Fed Cattle Spatial Transaction Price Relationships

by

Ted C. Schroeder

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Delineation of geographic markets for fed cattle is essential in monitoring price behavior and determining the extent of spatial price parity. This study uses transaction 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.

Introduction

Determining geographic markets for fed cattle is important for monitoring spatial price parity. How plants' prices react to each other, and the extent of spatial price integration is essential when monitoring beef packer competition. If spatially integrated, prices do not diverge widely from each other. If plants' prices diverge, the plants do not compete with each other for cattle purchases or 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 inability to trade cattle with plants in a particular location may reduce the strength of spatial price relationships. Identifying spatial price differences may not occur instantaneously as it takes time to recognize presence of an arbitrage opportunity or of consistently better pricing opportunities in a different location and to act upon it. The speed of spatial price adjustment provides evidence of market participants' reactions to new information. The more quickly price adjusts to price changes at other locations, the stronger the spatial competition for fed cattle. Spatial competition for slaughter cattle procurement is the essence of plants operating in the same geographic market.

Testing for price leadership is important in spatial markets. If dominant markets exist whereby information is discovered first, satellite markets may be responding less efficiently to evolving information. Alternatively, some markets may be sources of significant market information, whereas other markets may not generate much new information. Plants that are price followers may be in the same market as price leaders. However, if no feedback occurs from the price followers to the price leaders, the price leaders can essentially operate independently of the followers.

This study examines daily transaction prices at 28 beef packing plants to determine spatial price relationships. No previous study has determined fed cattle spatial price relationships using plant-level transaction 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. Plants with

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cointegrated prices maintain a stable spatial equilibrium suggesting 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 in the same spatial fed cattle procurement market than plants that respond slowly or not at all.

Previous Research

Several studies have examined price leadership and cointegration in spatial fed cattle markets. All published studies have used publicly reported Agricultural Marketing Service (AMS) weekly or monthly prices. Bailey and Brorsen examined dynamics of weekly slaughter steer prices from January 1978 through June 1983 in four cattle feeding regions. They found Texas Panhandle prices led prices in Utah-Eastern Nevada-Southern Idaho, Colorado-Kansas, and Omaha, Nebraska, but Omaha prices fed back to Texas. Koontz, Garcia, and Hudson examined Granger causality in eight weekly slaughter cattle markets from 1973 through 1984. They concluded that, the Nebraska direct market reacted fastest to evolving information though 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 leading price discovery locations were Iowa-Southern Minnesota, Eastern Nebraska, and Omaha. The Western Kansas market became 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.

Goodwin and Schroeder examined cointegration in 11 fed cattle markets using weekly price data over January 1980 through September 1987. 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.

This study adds to previous research by analyzing transaction prices from 28 plants located across the U.S. Transaction prices are aggregated to daily plant-level prices. This rich data set allows for analysis of daily pricing strategies and market dynamics across particular beef packing plants. No previous study has examined the spatial price dynamics of such detailed and disaggregated slaughter cattle transaction prices. However, 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 (more than two series) times series models could be used. Bivariate involves examining price relationships across two plants independently of prices at other plants. In bivariate modeling, one may conclude that prices from two plants are related to each other. However, the relation is assumed direct, when in fact it may be indirect through prices at each plant being directly related to prices at other plants located between the two (i.e., prices may be correlated in a multivariate fashion that may not surface in bivariate comparisons). Multivariate analysis, on the other hand, 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 in the multivariate model is problematic. As such, little confidence can be placed in standard statistical tests.

The data set used for this analysis consists of daily prices from 28 plants. This large number of plants have highly correlated daily prices and therefore, collinearity is a degrading problem using multivariate time series. Thus, bivariate time series models are used.

Time Series Model

If plants are operating in the same geographic market for fed cattle procurement, their prices should not diverge from each other. This suggests price series from competing plants should be 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:

$$(1) \quad Y_{1t} = \beta_0 + \beta_1 Y_{2t} + e_t.$$

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. As Goodwin and Schroeder discuss, this test does not require that spatial equilibrium is always present or that disequilibrium over time is uncorrelated. 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, transaction, 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:

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

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[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).

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 OLS regression. Parameter estimates of the cointegrating regression are used to calculate estimates of the residual errors, $\hat{e}$, where

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

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

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

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 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). The VAR error correction model is:

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

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

where the models in (5) are similar to standard VARs using differenced data, though, the lagged error correction term (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 deviations from long-run spatial equilibrium. A speed-of-adjustment parameter close to 1 in absolute value[2] indicates rapid adjustment, and a value close to zero suggests slow to no adjustment. If α_{1y} is zero and all $\alpha_{12}(i)=0$, then plant 2 price does not Granger cause plant 1 price. Similarly, for plant 1 causing plant 2.

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[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.

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 all 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. Strength of cointegration can be measured by the magnitude of the ADF cointegration test statistic (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. Also, the speed of adjustment parameter (α_ys in equation (5)) indicates how rapidly prices at a plant adjust to price changes at another plant. Speed of adjustment parameters close to 1.0 suggest rapid information flow and reaction and parameters close to 0.0 reflect slow reactions.

The following models are designed to test relationships between several factors and the strength of cointegration, significance of causality, and speed of adjustment.

$$(6)\ ADF_{ij} = \beta_{10} + \beta_{11}Distance_{ij} + \beta_{12}Distance^2_{ij} + \beta_{13}Procurement\ Overlap_{ij} + \beta_{14}Cash\ Purchases_i + \beta_{15}Slaughter_{ij} + \beta_{16}Slaughter^2_{ij} + \beta_{17}Price\ Data_i + \beta_{18}Same\ Firm_i + \varepsilon_{1ij}$$

$$(7)\ FSTAT_{ij} = \beta_{20} + \beta_{21}Distance_{ij} + \beta_{22}Distance^2_{ij} + \beta_{23}Procurement\ Overlap_{ij} + \beta_{24}Cash\ Purchases_i + \beta_{25}Slaughter_{ij} + \beta_{26}Slaughter^2_{ij} + \beta_{27}Price\ Data_i + \beta_{28}Same\ Firm_i + \varepsilon_{2ij}$$

$$(8)\ SPEED_{ij} = \beta_{30} + \beta_{31}Distance_{ij} + \beta_{32}Distance^2_{ij} + \beta_{33}Procurement\ Overlap_{ij} + \beta_{34}Cash\ Purchases_i + \beta_{35}Slaughter_{ij} + \beta_{36}Slaughter^2_{ij} + \beta_{37}Price\ Data_i + \beta_{32}Same\ Firm_i + \varepsilon_{3ij}$$

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*, number of miles between plant i and plant j; *Distance-squared,* squared mileage; *Procurement Overlap,* percentage of plant i's cattle purchased from a region overlapping with plant j's procurement area; *Cash Purchases,* percentage of cattle purchased in the cash market by the plant over the estimation time period; *Slaughter,* number of cattle slaughtered by the plant during the period; *Slaughter-squared,* slaughter variable squared; *Price Data,* percentage of days over the period that daily price data were available (discussed later); and *Same Firm,* a binary variable equal to 1 if the two plants are owned by the same parent firm and equal to 0 otherwise.

The strength of spatial price relationships are expected to be related to costs and risks of spatial arbitrage. Some variables are pertinent to plants competing in the same geographic market. These include distance between plants, procurement overlap, plant size, and whether the plants are owned by the same firm. Other variables are included for model completeness.

As distance between plants increases, strength of spatial price relationships is expected to decline. Therefore, *Distance* is expected to be negatively related to the ADF cointegration test statistic. As distance increases, speed of price adjustment to spatial equilibrium as prices change would be expected to decline, implying *Distance* should be negatively related to the speed of adjustment parameter. The significance level of the Granger F-statistic is expected to be inversely related to the other two independent variables. As the ADF and speed of adjustment parameter increase, the significance level of the Granger F-statistic would be expected to decline (i.e., increased significance implies reduced p-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 a similar effect as distance. Plants in close proximity to each other would be 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.

Cash Purchases 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 uses predominantly 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. This would suggest a negative relation between *Cash Purchases* and *ADF* and *SPEED*, and a positive relation with *FSTAT*.

Slaughter captures the relation between plant size and spatial market integration. This variable 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 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). As detailed later, 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 as more missing data exists. This would suggest the more missing data (smaller *Price Data*), the more likely the plant price series would be 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* as 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 was expected to positively affect *ADF* and *SPEED* and negatively affect *FSTAT*.

Data

Plant-level transaction data were obtained from the Grain Inspection, Packers and Stockyards Administration (GIPSA). Transaction data provides a rich data set for analyses and helps ensure results reflect plant-level market behavior. However, primary data also present analytical problems.

The original data set consisted of transaction data for fed cattle slaughtered in 43 U.S. plants procured from 23 March 1992 through 3 April 1993. As a result of missing data, unreconcilable differences in data, incompatibilities in data across plants, or obvious errors, the data set was condensed to 28 plants. A total of 103,442 pens of cattle slaughtered comprising 12.3 million head were in the final data set. Plants were represented from the states of Texas, Kansas, Colorado, Nebraska, Iowa, Minnesota, northwestern states, and eastern states.[3] Only pens of steers, heifers, fed Holsteins, or mixed sexes, with 35 or more head (minimum number GIPSA collected), purchased in the cash (spot) market, with average carcass weights, and yield and quality grades recorded were used.

Numerous plants did not maintain consistent transaction 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. Our general rule was to use data that had "standard" industry specifications that could be used to compare prices across plants. As rules are relaxed, the size of the data set increases, but the confidence associated with comparing increasingly heterogenous prices rapidly becomes suspect.

Daily Plant Prices

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

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:

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[3]The northwestern and eastern states are not identified to maintain plant confidentiality.

$$\text{(9) } Price = \beta_0 + \beta_1 Heifer + \beta_2 Holstein + \beta_3 Mixed + \beta_4 Yield\ Grade\ 3 + \beta_5 Pen\ Size + \beta_6 Pen\ Size\ Squared + \beta_7 Average\ Hot\ Weight + \beta_8 Average\ Hot\ Weight\ Squared + \beta_9 Purchase\ to\ Kill\ Days + \beta_{10} Wholesale\ Value + \beta_{11} Average\ Plant\ Price + \varepsilon.$$

Variables are defined in table 1. Perfect collinearity among the sex variables required specifying a default pen of steers. Pens of heifers, fed Holsteins, or mixed sexes were each expected to receive lower prices than steers. The percentage of cattle grading 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. 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 is expected to be positively related to price. Average plant price is 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 2.

Table 1. Variable Definitions.

Variable	Variable Description
Price	Price paid for cattle on a hot carcass basis including transportation and commission to the packing plant ($/cwt).
Steer	Binary variable equal to 1 if pen is steers; equal to 0 otherwise.
Heifer	Binary variable equal to 1 if pen is heifers; equal to 0 otherwise.
Holstein	Binary variable equal to 1 if pen is Holsteins; equal to 0 otherwise.
Mixed	Binary variable equal to 1 if pen is mixed; equal to 0 otherwise.
Yield Grade 3	Percent of cattle in the pen grading yield grade 1 to 3 (%).
Pen Size	Number of head in the transaction (head).
Pen Size Squared	Pen Size squared.
Average Hot Weight	Average hot carcass weight of cattle in the pen (lbs.).
Average Hot Weight Squared	Average Hot Weight squared.
Purchase to Kill Days	The number of days between cattle purchase and plant delivery (days).
Wholesale Value	Daily Wholesale value. USDA Choice carcass cutout price times proportion of pen grading Choice or higher plus USDA Select carcass cutout price times proportion of pen grading Select or lower ($/cwt).
Average Plant Price	Average carcass price across all plants in study that day ($/cwt).

The model described in equation (9) is estimated separately for each plant and for all plants combined. Parameter estimates from all 28 plants combined are reported in table 3. The model explains 89 percent of price variability. All estimates are significant at the 0.001 level and have expected signs. Estimated price impacts of the nonlinear variables *(Pen Size* and *Average Weight)* are illustrated in figures 1 and 2. Premiums and discounts are comparable with previous work (Ward 1992; Schroeder et al.; and Jones et al.).

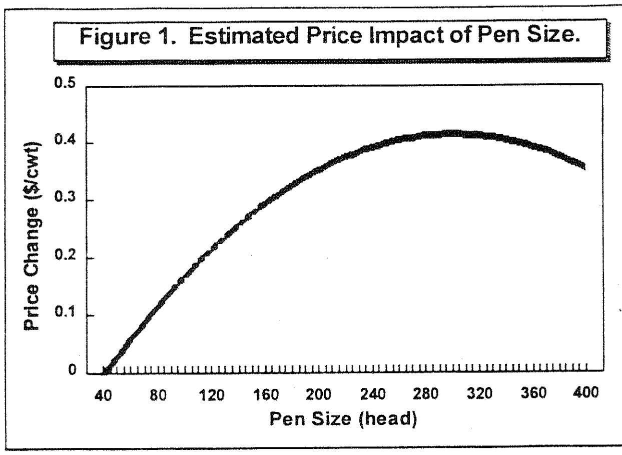
Table 2. Summary Statistics of Data used to Estimate Daily Price Explanatory Models.

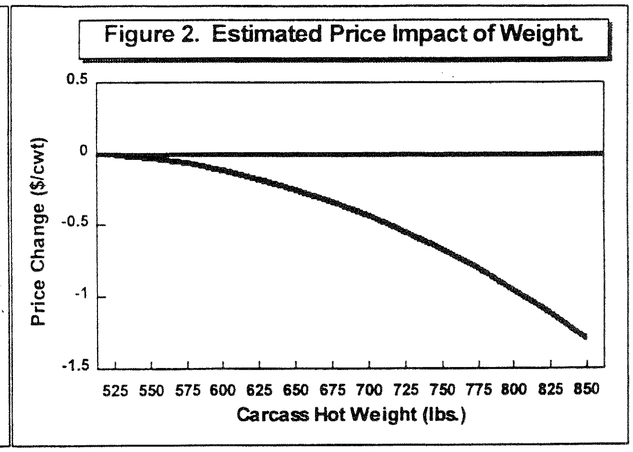
Variable	Average	Std. Dev.	Minimum	Maximum
Price ($/cwt)	121.61	6.05	91.47	148.58
Steer (binary)	0.56	-	0	1
Heifer (binary)	0.36	-	0	1
Holstein (binary)	0.01	-	0	1
Mixed (binary)	0.07	-	0	1
Yield Grade 3 (%)	95.55	5.84	0	100
Pen Size (head)	118.55	94.04	35	1055
Average Hot Weight (lbs.)	733.37	61.02	441.97	1021.57
Purchase to Kill Days (days)	5.84	3.08	0	30
Wholesale Value ($/cwt)	115.86	4.57	107.10	128.69
Average Plant Price ($/cwt)	121.61	5.62	112.64	138.50

Table 3. Price Adjustment Model Parameter Estimates, Combined Plant Data.

Variable	Estimate	t-statistic
Intercept	-6.1843	-7.954*
Heifer	-0.8687	-52.799*
Holstein	-6.0869	-111.673*
Mixed	-1.7248	-63.8798*
Yield Grade 3	0.0456	40.133*
Wholesale Value	0.0888	22.771*
Average Hot Weight	0.0097	4.929*
Average Hot Weight Squared	-9.95×10^{-6}	-7.468*
Pen Size	0.0037	21.166*
Pen Size Squared	-6.13×10^{-6}	-16.630*
Purchase to Kill Days	0.0747	35.095*
Average Plant Price	0.9142	288.041*
R-Squared	0.89	
RMSE	2.027	
Equation F-statistic (significance level)	74,454 (0.001)	
Observations (pens)	103,442	

Asterisk indicates significantly different from zero at the 0.0001 level.





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

The plant-specific models were used to estimate a daily carcass beef price at each plant. To do this, a selected standard pen characteristics of: 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 were plugged into the plant-specific hedonic models. For each day cattle were purchased in the cash market, actual price paid for each pen was adjusted for quality differentials typically paid by the plant. The simple average of these 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 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 the 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 pair-wise 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, pair-wise correlations of the plants' prices were nearly unaffected by replacing missing prices with proxies.

Additional data were needed to estimate equations (6)-(8). Distances between plants were estimated as optimized routes using SoftKey International Inc. software *Key Travel Map*. Procurement overlap of plants was obtained from Hayenga, Hook, and Jiang and represents the percentage of cattle purchases by a plant that overlaps the other plant's procurement area. Percentage of cattle purchased in the cash market and the slaughter number 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.

The cointegration tests suggest that 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 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 keeps the prices from diverging from each other 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 appropriate. Granger causality F-statistic results from the error correction VAR support plants in Nebraska as price leaders. Plants within Texas have only 50% of their F-statistics significant with each other. When 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 in 84% of the possible plant pair-wise comparisons in Texas, Kansas, and Colorado and 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. These results suggest 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.

The speed-of-adjustment parameters indicate how rapidly price in the plant reacts 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), suggesting that one-third of deviations from spatial price equilibrium were typically corrected in one day. Different prices at different plants react to and are reacted to differently.

Table 4 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, indicating that one-half of the total response to price changes at other plants are completed within one day. Plants in Nebraska as well as those located the rest of the country tend to react quite slowly to price changes in Texas and Kansas with typical price speed of adjustment parameters less than 0.20. This reinforces 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 indicate 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 operating in the same market would be expected to have rapid adjustments to price changes at other plants in the market.

Table 4. Average Speed of Adjustment Parameter Estimates from Error Correction Models, by Region.

Location of Causing Plants	Location of Plant being Caused by Plants in States in Left Column		
	Texas & Kansas	Nebraska & Colorado	Other States
Texas & Kansas	0.37	0.15	0.19
Nebraska & Colorado	0.45	0.43	0.35
Other States	0.35	0.35	0.29

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. Therefore, these equations were estimated using bootstrapping techniques (Efron).

The bootstrapping procedure is as follows: the model is initially estimated using ordinary least squares. The 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 the new dependent variable. The parameters from this estimation are stored. This process is repeated a large number of times storing the parameters each time. Parameter estimates are the means of the parameters across all estimations. Standard errors and other statistics can be calculated from this distribution of parameter estimates. Bootstrapping requires only that the residuals be independently and identically distributed. The bootstrapped coefficient estimates were obtained from 500 replications.

Summary statistics of the data used in the bootstrap equations are presented in table 5. Empirical estimates of the coefficients and implied t-statistics are reported in table 6. Nearly all of the variables have the a priori expected signs on their respective parameters. Most of the coefficient estimates are different from zero at the 0.05 level of significance.

Table 5. Summary Statistics of Variables Explaining Error Correction Test Statistics.

Variable	Mean	Standard Deviation	Minimum	Maximum
ADF Test Statistic	4.63	1.16	2.09	8.22
Granger F-Statistic	0.23	0.29	0.00	1.00
Speed of Adjustment	0.33	0.21	0.00	1.12
Distance (miles)	657.85	501.85	5.00	2970.00
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

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 findings of Goodwin and Schroeder. *Distance* was negative and statistically significant in the *FSTAT* equation, which was not expected. This indicates that plants that are located further from each other have higher levels of causality. This contrasts with Schroeder and Goodwin who found that as distance between markets increased, the strength of spatial price causality declined. Why these results are not consistent is not apparent. Several important differences between this study and their study make identifying the precise rationale for the different findings difficult.[4] In addition, and more importantly, this 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, multicollinearity is present between these two variables as might be expected.

[4]Important differences include: 1) the time periods, this study uses data from 1992-93, Schroeder and Goodwin (S-G) used data from 1976-87, 2) this data set consists of daily prices, S-G used weekly prices, 3) this study uses plant level prices, S-G used AMS aggregate market prices and terminal prices, and 4) these estimates are from an error correction model, S-G estimates were from a VAR in first-differences.

Procurement Overlap is an important determinant of spatial price relationships. Cointegration increases as expected for plants whose trade areas overlap. Similarly, firms with overlapping trade areas are more likely to have significant price causality with each other. Plants with overlapping trade areas also tend to react more quickly to spatial price shocks. Plants that have high percentages of cattle purchased in the cash market are less

Table 6. 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 (14.71)*	-0.169 (-1.15)	0.956 (7.68)*
Distance	-0.00174 (-6.07)*	-1.756×10^{-4} (-2.09)*	-1.428×10^{-4} (-2.49)*
Distance squared	5.524×10^{-7} (4.65)*	5.935×10^{-8} (1.66)	3.207×10^{-8} (1.33)
Procurement Overlap	0.0115 (6.34)*	-0.00143 (-2.56)*	6.231×10^{-4} (1.80)
Cash Purchases	-0.0148 (-3.42)*	0.00305 (2.40)*	-0.00316 (-2.98)*
Slaughter	-6.652×10^{-7} (-1.29)	3.616×10^{-7} (2.35)*	-5.088×10^{-7} (-3.76)*
Slaughter squared	1.156×10^{-13} (0.42)	-2.481×10^{-13} (-2.19)*	3.132×10^{-13} (3.10)*
Price Data	-0.0103 (-3.92)*	0.00253 (3.18)*	-0.00241 (-3.55)*
Same Firm	0.333 (3.72)*	-0.0180 (-0.63)	0.0297 (1.54)
OLS R-Squared	0.37	0.08	0.18
RMSE	0.920	0.278	0.186
Number of Observations	756	756	756
Dependent Variable Mean	4.63	0.229	0.332

T-statistics are reported in parentheses. Asterisk indicates statistically different from zero at 0.05 level.

likely to have prices cointegrated with other plants, slower to adjust to price changes elsewhere, and more likely to have price changes at other plants influence their prices. This could suggest that as plants reduce their use of the cash market, they are more apt to use external markets as sources of market information to determine their cash bids as opposed to incurring the increased costs of discovering local prices.

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 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 concern regarding filling their plant than concern regarding relative prices leading to greater pricing independence. Larger plants also naturally have more influence on prices because they purchase cattle over larger areas. This indicates 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 between the plant prices without missing data replaced and plant prices containing proxies for missing data were similar, 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 spatial equilibrium, and were less likely to have price changes caused by price changes at other plants. This indicates, 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 had actual prices been available throughout the period. This is not surprising in that prices used to proxy for missing data likely had less variability than actual data. However, the number of missing observations was correlated with plant size; smaller plants had more days without price quotes. Thus, this could be additional evidence of large plants operating independently in price discovery.

Plants owned by the same firm were more likely to have cointegrated prices. This indicates firms owning plants in different locations can more easily arbitrage across plants. This explains 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, as expected, that prices at the 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 are graphed as distance between plants increases 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:

$$(10)\quad \textit{Procurement Overlap} = 67.46 - \underset{(-27.84)}{0.109}\,(\textit{Distance}) + \underset{(19.49)}{0.000038}(\textit{Distance squared})$$

R-squared = 0.60, *t-statistics are in parentheses.*

Therefore, to allow overlap to adjust with distance, the above equation was substituted into the three regressions for the *Procurement Overlap* variable in creating the graphs of each statistic over distance. This equation suggests *Procurement Overlap* on average reaches zero as distance increases to about 900 miles. Figures 3, 4, and 5 illustrate how *ADF, FSTAT*, and *SPEED* change as distance between plants increases using estimates from the bootstrapped equations and making the above substitution for the *Procurement Overlap* value. *Distance* has little influence on the significance of the Granger F-statistic suggesting other factors are more important in price causality (figure 4). 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 1500 miles (figure 3). Plants are 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, however plants separated by 900 miles take 4 days to adjust (figure 5).

Figure 3. Impact of Distance between Plants on Cointegration Test Statistics, with Other Variables at their Means

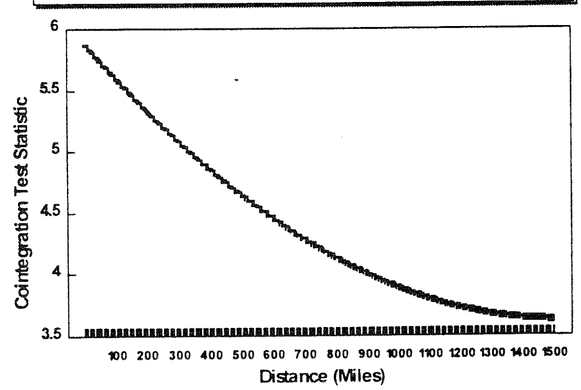


Figure 4. Impact of Distance between Plants on Granger F-Statistic Significance Level, with Other Variables at their Means

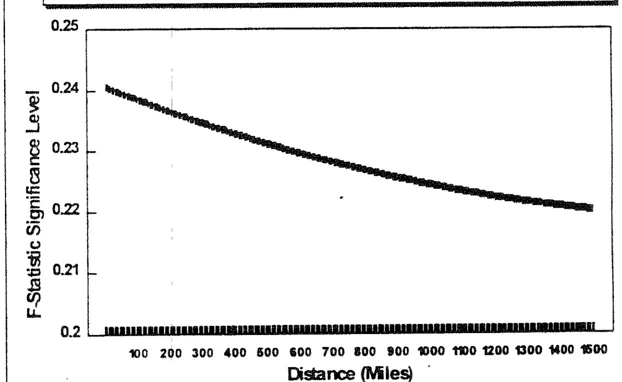
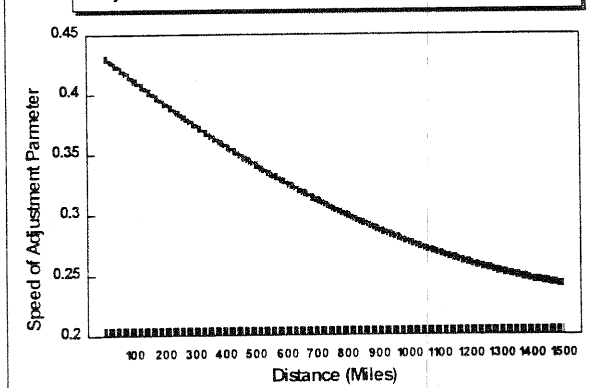


Figure 5. Impact of Distance between Plants on Speed of Adjustment Parameter, with Other Variables at their Means



Conclusions

Spatial price relationships among beef packing plants have important implications in defining geographic fed 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. Strength of market price relationships vary continuously therefore, relevant markets are also continuous measures.

Daily plant prices were generally cointegrated with over 95% of the 756 pair-wise plant comparisons being cointegrated. This indicates prices at the various 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 in their own area and were reacted to most quickly by other plants in the study. This suggests plants in Nebraska were price leaders and were a source of significant evolving price information.

Plants separated by long distances tend to have lower degrees of cointegration and are slower to react to price movement away from equilibrium. This is logical given the relatively high costs of shipping live cattle or carcasses long distances. This suggests 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. This indicates plants with smaller percentages of cattle purchased in the cash market and large plants are more independent in their cash market purchases than plants that rely exclusively on the cash market and small plants. This may also reflect larger plants being more concerned with keeping their plants full to maintain cost competitiveness than with cattle prices. This is important because it also indicates factors in addition to geographic locale are important in determining price relationships across plants.

Plants owned by the same firm have prices that are more cointegrated and react faster to each others price changes. This is expected as costs and risks associated with spatial trade are reduced if potential arbitrage is by plants owned by the same firm. In addition, information flow between the plants should be more direct and reliable making reacting to the news less risky.

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