differing by less than 0.05. Thus, pairwise correlations of the

Table 2. Price Adjustment Model Parameter Estimates for Combined Plant Data

Variable	Parameter Estimate	t-Statistic
Intercept	−6.1843	−7.954*
Sex/Type Variables:		
Heifer	−0.8687	−52.799*
Holstein	−6.0869	−111.673*
Mixed	−1.7248	−63.880*
Quality Variables:		
Yield Grade 3	0.0456	40.133*
Wholesale Value	0.0888	22.771*
Average Hot Weight	0.0097	4.929*
Average Hot Weight^2	-9.95×10^{-6}	−7.468*
Other Traits:		
Pen Size	0.0037	21.166*
Pen Size^2	-6.13×10^{-6}	−16.630*
Purchase to Kill Days	0.0747	35.095*
Average Plant Price	0.9142	288.041*
R^2	0.89	
RMSE	2.027	
Equation F-Statistic/(signif. level)	74,454 (0.001)	
No. Observations (pens)	103,442	
No. Observations (head)	12,262,770	

* Indicates significantly different from zero at the 0.0001 level.

plants' prices were nearly unaffected by the replacement of missing prices with proxies.

Additional data were needed to estimate equations (6)–(8). Distances between plants were estimated as optimized routes using the Key Travel Map software program (SoftKey International, Inc.). Plant procurement overlaps were obtained from Hayenga, Hook, and Jiang. The percentage of cattle purchased in cash markets and slaughter numbers were calculated from the GIPSA data.

Results

Stationarity and Cointegration Estimates

Prior to estimating cointegrating regressions, nonstationarity of the series must be determined. All of the series were nonstationary in levels using the ADF test. First differences of the prices resulted in all data series being stationary. Therefore, cointegration tests were appropriate in price levels.

Nearly all of the plants' prices are cointegrated with each other. Only 3.7% of the 756 plant pairwise comparisons are not cointegrated at the 0.05 level, and only 1.2% are not at the 0.10 level. This indicates that on a daily basis, during the time period studied, a long-run spatial equilibrium price relationship was present among the different plants, and prices did not significantly diverge from each other across plants. Market information, spatial trade, and opportunity for arbitrage keep prices from diverging in a nonstationary manner.

Error Correction VAR

Given the data are nonstationary and plant prices are generally cointegrated, an error correction model specification of the VAR is most appropriate. The Granger causality F-statistic results from the error correction VAR indicate that Nebraska plants are price leaders. Only 50% of the F-statistics for the Texas plants are significant with each other. When

Table 3. Average Error Correction Model Speed-of-Adjustment Parameter Estimates, by Region

	Location of Plants Reacting to Price Changes Caused by Plant Locations in First Column		
Location of Plants Causing Price-Change Reaction	Texas and Kansas	Nebraska and Colorado	Other States
Texas and Kansas	0.37	0.15	0.19
Nebraska and Colorado	0.45	0.43	0.35
Other States	0.35	0.35	0.29

Kansas plants are added to the Texas comparisons, 41% of the F-statistics are significant; adding Colorado and Nebraska results in 39% significant; and overall, 43% of the F-statistics are statistically significant at the 0.05 level. Plants in Nebraska cause prices at 84% of the plant pairwise comparisons in Texas, Kansas, and Colorado, and at 62% of the rest of the plants in the sample. This is considerably more than plants located in any other state. Only 6% of the F-statistics indicate causality from Texas and Kansas plants to Nebraska and Colorado plants. Results suggest that plants in Texas and Kansas follow prices discovered in Nebraska. Plants in the other regions have less strong links to prices at plants in Nebraska or other regions.

Speed-of-adjustment parameters indicate how rapidly price reacts to get back to spatial equilibrium when price changes at another plant. A value of 1.0 suggests immediate reaction within the same day. A value close to zero suggests slow reaction. The overall average speed-of-adjustment parameter value was 0.33 (with a range from 0.67 to 0.13), indicating that one-third of deviations from spatial price equilibrium were typically corrected in one day.

Table 3 illustrates the averages of absolute values of speed-of-adjustment parameters by regions. Plants in Texas and Kansas react most quickly to price changes at plants in Nebraska and Colorado, with the average speed-of-adjustment parameter close to 0.50. This indicates that one-half of the total responses to price changes at other plants are completed within one day. Plants in Nebraska, as well as those located in the rest of the country, tend to react quite slowly to price changes in Texas and Kansas, with typical speed-of-adjustment parameters less than 0.20. This reinforces the observation that plants in Texas and Kansas generally do not have rapid influence on daily price adjustments in other areas. The fact that plants in other regions do not respond rapidly to price changes in Texas and Kansas does not signify that these plants are not adjusting at all, but simply that their responses are slower than they are to price changes in other regions. Of course, plants would be expected to have rapid adjustments to price changes at other plants operating in the same market.

Empirical Estimates of ADF, SPEED, and FSTAT Determinants

Given the large number of parameters and test statistics estimated, it is difficult to generalize the results. Therefore, equations (6)–(8) are estimated to provide generalizations of results. Equations (6), (7), and (8) have dependent variables that represent test statistics, parameter estimates, or statistical significance levels. As such, they are not normally distributed, suggesting that OLS estimates would not be interpretable. Consequently, these equations were estimated using bootstrapping techniques (Efron).

The bootstrapping procedure is described as follows. The model is initially estimated using ordinary least squares regression. Residuals are stored and randomly added with replacement to the original dependent variables and the model is re-estimated using these modified dependent variables as new dependent variables. Parameters from this estimation are stored. This process is repeated a large number of times, storing the parameters each

Table 4. Summary Statistics of Variables Used in Explaining Error Correction Model Test Statistics

Variable	Mean	Std. Dev.	Min.	Max.
Dependent Variables:				
ADF Test Statistic (*ADF*)	4.63	1.16	2.09	8.22
Granger *F*-Statistic (*FSTAT*)	0.23	0.29	0.00	1.00
Speed of Adjustment (*SPEED*)	0.33	0.21	0.00	1.12
Independent Variables:				
Distance (miles)	657.85	501.85	5.00	2,970.00
Procurement Overlap (%)	21.97	29.36	0.00	98.00
Cash Purchases (%)	85.57	15.92	40.00	100.00
Slaughter (head)	700,677.89	392,087.39	97,134.00	1,431,676.00
Price Data (days)	60.75	18.39	23.00	86.00
Same Firm	0.20	0.40	0.00	1.00

time. Final parameter estimates are calculated as the means of the stored parameters across all estimation iterations. Similarly, standard errors and other statistics can be calculated from this distribution of parameter estimates. Bootstrapping requires only that residuals be independently and identically distributed. The bootstrapped coefficient estimates were obtained from 500 replications.

Summary statistics of data used in the bootstrap equations are presented in table 4. Empirical estimates of the bootstrapped coefficients and implied t-statistics are reported in table 5. Nearly all of the variables have the a priori expected signs on their respective parameters. Most coefficient estimates are different from zero at the 0.05 level.

Plants located in close proximity to each other exhibit prices that are more strongly cointegrated (*ADF* equation) and adjust more rapidly to price shocks (*SPEED* equation) as expected. This is consistent with the findings of Goodwin and Schroeder. *Distance* was negative and statistically significant in the *FSTAT* equation, which was not expected. This finding indicates that plants that are located farther from each other have higher levels of causality. In contrast, Schroeder and Goodwin found that as distance between markets increased, the strength of spatial price causality declined. Why these results are inconsistent is not apparent. One possible explanation noted by a reviewer is that if large plants are located greater distances from each other than small plants, and if large plants respond more to each other, this could help explain the observed relationship between *Distance* and causality. Several important differences between this study and the analysis conducted by Schroeder and Goodwin make identification of the precise rationale for the different findings difficult.[5] In addition, the negative distance parameter is sensitive to inclusion of the *Procurement Overlap* variable. Excluding the *Procurement Overlap* variable from the regression resulted in insignificant *Distance* parameters in the *FSTAT* model. Thus, collinearity is present between these two variables.

Procurement Overlap is an important determinant of spatial price relationships. Cointegration increases for plants whose trade areas overlap. Similarly, firms with overlapping trade areas are more likely to have significant price causality with each other, and they also tend to react more quickly to spatial price shocks.

[5] Important differences between this study and that of Schroeder and Goodwin (S-G) include the following: (*a*) this study uses data from 1992–93, while S-G used data from 1976–87; (*b*) the current data set consists of daily prices, whereas S-G used weekly prices; (*c*) this study uses plant-level prices, and S-G used AMS aggregate market prices and terminal prices; and (*d*) the current estimates are derived from an error correction model, while S-G estimates were from a VAR in first differences.

Table 5. Bootstrapped Parameter Estimates of Factors Related to Error Correction Model Test Statistics

	Dependent Variable		
Independent Variable	Cointegration Test Statistics (*ADF*)	*F*-Statistic Significance Levels (*FSTAT*)	Speed-of-Adjustment Parameters (*SPEED*)
Intercept	7.333	−0.169	0.956
	(14.71)*	(−1.15)	(7.68)*
Distance	−0.00174	-1.756×10^{-4}	-1.428×10^{-4}
	(−6.07)*	(−2.09)*	(−2.49)*
Distance^2	5.524×10^{-7}	5.935×10^{-8}	3.207×10^{-8}
	(4.65)*	(1.66)	(1.33)
Procurement Overlap	0.0115	−0.00143	6.231×10^{-4}
	(6.34)*	(−2.56)*	(1.80)
Cash Purchases	−0.0148	0.00305	−0.00316
	(−3.42)*	(2.40)*	(−2.98)*
Slaughter	-6.652×10^{-7}	3.616×10^{-7}	-5.088×10^{-7}
	(−1.29)	(2.35)*	(−3.76)*
Slaughter^2	1.156×10^{-13}	-2.481×10^{-13}	3.132×10^{-13}
	(0.42)	(−2.19)*	(3.10)*
Price Data	−0.0103	0.00253	−0.00241
	(−3.92)*	(3.18)*	(−3.55)*
Same Firm	0.333	−0.0180	0.0297
	(3.72)*	(−0.63)	(1.54)
OLS R^2	0.37	0.08	0.18
RMSE	0.920	0.278	0.186
No. of Observations	756	756	756
Dependent Variable Mean	4.63	0.229	0.332

Note: Numbers in parentheses are *t*-statistics.
* Indicates significantly different from zero at the 0.05 level.

Plants that have high percentages of cattle purchased in the cash market are less likely to have prices cointegrated with other plants, are slower to adjust to price changes elsewhere, and are more likely to have price changes at other plants influence their prices. Plants that use a lot of formula pricing are more apt to use external markets as sources of information to determine their price bids as opposed to incurring the increased costs of discovering local prices. This could contribute to increased spatial price integration by firms using formula pricing.

Larger plants have prices that are less likely to be cointegrated, respond more slowly to deviations from spatial equilibrium, and are less apt to have price affected by price changes at other plants. This is consistent with findings of previous research using aggregate market-level data (Goodwin and Schroeder; Schroeder and Goodwin). This result is interesting because it suggests that large plants operate somewhat independently relative to smaller plants in discovering daily prices. Large plants generally maintain slaughter nearer capacity than smaller plants to achieve cost competitiveness (Ward 1990). Thus, they may operate with greater emphasis on filling their plant than emphasis on relative prices, leading to greater pricing independence. Because they purchase cattle over larger areas, larger plants also naturally have more influence on prices. This indicates that the strength of cattle price relationships is not solely determined by geographic concerns. Thus, beef packers may not compete purely based upon geographic plant location.

Although correlations were similar between the plant prices without missing data replaced and plant prices containing proxies for missing data, the need to supplant missing prices with proxy prices affected the cointegration, causality, and speed-of-price-adjustment results. Plants having more days containing price quotes were less likely to be cointegrated, had less rapid adjustment back to long-run spatial equilibrium, and were less likely to have price changes caused by price changes at other plants. This suggests that replacing missing prices with the method used here could have biased upward the amount of cointegration and increased the speed of price adjustment relative to what would be the case had actual prices been available throughout the time period. Since prices used to proxy for missing data likely had less variability than actual data, this finding is not surprising. However, the number of missing observations was correlated with plant size; smaller plants had more days without price quotes—which could represent additional evidence that large plants operate more independently in price discovery relative to smaller plants.

Plants owned by the same firm were more likely to have cointegrated prices, confirming that firms owning plants in different locations can more easily arbitrage across plants. This supports Goodwin and Schroeder's findings that as beef packer concentration over time increased, regional cattle price cointegration increased. Speed of adjustment was positively related to whether the plants were owned by the same firm, suggesting that prices at different plants also adjust more rapidly to shocks if the plants are owned by the same firm. However, this parameter was only marginally significant. *FSTAT* was not significantly related to whether the plants were owned by the same firm.

To further interpret results of these regressions, the values of the dependent variables were graphed as distance between plants increases (see figures 1–3), using the estimated parameters and holding all other variables except *Procurement Overlap* at their means. *Procurement Overlap* and *Distance* between plants are related. A regression of *Procurement Overlap* on *Distance* gave the following relationship, where numbers in parentheses are t-statistics:

$$\text{(10)}\quad \textit{Procurement Overlap} = \underset{}{67.46} - \underset{(-27.84)}{0.109 \textit{Distance}} + \underset{(19.49)}{0.000038 \textit{Distance}^2}, \quad R^2 = 0.60.$$

To allow overlap to adjust with distance, the above equation was substituted into the three regressions for the *Procurement Overlap* variable in creating graphs of each statistic over *Distance*. This equation suggests that *Procurement Overlap,* on average, reaches zero as *Distance* increases to about 900 miles. Figures 1, 2, and 3, respectively, illustrate how *ADF, FSTAT,* and *SPEED* change as distance between plants increases using the regression estimates and making the above substitution for *Procurement Overlap*. As seen in figure 1, *Distance* has little influence on the significance of the Granger F-statistic, suggesting that other factors are more important in price causality. Cointegration and speed of adjustment, however, are more strongly influenced by distance between plants. Cointegration strength declines by nearly 50% as distance between plants increases from 100 miles to 1,500 miles (figure 2). Plants also become much slower to react to new information in other locations as distance between them increases. Plants located within 200 miles of each other adjust to price changes on average within 2.5 days, while plants separated by 900 miles take four days to adjust (figure 3).

Conclusions

Spatial price relationships among beef packing plants have important implications in defining

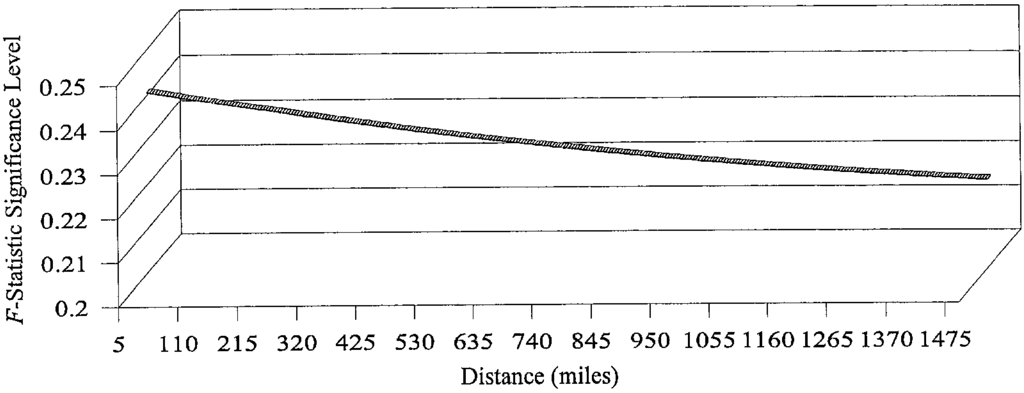

Figure 1. Impact of distance between plants on Granger F-statistic significance level, with other variables at their means

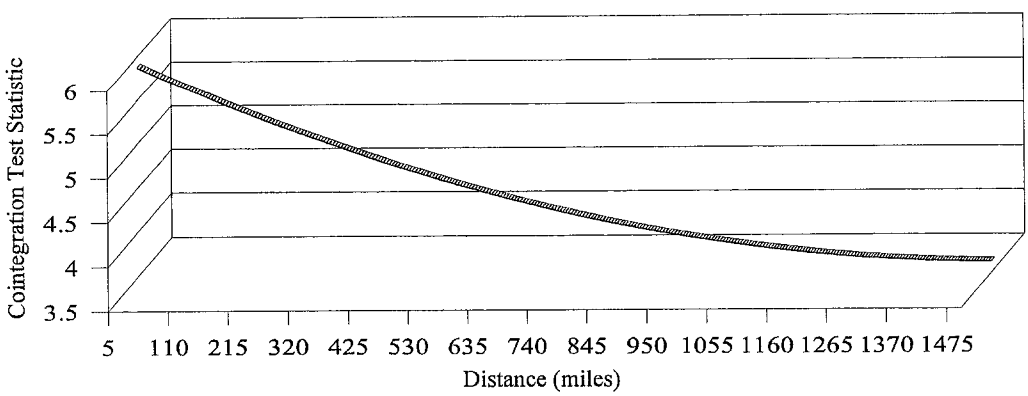

Figure 2. Impact of distance between plants on cointegration test statistics, with other variables at their means

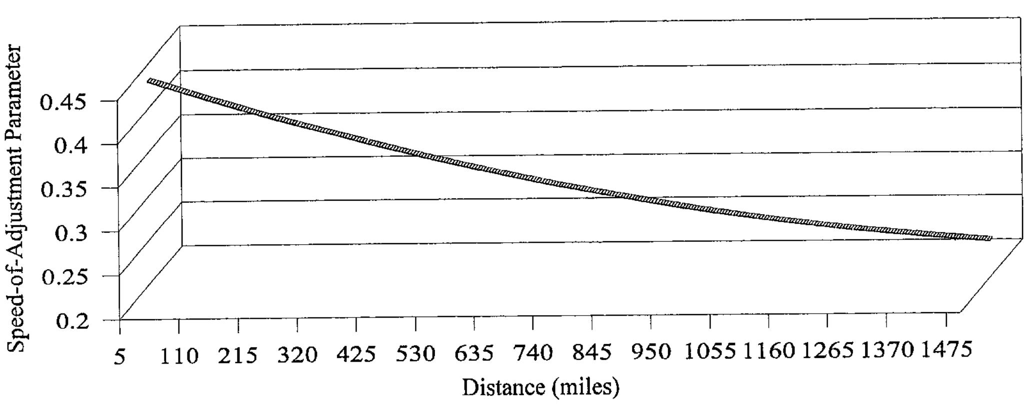

Figure 3. Impact of distance between plants on speed-of-adjustment parameter, with other variables at their means

geographic live cattle markets. Plants whose prices are not integrated may convey inaccurate price information that could distort marketing decisions and contribute to inefficient product movements. This study was undertaken to determine the extent of market integration, price leadership, and speed of adjustment to price changes among beef packing plants to discern information regarding relevant spatial markets for slaughter cattle.

Daily plant prices were generally cointegrated, with over 95% of the 756 pairwise plant comparisons cointegrated. Prices at the 28 plants tended to move together and did not diverge from each other, suggesting the plants were competing for cattle in linked markets. Error correction model estimates indicated that, on average, plants made one-third of the total reaction to price movements to return to spatial equilibrium in one day. However, reaction speed varied considerably across plants. Prices at plants located in Nebraska reacted most quickly to price changes at plants in their own area and were reacted to most quickly by other plants in the study. This finding suggests that plants in Nebraska were price leaders and were a source of significant evolving price information.

Based on the results of this analysis, plants separated by long distances tend to have lower degrees of cointegration and are slower to react to price movement away from equilibrium. Given the relatively high costs of shipping live cattle or carcasses long distances, this observation is logical and implies a distance-decay in strength of spatial price linkages. The larger the overlapping trade areas for two plants, the more highly cointegrated, the stronger the price causality, and the more rapid the speed of adjustment to price movements from spatial equilibrium. This is consistent with direct competition among nearby plants.

Plants that purchase large percentages of cattle through noncash means have cash prices less cointegrated, have less causality, and are slower to react to other plants' price changes than plants that purchase their cattle in the cash market. Larger plants also react more slowly to price changes from equilibrium and have lower degrees of price causality from other plants. Large plants and plants with smaller percentages of cattle purchased in the cash market act more independently in their cash market purchases than small plants and plants that rely exclusively on the cash market. This also demonstrates that larger plants are less concerned with cattle prices and are more concerned with keeping their facilities full to maintain cost competitiveness. This finding is important because it indicates factors in addition to geographic locale are important determinants of price relationships across plants.

Finally, plants owned by the same firm have prices that are more cointegrated and they react faster to each other's price changes. Such a finding is expected, since costs and risks associated with spatial trade are reduced if arbitrage is by plants owned by the same firm. Furthermore, information flow between these plants is inherently more direct and reliable, making reacting to the news of price changes less risky.

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