Definition of Regional Cattle Procurement Markets

by

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PREFACE

Congress included $500,000 in the U.S. Department of Agriculture's (USDA) Packers and Stockyards Administration (now Grain Inspection, Packers and Stockyards Administration (GIPSA)) 1992 fiscal-year appropriation to conduct a study of concentration in the red meat packing industry. GIPSA solicited public comments on how to conduct the study and formed an interagency working group to advise the Agency on the study. Based on the public input and comments of the working group, GIPSA selected seven projects and contracted with university researchers for six of them.

The findings of the study are summarized in Packers and Stockyards Programs, GIPSA, USDA, *Concentration in the Red Meat Packing Industry*, February 1996. The technical reports of the contractors are published as a series of Grain Inspection, Packers and Stockyards Administration Research Reports (GIPSA-RR). The technical reports of the contractors are:

GIPSA-RR 96-1	Marvin L. Hayenga, Stephen R. Koontz, and Ted C. Schroeder, *Definition of Regional Cattle Procurement Markets*.
GIPSA-RR 96-2	Slaughter Cattle Procurement and Pricing Team, Texas A&M Agricultural Market Research Center, *Price Determination in Slaughter Cattle Procurement*.
GIPSA-RR 96-3	Clement E. Ward, Ted C. Schroeder, Andrew P. Barkley, and Stephen R. Koontz, *Role of Captive Supplies in Beef Packing*.
GIPSA-RR 96-4	S. Murthy Kambhampaty, Paul Driscoll, Wayne D. Purcell, and Everett D. Peterson, *Effects of Concentration on Prices Paid for Cattle*.
GIPSA-RR 96-5	Marvin L. Hayenga, V.J. Rhodes, Glenn A. Grimes, and John D. Lawrence, *Vertical Coordination in Hog Production*.
GIPSA-RR 96-6	Azzeddine Azzam and Dale Anderson, *Assessing Competition in Meatpacking: Economic History, Theory, and Evidence*. This project reviewed relevant research literature.

The seventh project analyzed hog procurement in the eastern Corn Belt, and was conducted by the Economic Research Service, U.S. Department of Agriculture. The findings of this project are included in the summary report on the study referenced above and are not published in a separate technical report.

This report is based on work performed under contract for GIPSA, USDA. The views expressed in this report are those of the authors and are not necessarily those of GIPSA or USDA.

ORGANIZATION OF REPORT AND CONTRIBUTORS

This project was completed by three research teams, each preparing its own report. They are combined in this publication as parts I, II, and III.

Clement E. Ward, Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma, was the overall project leader.

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ARBITRAGE COSTS BETWEEN REGIONAL FED CATTLE MARKETS:
ESTIMATES USING PUBLIC PRICE DATA

Introduction

Monitoring fed cattle pricing competitiveness and enforcement of the Packers and Stockyards Act require identification of regional economic market boundaries. Determining the relevant market is a critical first step in analyzing industry structure and performance, and in reviewing the economics of antitrust questions. Economic market boundaries identify separate geographic areas within which partial equilibrium analyses are valid. It is within the context of an economic market that, if the exercise of market power is possible, a firm may impose significant and nontransitory changes in price through noncompetitive conduct. Economic market definition specifies the relevant universe within which analyses of noncompetitive behavior and antitrust regulation should be focused.

While the concept of an economic market may be different from that of an antitrust market, a delineation necessary for antitrust action following the Merger Guidelines of the Federal Trade Commission and Department of Justice, the two concepts are closely related. Economic markets are defined by arbitrage while antitrust markets are defined by the ability of economic agents to exercise market power. An antitrust market for an oligopsony will be smaller or larger than the local economic market depending on the elasticities of demand for each oligopsonist.[1] However, defining economic markets is a useful first step for the more detailed procedure of identifying antitrust markets.

There is a long history of economic market definition which can be found in the antitrust literature. The theoretical constructs are summarized in industrial organization textbooks (e.g., Scherer). The regional economic markets used for fed cattle procurement market delineation in U.S. House of Representatives Small Business Committee studies in the late 1970s and more recent studies by Quail et al., and Marion et al., were estimated by Willard Williams based primarily on his analysis of fed cattle movements during the 1970s.

The relevant geographic market for industrial organization and antitrust analysis is often based on product flows of firms transacting in the same and closely related products. In addition, consideration may be given to competitors who may move into the trade area if prices change enough to make entry attractive. Some of the notable research of economic market definition includes Elzinga and Hogarty, Horowitz, and Stigler and Sherwin. Price correlations are often relied on as one tool to characterize product, firm, or geographic market relationships.

[1] An oligopsonist with inelastic demand will be less able to circumvent market power exercised by other firms than one with elastic demand. Therefore, this firm may be included in the local economic market but may not be included in the antitrust market.

However, price correlation findings may be misleading, especially in markets where the many other common factors that influence supply and demand conditions may have a stronger influence on price behavior than competitive arbitrage, or lack thereof, among geographic areas.

The classic procedure for market delineation involves estimating cross elasticities (Scheffman and Spiller). These types of measurements determine which firms have sufficiently strong direct effects on product flows; cross-supply elasticities delineate procurement areas. This approach can identify economic and antitrust markets. However, cross elasticity procedures are often impractical due to unavailability of product flow data. Further, making the necessary data available is costly.

One alternative procedure, which uses publicly available price data and which offers an inexpensive alternative to collecting firm-level price and quantity data, involves estimating arbitrage cost models. Implicit arbitrage costs can be estimated using historical geographic price differences. Observed prices from various geographic areas will implicitly contain information about the cost of arbitrage between the areas. These estimates can be compared with estimates of actual transaction costs. If the estimated implied costs are low relative to estimates of actual costs, the different geographic areas are well arbitraged and are likely in the same economic market.[2] Exercise of market power requires segmented markets. While arbitrage does not necessarily eliminate market power, low arbitrage costs across geographic areas do imply the existence of a larger economic market.

The research reported herein takes this alternative approach. Further, it will be useful to compare the findings of this approach with those using more data-intensive methods. To the extent that results are similar, using different approaches and data can reduce criticism of the research and may identify less costly monitoring methods to be used in the future.

Objective

Arbitrage cost models are used to identify regional fed cattle market boundaries between USDA AMS Market News price reporting districts. A comprehensive analysis of publicly available fed cattle price data is performed. The research provides information on degree with which U.S. geographic cattle price reporting regions are linked by estimating the implied arbitrage costs in observed market prices. Arbitrage costs include physical transportation costs, information gathering and processing costs, returns to risk, and regional market power. The implied arbitrage costs are used to identify geographic market boundaries, potential market isolation, and regions within which regulatory monitoring should be focused.

[2] This is true provided there is demand for the product in each geographic area, as there is in the cattle markets examined.

Previous Research

Considerable literature has been devoted to examining regional price dynamics and interactions in fed cattle markets. This research has usually been conducted within the context of efficient markets and price discovery. The objective of this literature has been to determine the relative effectiveness of different markets in incorporating information into price. Research on regional price dynamics can also provide information on the extent of geographic markets. Stigler and Sherwin concluded that comparisons of price movements are essentially equivalent to cross elasticities of demand in relevant market research.

Bailey and Brorsen used vector autoregression models to examine the dynamics of AMS weekly fed cattle prices from January 1978 through June 1983 in Idaho, Colorado, Texas, and Omaha, Nebraska. They surmised that Texas prices were generating the clearest signals of market conditions. Koontz et al., performed pairwise Granger causality tests on eight weekly AMS regional fed cattle markets using data from 1973 through 1984. They concluded that the eastern Nebraska direct market reacted the fastest to new market information, though some markets interacted with it. Schroeder and Goodwin applied vector autoregression methods to weekly AMS data from eleven regional cattle markets over the 1976-1987 period. They determined that the eastern Nebraska, Iowa-southern Minnesota, and western Kansas direct markets were the locations leading price discovery. They also found that the strength of the relationship was related to the distance between markets, market type, and relative market volumes. Hayenga and O'Brien, conducting correlation, vector autoregression, and co-integration analyses with weekly and daily AMS data, concluded that the relevant geographic market for fed cattle was larger than either plant trade areas or any state. Schultz used trade area cross elasticities to analyze the relevant market for fed cattle. She concluded that the Midwest-Texas market seemed to constitute a relevant market, with weaker ties to coastal regions. Goodwin and Schroeder (1991) examined the long-run equilibrium relationship between weekly AMS fed cattle prices in 11 regional markets from 1980 through 1987. They found that the strength of the relationship was positively related to increased packer concentration and negatively related to relative market volume and distance between markets.

Although relatively high correlations can be important information for market delineation, this analysis may not be sufficient to conclude whether prices for different geographic areas are in the same economic market. For example, common influences affect the price of fed cattle, e.g., variation in wholesale beef prices, which could contribute to high correlations. In addition, long-term trends in data series could contribute to high correlations. It is difficult to determine if co-movements in prices occur because the different areas are in the same economic market, because there is arbitrage between regions, or because the regions experience common changes in supply and demand conditions. This is a significant shortcoming of existing research. The reaction of regional prices to common supply and demand conditions does not imply the areas are in the same economic market.

Methods which examine discontinuous relationships between geographic prices, as opposed to the continuous linear measures, allow estimation of the implied distribution of arbitrage costs. These arbitrage cost models were developed due to the lack of quantity data for many products and also to circumvent the problem of geographic prices responding largely to the supply and demand factors common to all regions. These models have been used to assess boundaries for regional wholesale gasoline markets (Spiller and Huang; Spiller and Wood (1988b)), examine arbitrage of the Dollar-Sterling gold standard (Spiller and Wood (1988a)), and test integration of U.S. celery markets (Sexton et al.). This study is the first application of the method to fed cattle markets.

Method and Procedures

A statistical model is used to estimate the implied arbitrage costs from fed cattle prices observed across geographic areas. The method uses spatial equilibrium arbitrage conditions to specify a parametric relationship between regional prices. The spatial equilibrium arbitrage conditions state that, if the difference between two regional prices is large enough to cover arbitrage costs, the price in the high-price region must equal the price in the low-price region plus arbitrage costs. If the difference is less than arbitrage costs, price movements may be unrelated or related due to changes in common supply and demand conditions. There is no explicit use of actual transaction cost data in the model. Rather, implied arbitrage costs are revealed by how large (positive and negative) the difference between the two prices becomes and the frequency of these large differences.

The model is different from, and expands on, previous research in that it does not measure correlations between regional prices. The method ignores co-movements in price due to changing supply and demand conditions which are common between markets. Changes in these conditions are revealed by changes in price levels or changes in first differences of price levels across time. Rather, the method focuses on co-movements due to arbitrage which are revealed through changes in the difference between two prices. Co-movements due to arbitrage identify market boundaries whereas co-movements due to similar changes in regional supply and demand conditions do not.

The difference between prices in two regions, 1 and 2, between which there is no arbitrage, is assumed constant but stochastic

$$(1) \qquad Y_t = P_{1t} - P_{2t} = \alpha + \varepsilon_t$$

where the error term captures relative differences in local supply and demand shocks, is identically and independently distributed, and has a zero mean and variance σ^2. The subscript *t* denotes time. This is the relationship between prices in two markets where no arbitrage occurs. The transaction costs between the two regions have a distribution restricted to positive values

$$(2) \qquad T_{it} = T_i^* + \varepsilon_{it} > T_i^k \geq 0 \quad \text{for } i=1,2$$

where T_{it} represents stochastic arbitrage costs from region *i* to *j* with mean T_i^*, the variance of ε_{it} is σ_i^2, and T_i^k is the transaction cost lower bound. Arbitrage occurs only if the price difference exceeds transaction costs. In this case the equilibrium price difference equals those costs. If the price difference is small, no arbitrage takes place and the equilibrium price difference equals α. There are three mutually exclusive regimes:

$$
(3)\quad
\begin{array}{lll}
\text{Arbitrage from 2 to 1:} & P_{1t}-P_{2t} = T_2^*+\varepsilon_{2t} & \text{if } Y_t \geq T_{2t} \\
\text{Arbitrage from 1 to 2:} & P_{1t}-P_{2t} = -T_1^*-\varepsilon_{1t} & \text{if } Y_t \leq -T_{1t} \\
\text{No binding arbitrage:} & P_{1t}-P_{2t} = \alpha+\varepsilon_t & \text{if } -T_{1t} < Y_t < T_{2t}.
\end{array}
$$

The probability that each regime occurs is as follows:

$$
(4)\quad
\begin{array}{l}
\lambda_1 = \text{Prob}\{\varepsilon_t-\varepsilon_{2t} \geq -\alpha+T_2^*\} \\
\lambda_2 = \text{Prob}\{\varepsilon_t+\varepsilon_{1t} \leq -\alpha-T_1^*\} \\
\lambda_3 = \text{Prob}\{-T_1^*-\varepsilon_{1t} < \alpha+\varepsilon_t < T_2^*+\varepsilon_{2t}\} = 1-\lambda_1-\lambda_2.
\end{array}
$$

The probability of observing arbitrage ($\lambda_1+\lambda_2$) is a function of the arbitrage cost distributions and the distribution of supply and demand shocks that influence prices when no arbitrage occurs. With assumptions about the distribution of ε_t, ε_{1t}, and ε_{2t}, the model can be estimated yielding information on arbitrage costs and the probability of arbitrage between the two markets. Previous applications of this model have assumed ε_t is distributed normal and ε_{it}, i=1,2, are distributed from truncated normal distributions or from gamma distributions. The normal distribution assumption was used for the third regime and both assumptions for the distribution of ε_{it} were examined in this research. However, computational problems were encountered when using the truncated normal distribution; thus the remainder of the discussion is limited to the gamma distribution assumption.[3]

When transaction costs follow a gamma distribution, $T_{it} \sim \text{gamma}(\alpha_i, ß_i \mid T_{it}>0)$, the mean of the transaction cost distribution of arbitrage from region *i* to region *j* is

$$(5a)\quad E(T_{it}) = \alpha_i \cdot ß_i$$

and the variance of the transaction cost distribution is

$$(5b)\quad V(T_{it}) = \alpha_i \cdot ß_i^2.$$

The distribution is truncated at zero so T_i^k is zero. Assuming independence of ε_t, ε_{1t}, and ε_{2t}, the likelihood function of the arbitrage cost model is

[3] The truncation parameter was the source of the problem. This parameter violates conditions assumed when using maximum likelihood estimation, and this is likely the reason that the technique failed. The truncation parameter is not present in the gamma distribution.

$$(6) \quad L = \prod_{t=1}^{N} \{\lambda_1 f_{1t} + \lambda_2 f_{2t} + (1-\lambda_1-\lambda_2) f_{3t}\}$$

where

$$(6a) \quad \lambda_1 = \int_0^{\infty} [1-\Phi((u-\alpha)/\sigma)] \; u^{\alpha_2-1} \exp\{-u/ß_2\} \; / \; ß_2^{\alpha_2} \; \Gamma(\alpha_2) \; du$$

$$(6b) \quad \lambda_2 = \int_0^{\infty} [1-\Phi((u-\alpha)/\sigma)] \; u^{\alpha_1-1} \exp\{-u/ß_1\} \; / \; ß_1^{\alpha_1} \; \Gamma(\alpha_1) \; du$$

and

$$(6c) \quad f_{1t} = Y_t^{\alpha_2} \exp\{-Y_t/ß_2\}/[ß_2^{\alpha_2} \; \Gamma(\alpha_2)]$$

$$(6d) \quad f_{2t} = Y_t^{\alpha_1} \exp\{-Y_t/ß_1\}/[ß_1^{\alpha_1} \; \Gamma(\alpha_1)]$$

$$(6e) \quad f_{3t} = \varphi[(Y_t-\alpha)/\sigma]/\sigma$$

where $\Gamma(\cdot)$ is the incomplete gamma function, and $\varphi(\cdot)$ and $\Phi(\cdot)$ are the standard normal density and distribution functions.[4] The probability of arbitrage from market *i* to market *j* (λ_j) depends on parameters of the arbitrage cost distribution (α_i and $ß_i$). This restriction is incorporated into the model through equations (6a) and (6b).

Estimates of the parameters in (6) were obtained by maximizing the logarithm of the likelihood function less a smoothing penalty. The penalty is based on the size of the variances in each regime and the relative size of the gamma distribution parameters. The likelihood function is very similar to that of a switching regression model. A classic problem with switching regression models is that optimization algorithms may choose combinations of parameters that are pathological to finding the maximum of the likelihood function (Quandt and Ramsey). This phenomenon occurs when a variance of one of the regimes approaches zero. The model used in this research has the same problem. To correct this, the likelihood function is increasingly penalized as any one of the variances approaches zero.

[4] The arbitrage cost parameters and the probabilities of arbitrage are found not to be sensitive to the independence assumption.

The likelihood function also appeared to be an ill-posed optimization problem. The two gamma distribution parameters were highly negatively correlated. Optimization of the log-likelihood function without the penalty required close to one hundred iterations. Many adjustments were made to the two parameters although the resulting mean and variance of the arbitrage costs, (5a) and (5b), were essentially the same, and one parameter became very large while the other became very small often causing floating point calculation errors in computing. It is difficult for optimization algorithms to find a solution with this type of problem. Usually this indicates a scaling problem. In this case, the elements of the Hessian matrix are small for one or more parameters relative to other parameters in the matrix. This is the most common problem in nonlinear optimization. However, no amount of scaling helped the models estimated in this research. In fact, reasonable amounts of scaling did not change the solution path. To alleviate the difficulty with optimizing the ill-posed problem, the likelihood function was increasingly penalized when the gamma distribution parameters diverged greatly. Maximum penalized likelihood is very similar to shrinkage estimation (Titterington) which is well-known as a very good choice for ill-conditioned and ill-posed optimization problems (Judge et al.). However, the gamma distribution parameter estimates will be biased downwards.

The penalized likelihood functions were maximized using the MAXLIK routine (version 2.01) in the software package GAUSS-386 (version 2.2). The routine contains several optimization algorithms. Steepest Descent was used at the start of each optimization problem; the Broyden-Fletcher-Goldfarb-Shanno algorithm was used in intermediate iterations; and Newton-Raphson was used when each problem was close to a solution.[5] Numerical methods were used to calculate gradient vectors and Hessian matrices and to integrate equations (6a) and (6b). Asymptotic standard errors were calculated for the parameter estimates using White's method which uses the cross-product of the gradient vector and the inverse of the negative Hessian matrix

$$(7)\quad V(\theta) = N\cdot[\partial^2 LnL/\partial\theta\partial\theta']^{-1}[\partial LnL/\partial\theta\cdot\partial LnL/\partial\theta'][\partial^2 LnL/\partial\theta\partial\theta']^{-1}$$

where θ denotes the vector of parameters. If the model is specified correctly the inverse of the negative Hessian will be approximated well by the cross-product of the gradient. The method inflates estimates of variance in misspecified models.

Each maximum penalized likelihood problem was moderately sensitive to the choice of starting values. The mean and variance of the data series (Y_t) were used as starting values for α and σ^2. One thousand different sets of starting values were generated for α_1, $ß_1$, α_2, and $ß_2$. Each value was drawn randomly from a uniform distribution bounded by 0.25 and 4.0. A set of starting values was also generated using an adaptation of the EM algorithm (Kiefer). The EM algorithm estimates parameters in (6) without imposing the distribution restrictions in (6a) and

[5] This combination of algorithms was chosen for computational efficiency. The final parameter estimates were never affected by the choice of algorithm. Further, the Newton-Raphson algorithm is very demanding and shows the likelihood function is well behaved close to its maximum.

(6b). The likelihood was evaluated for each set of parameters and the set resulting in the highest value was used as the starting value for the final maximum penalized likelihood problem.

The results of interest for defining economic market boundaries with a given set of geographic prices are the arbitrage cost parameters and the probabilities of arbitrage. Estimates of the arbitrage cost parameters help identify whether different areas were likely to be contained in the same economic market if prices in one of the regions changed sufficiently. The results answer the question, how costly is arbitrage? Low costs suggest the areas in question are contained in the same economic market. High costs suggest some degree of economic market separation. In contrast, estimates of the probability of arbitrage help identify which regions frequently face binding arbitrage conditions. The results answer the question, how frequent is arbitrage (or how frequent is the binding arbitrage condition satisfied)? Arbitrage is expected to be infrequent between neighboring areas and more frequent between areas which are geographically more separate.

In addition to the general information about arbitrage, the model is used to test the 5% rule in the Federal Trade Commission and Department of Justice Merger Guidelines. The probability that no arbitrage occurs from market 1 to market 2 when the price in market 1 is 5% below the price in market 2 is calculated as follows. The 5% price difference implies

$$(8) \quad Y_t^* = P_{1t} - P_{2t} - \alpha = 0.95P_{2t} - P_{2t} - \alpha = -0.05P_{2t} - \alpha.$$

However, notice that the average difference in market prices when there is no arbitrage (α) is included to allow for different levels of excess supply and demand between the regions. Following Kiefer and Porter, this series is used with the maximum likelihood estimates to calculate the probability that each observation is in regime 2, i.e., arbitrage from market 1 to market 2

$$(9) \quad \omega_t = \lambda_2 f_{2t}(Y_t^*) \; / \; (\lambda_1 f_{1t}(Y_t^*) + \lambda_2 f_{2t}(Y_t^*) + \lambda_3 f_{3t}(Y_t^*)).$$

The probability that arbitrage occurs between the two markets is the sample average of ω_t. The probability that arbitrage does not occur between the two markets is one minus this sample average. A large probability of no arbitrage implies the two markets are segmented and do not pass the 5% rule. A small probability of no arbitrage implies the two markets are in the same economic market according to the 5% rule.

In addition to testing the 5% rule, a 2.5% price difference rule was also examined. Profit margins in the meatpacking industry are relatively small when expressed as a percent of gross margins or fed cattle costs. A 5% reduction in the fed cattle price in a given area would be a substantial exercise of market power. Thus, there is a need to test a smaller percentage price difference rule.

Data

Data used in the arbitrage cost models were obtained from USDA AMS LS-214 reports. Daily fed cattle price ranges for several terminal markets and all direct trade regions within the continental U.S. were used. The specific regional direct trade regions include:

- Illinois
- Iowa and Southern Minnesota
- Eastern Nebraska (eastern two-thirds of the state)
- Western Nebraska, Wyoming, and Southwest South Dakota
- Colorado
- Eastern Kansas
- Western Kansas
- Texas, Oklahoma, and New Mexico
- Arizona
- Southern California (El Centro - Desert Area)
- Northern California (Visalia - Southern San Joaquin Valley)
- Washington and Oregon
- Idaho

The following midwestern terminal markets and auction markets from the east coast complete coverage of the continental U.S.

- Omaha, Nebraska
- Sioux City, Iowa
- Lancaster County, Pennsylvania (local auctions).

The sample period used includes prices from January 1980 through December 1992. However, prices were not reported for eastern Kansas after December 1986. Prices for Choice 2-4 1100-1300 pound steers were used initially. After January 1988 AMS began reporting Choice 2-3 grade animals. This price was used to complete most of the series. However, prices for Choice 2-4 animals are reported more regularly for some of the upper midwest markets and were used in these cases. In addition, almost no cattle were marketed in Arizona and southern California in the 1100-1300 pound category. Thus, the 900-1100 pound price series was used for these two markets. This category was changed to 1000-1100 pounds after January 1988.

Some of the regional price series for heifers were also examined but the results are not reported. Heifer prices were reported slightly less frequently and the results were identical to those using steer prices. Further, it was not computationally possible to estimate the arbitrage costs between steer and heifer prices for the same geographic area because these costs are so small. The implication is that fed steers and heifers are in the same economic market.

There are 16 market price series used in this research. Pairwise differences of each series resulted in 120 models. The midpoint of daily price range was used. Nominal prices were also used.[6] Missing prices were replaced using the AMS reporting rule -- whereby a missing price is

[6] There is no trend in any of the paired differences, suggesting no need to deflate the price levels.

replaced with the most recent prior reported price. However, missing prices were replaced only if there is a reported price in the previous 9 business days. If prices are not reported in any one market for longer than 2 weeks, those days were not included in the analysis.

Results

Summary statistics for the price series are reported in table A1 in the appendix. Average prices are approximately $68/cwt. The prices range from $49/cwt. to $84/cwt. Markets in the southern plains states are the high-priced markets, while terminal markets, markets in the northwest and east coast are the low-priced markets. Summary statistics of the differences between prices are reported in table A2 in the appendix. The differences are generally small and variable. All of the differences range over positive and negative values allowing for the measurement of implicit costs of arbitrage in both directions.

Complete results of the maximum penalized likelihood estimation are presented in table A3 in the appendix. Estimates of all of the parameters are reported and P-values associated with the asymptotic standard errors accompany the estimates. The majority of the arbitrage cost parameters are highly significant. Further, the standard errors calculated from the inverse of the negative Hessian, the cross-product of the gradient matrix, and White's method are all very similar. This suggests that the model is specified correctly and that the data fit the model. The penalized log-likelihood value (LnL) is also reported, along with the value of the penalized log-likelihood function when arbitrage costs are not included in the model (LnL Null).[7] Testing the significance of the model with Likelihood Ratio statistics is not advised. The λ_i parameters violate the regularity assumption of maximum likelihood; the null is on the edge of the parameter space. Also, Likelihood Ratio tests may not be applicable with penalized likelihood functions. However, the models can be evaluated by examining improvements in Akaike's Information Criterion (AIC).[8] In over 90% of the models, the AIC improves substantially with the introduction of arbitrage costs. The models explain price differences well. However, there are a few problematic models.

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[7] When the arbitrage costs are not included ($\lambda_1 = \lambda_2 = 0$ or $\alpha_i = \beta_i = 0$ for i=1,2), the model reduces to a normal distribution for the price differences.

[8] The general form for the AIC is [ln(likelihood)-k] where k is the number of parameters. This measure is itself a penalized log-likelihood function.

The problem models are between the following 11 market pairs: Illinois and Iowa, Illinois and western Kansas, Omaha and eastern Kansas, Sioux City and eastern Kansas, western Nebraska and western Kansas, western Nebraska and Texas, Colorado and western Kansas, Colorado and Texas, eastern Kansas and western Kansas, eastern Kansas and Texas, and Arizona and Idaho. In each of these models, at least one arbitrage cost distribution was not estimable. With the exception of Arizona and Idaho, all of the pairs are neighboring markets or are relatively important marketplaces. The results imply that the arbitrage cost parameters cannot be reliably estimated. It is likely that the arbitrage costs are very small or that binding arbitrage rarely occurs. In the cases where both arbitrage cost distributions cannot be estimated, the likelihood value for the arbitrage cost model is the same as the likelihood value of the model without arbitrage. Failure of the model to estimate arbitrage costs suggests these pairs of geographic areas are in the same economic market or are completely separate markets.[9]

Average arbitrage costs between markets ($\alpha_i \cdot ß_i$ for i=1,2) are reported in table 1. These results and the standard deviation of arbitrage costs are also reported in table A3. The probabilities of binding arbitrage between markets (λ_1 and λ_2) are reported in table 2. Table 3 reports the probabilities of not observing arbitrage between two markets when the price in the market on the vertical axis is 5% below the price in the market on the horizontal axis. These are the three sets of measures that are crucial for determining economic market boundaries. Table 4 reports the probability of not observing arbitrage between two markets following the 2.5% rule. The information is similar to that in table 3.

In general, the means of the arbitrage costs are all relatively small. The estimates are between 1% and 5% of the average price level. Distances between each market were identified and transportation costs were calculated based on a \$0.40/cwt/100 miles variable cost figure. The arbitrage cost estimates were approximately equal to transportation cost figures for pairs of neighboring markets. For example, the distance between western Kansas (Liberal) and Texas (Amarillo) is approximately 200 miles, the transportation cost is \$0.80/cwt, and the arbitrage cost estimates are \$0.89/cwt. from western Kansas to Texas and \$0.66/cwt from Texas to western Kansas. The majority of the implicit arbitrage cost estimates were well below the transportation cost figures. Arbitrage cost estimates are small relative to the transportation costs because there is demand for fed cattle in all of the geographic areas.[10] Arbitrage costs are small relative to the transportation costs in neighboring areas because of the contiguous nature of cattle feeding. Transportation costs were calculated based on a distance between two cities while arbitrage occurs somewhere between the two locations.[11] The small estimated arbitrage costs

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[9] Co-integration and causality tests were conducted between each of these pairs of markets. All pairs are co-integrated and exhibit significant causality, and most exhibit bi-directional causality. The weakest relationship was between Arizona and Idaho.

[10] Arbitrage cost estimates also would be inflated if there are differences in cattle quality or differences in price reporting conventions across the geographic areas. The commodity is less similar in these cases and arbitrage costs are higher.

[11] The cities chosen were in the center of the largest area of production within each geographic region.

suggest that all of the U.S. fed cattle markets are reasonably well linked. The linkage is due to an indirect relationship through a relatively national market for fresh beef and the national transportation infrastructure. There are no geographic areas in the continental U.S. which are completely separate economic markets. However, the results also show that there is variation in the strength of the linkage between geographic areas.

Much of the variation in market integration appears in arbitrage cost asymmetry. The distance between two geographic areas is symmetric. Asymmetric arbitrage costs imply it is more costly to ship cattle in one direction than in the other. This implies market separation.[12] For example, the arbitrage cost estimates are \$1.72/cwt. from Idaho to Texas and \$3.13/cwt. from Texas to Idaho. Both of these figures are much lower than the transportation costs, but the asymmetry suggests that, within the national market for fed cattle, the Texas price achieves a much lower discount to the Idaho price before regional flows of cattle change. Idaho achieves a smaller discount to Texas before regional flows of cattle change. This is one of the more pronounced cases, but similar asymmetries occur between markets in the desert Southwest (southern California and Arizona) and markets in the Plains states (western Nebraska, Colorado, western Kansas, and Texas) and midwest markets west of the Mississippi River (eastern Nebraska and eastern Kansas). Likewise, there are asymmetries in arbitrage costs between plains states markets and midwest markets. Plains states markets achieve larger discounts to Midwest markets than the reverse; the results show it is more costly for the Plains markets to ship cattle to the Midwest than for the midwest to ship cattle to the plains. The asymmetry has structure. The results show costs are lower for a smaller volume market to ship cattle to a larger market with higher regional meatpacking plant capacity, while it is more costly for larger markets to ship cattle to smaller markets. This structure would mitigate the exercise of market power in smaller markets but suggests that smaller regional markets should not be considered part of the relevant market when examining market power in the larger regional markets.[13]

The probabilities of observing arbitrage (table 2) are, for the most part, also relatively small. The distribution of fed cattle across markets does not change often because arbitrage conditions are not triggered often, even given the relatively low average arbitrage costs. However, the standard errors of these estimates are very low suggesting that arbitrage conditions do occur. Arbitrage is necessary to link the system of markets together. For example, the

[12] Further, the direction of the asymmetry is inconsistent with lower costs because of backhauling.

[13] This conclusion should also apply to the delineation of antitrust markets. Within the context of Scheffman and Spiller, demand for fed cattle within the smaller capacity regions is more inelastic than demand by meatpackers in larger capacity regions. Therefore, the relevant antitrust market for the larger region may not include the smaller region while the smaller region would include the larger.

probability of arbitrage from Western Kansas to Texas is 7.5%, while arbitrage from Texas to western Kansas occurs 7.6% of the time. The probabilities are all very small within and between the group of markets in the Plains states and the group of markets in the upper Midwest.

The probabilities are much larger and asymmetric between these two groups of markets in the central U.S. and the east coast market, the southwest markets, and the Pacific northwest markets. For example, the probability of arbitrage from Texas to Idaho is 4.7% while arbitrage from Idaho to Texas occurs 28.4% of the time. The probability of arbitrage from Washington to Idaho is 4.7% while the probability of arbitrage from Idaho to Washington is 20.5%. The structure of the asymmetry is similar to that of the mean arbitrage costs. Results show it is more costly for large-volume markets to ship cattle to smaller markets; therefore, arbitrage occurs infrequently, and where the arbitrage costs are low, arbitrage occurs more frequently. The probability results lead to conclusions that are similar to those drawn from the arbitrage cost results. There is a separation of markets on the coasts from markets in the central U.S. There is also some separation between markets within the Southwest and Northwest. Larger volume areas need to be studied in isolation whereas the smaller volume areas should include the neighboring larger areas.

The probability of no arbitrage results generated from the 5% rule (table 3) complements the earlier findings. To determine whether or not effective arbitrage occurs with a 5% decrease in one market price, the probability estimate is compared to 0.5 relative to the standard error of the estimate (Lee and Porter). When the probability of no arbitrage is significantly larger than 50%, this implies segmented markets. A probability significantly less than 50% implies a single market. The standard errors of the probabilities are roughly 0.05. If the probability is 45% or less (≈1 standard error), the conclusion is that arbitrage occurs. If the probability is 68% or greater (≈3 standard errors), the conclusion is that arbitrage does not occur. This cautious interpretation errs toward finding larger economic markets. Further, it is somewhat necessary to draw conclusions from the results. This is discussed after the following paragraph.

When the price in Pennsylvania is reduced 5%, there is no effective arbitrage with any of the other market prices. Further, we can conclude there will be no arbitrage linking Pennsylvania with Colorado, western Kansas, Texas, and southern California. Pennsylvania is a separate economic market. Likewise, Arizona, southern California, northern California, Washington, and Idaho each display evidence of being a reasonably separate economic market. Arizona and southern California display strong separation from the Illinois, Omaha, and Sioux City markets. Northern California displays strong separation from the Iowa, eastern Nebraska, eastern Kansas, and plains markets. Washington and Idaho display strong separation from Pennsylvania. However, prices of fed cattle in Idaho are arbitraged with the terminal market prices, and Washington is arbitraged with the upper midwest markets of eastern Nebraska and eastern Kansas, and the northern plains markets of western Nebraska and Colorado. Upper midwest and northern plains cattle will move to the Pacific Northwest with a 5% price difference. The reverse does not occur.

The upper midwest geographic areas of Illinois, Iowa, eastern Nebraska, eastern Kansas, Omaha, and Sioux City appear to be an economic market, and the plains states geographic areas of western Nebraska, Colorado, western Kansas, and Texas also appear to be an economic market. There is effective arbitrage from some of the upper midwest markets to the plains states markets, in particular from Illinois to western Kansas, and from eastern Nebraska to western Kansas and Texas. However, there is little arbitrage from plains markets to midwest markets, and the arbitrage is not uniform between geographic areas of the two groups, while the arbitrage is very uniform between markets within each group. Further, many upper midwest geographic areas are distinctly separate from the two reporting regions in the desert Southwest.

While a 5% reduction in fed cattle prices is substantial, it is apparently not large enough to initiate much arbitrage. This is further supported by the probability of no arbitrage results generated from the 2.5% rule (table 4). Little regional arbitrage results from this smaller reduction in price.[14] It is interesting that a 5% reduction in price in many of the geographic areas does little to change regional flows of cattle. While the average arbitrage cost is relatively small, there appears to be enough variability in cost and arbitrage occurs infrequently enough that, in the short run, price in many fed cattle markets can be reduced 5% with little effect. However, the model uses daily observations so any price reduction likely will occur only for short time periods.

Summary and Conclusions

This research is a comprehensive examination of geographic arbitrage costs as revealed in publicly reported fed cattle price data. The work identifies the extent of economic markets within the set of geographic fed cattle areas and helps identify regions within which there is the greatest potential for the exercise market power. This information on the extent of regional economic markets is useful for focusing monitoring activities and executing public policy.

The estimated distributions of arbitrage costs were compared to transportation cost estimates. High arbitrage costs imply market isolation, separate economic markets, and an increased likelihood of market power. Estimated arbitrage costs were examined for symmetry between markets. The potential for exercise of market power is higher in a geographic area which is costly to arbitrage. The models reveal probabilities that various geographic areas do not exhibit direct arbitrage (i.e., the degree to which markets are separate) and the probability that direct arbitrage occurs (i.e., the two geographic areas are the same economic market). Also, the probability that reducing a price 5% will cause arbitrage from other regions was examined. This is a direct assessment of the potential for abusive market power as defined by the Federal Trade Commission and Department of Justice Merger Guidelines.

[14] Sioux City will ship to Omaha, Illinois will ship to Eastern Kansas, Colorado and Western Kansas will ship to Texas, and Idaho will ship to Washington.

The means of the arbitrage costs are small. The estimates are between 1% and 5% of the average price level. The arbitrage cost estimates were below the transportation cost estimates. The results suggest that all of the U.S. geographic fed cattle price reporting regions are reasonably well linked into a national fed cattle market. However, the markets are not perfectly integrated. There are some areas which form reasonably separate economic markets. Costs are lower for arbitrage from smaller volume markets to larger markets. It is much more costly for larger volume markets to ship cattle to smaller volume markets. This appears to be related to the level of regional meatpacking plant capacity. Arbitrage mitigates the exercise of market power in smaller markets but suggests that smaller regional markets should not be considered part of the relevant market when examining market power in the larger markets.

The probabilities of arbitrage are also small, especially within and between the group of markets in the Plains states and the group of markets in the upper Midwest. However, arbitrage does link these markets together. Arbitrage probabilities are much larger and more asymmetric between the markets in the central U.S. and the markets on the east coast, markets in the Southwest, and markets in the Northwest. The interpretation is the same as with the mean arbitrage costs. There is a separation of markets on the coasts from markets in the central U.S. and larger volume market areas need to be studied as separate markets, whereas the smaller volume market areas should include the neighboring larger volume markets within their relevant market definition.

The test of the 5% rule confirms Pennsylvania is a separate economic market, and that Arizona, Southern California, Northern California, Washington, and Idaho each appears to be a separate economic market. However, prices of fed cattle in Washington and Idaho are linked to markets in the northern Plains states and the upper Midwest. The upper midwest markets appear to be an economic market and the plains states markets also appear to be an economic market. There is arbitrage from the upper Midwest to the Plains states. However, there is little arbitrage from Plains states to Midwest. Arbitrage is uniform between markets within each of these two groups. Further, the upper Midwest is distinctly separate from the desert Southwest. The test also suggests that, for a period of 1 day to 1 week, it is relatively easy for price in many of the geographic areas to be reduced by 5% with little change in the regional flows of cattle.

A summary of how relevant economic markets should be defined for antitrust actions is as follows. Antitrust actions in the Plains states should consider only the plains states markets. Actions in the upper midwest markets should consider those markets and the Plains states markets. Actions in the desert Southwest and California should consider each market individually or the markets as a group. Actions in the Pacific Northwest should consider markets in the northern Plains and markets in the upper Midwest west of the Mississippi River. Actions in the Northeast should consider only east coast markets.

Tables

Table 1. Mean Transaction Costs ($/cwt. fed cattle) of Arbitrage from Market *x* to Market *y*.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	NCal	Wash	Idah
Penn		1.53	1.69	1.78	1.62	1.49	1.56	1.40	1.15	1.20	1.14	2.12	1.52	1.84	1.72	1.75
Illi	1.56		1.13	1.15	1.20	1.26	1.42	1.43	0.94	1.39	1.15	1.30	1.22	2.19	1.85	1.78
Omah	1.39	0.84		0.80	0.84	0.93	1.10	1.07	1.21	0.89	0.99	2.17	2.10	2.06	1.57	1.49
Siou	1.63	1.05	0.97		0.99	1.12	1.28	1.28	1.19	0.96	1.00	2.27	1.20	2.14	1.78	1.72
Iowa	1.20	----	0.78	0.88		0.93	1.20	1.27	1.16	1.01	1.10	2.26	2.28	2.01	1.61	1.73
ENeb	1.26	0.79	0.79	0.87	0.82		0.91	1.08	1.05	1.00	1.12	2.18	2.24	2.08	1.64	1.98
WNeb	1.31	0.96	0.87	0.99	0.95	0.93		1.01	0.78	0.89	1.04	2.14	2.22	2.09	1.45	2.05
Colo	1.26	0.86	0.87	0.88	0.90	0.94	0.76		0.86	----	1.07	2.20	2.15	2.04	1.60	2.53
EKan	1.15	0.80	----	----	0.93	1.04	0.73	0.70		----	----	1.68	1.80	2.02	1.57	2.41
WKan	1.14	----	0.77	0.86	0.84	0.84	----	----	----		0.89	2.27	2.29	2.15	2.55	2.82
Texa	1.20	0.65	0.79	0.83	0.85	0.82	----	----	----	0.66		2.09	2.07	2.39	2.60	3.13
Ariz	1.83	1.27	1.56	1.69	1.87	1.75	1.79	1.81	1.26	1.89	1.77		1.09	1.96	1.64	----
SCal	1.72	1.32	1.68	1.53	1.79	1.76	1.84	1.81	1.21	1.93	1.78	1.14		1.88	1.73	1.65
NCal	1.90	1.80	1.80	1.73	2.08	2.04	1.94	2.05	2.20	2.28	2.21	1.81	1.86		1.44	1.45
Wash	1.51	1.21	1.30	1.24	1.50	1.47	1.35	1.38	1.43	1.64	1.58	1.62	1.65	1.32		2.20
Idah	1.70	1.47	1.35	1.31	1.59	1.51	1.47	1.51	1.40	1.70	1.72	1.97	1.87	1.43	1.16	

Table 2. Probability of Arbitrage from Market *x* to Market *y*.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	NCal	Wash	Idah
Penn		0.251	0.196	0.238	0.171	0.173	0.180	0.173	0.160	0.142	0.142	0.427	0.227	0.287	0.216	0.267
Illi	0.258		0.097	0.145	0.075	0.053	0.070	0.071	0.058	0.070	0.060	0.219	0.224	0.257	0.135	0.168
Omah	0.239	0.118		0.168	0.074	0.066	0.104	0.096	0.115	0.065	0.067	0.187	0.188	0.232	0.160	0.207
Siou	0.264	0.161	0.184		0.064	0.060	0.082	0.077	0.092	0.062	0.067	0.179	0.235	0.250	0.136	0.173
Iowa	0.219	----	0.080	0.068		0.082	0.138	0.118	0.115	0.080	0.083	0.237	0.222	0.259	0.208	0.178
ENeb	0.197	0.061	0.068	0.065	0.089		0.137	0.114	0.103	0.068	0.078	0.258	0.232	0.228	0.198	0.120
WNeb	0.208	0.087	0.119	0.098	0.170	0.151		0.070	0.048	0.055	0.074	0.269	0.240	0.215	0.224	0.100
Colo	0.186	0.094	0.110	0.096	0.153	0.128	0.074		0.067	----	0.066	0.245	0.250	0.203	0.190	0.060
EKan	0.163	0.062	----	----	0.138	0.107	0.051	0.068		----	----	0.183	0.173	0.207	0.154	0.069
WKan	0.149	----	0.072	0.065	0.091	0.075	----	----	----		0.075	0.218	0.209	0.195	0.069	0.064
Texa	0.140	0.069	0.074	0.072	0.097	0.091	----	----	----	0.076		0.213	0.214	0.151	0.059	0.047
Ariz	0.430	0.226	0.233	0.206	0.245	0.287	0.262	0.258	0.224	0.275	0.284		0.113	0.167	0.202	----
SCal	0.207	0.217	0.215	0.203	0.254	0.273	0.245	0.265	0.235	0.271	0.295	0.114		0.193	0.190	0.249
NCal	0.275	0.262	0.266	0.281	0.248	0.264	0.264	0.261	0.241	0.257	0.251	0.252	0.248		0.127	0.157
Wash	0.238	0.193	0.189	0.184	0.223	0.235	0.247	0.276	0.184	0.261	0.269	0.214	0.206	0.138		0.048
Idah	0.269	0.191	0.235	0.220	0.235	0.250	0.236	0.263	0.300	0.291	0.284	0.181	0.237	0.161	0.205	

Table 3. Probability of No Arbitrage from Market *x* to Market *y* if the Price in Market *x* is 5% Below the Price in Market *y*.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	NCal	Wash	Idah
Penn		0.62	0.64	0.65	0.65	0.68	0.67	0.70	0.67	0.72	0.72	0.51	0.70	0.64	0.68	0.63
Illi	0.63		0.37	0.44	0.01	0.36	0.42	0.48	0.11	0.42	0.60	0.68	0.69	0.49	0.57	0.48
Omah	0.70	0.70		0.49	0.44	0.42	0.40	0.46	0.19	0.55	0.55	0.66	0.67	0.55	0.48	0.44
Siou	0.68	0.58	0.50		0.45	0.42	0.45	0.48	0.40	0.62	0.65	0.69	0.70	0.52	0.52	0.45
Iowa	0.75	----	0.59	0.59		0.42	0.37	0.37	0.44	0.47	0.49	0.54	0.58	0.54	0.47	0.49
ENeb	0.73	0.72	0.60	0.63	0.60		0.44	0.42	0.49	0.43	0.40	0.49	0.54	0.56	0.44	0.49
WNeb	0.72	0.67	0.64	0.63	0.64	0.57		0.37	0.26	0.01	0.03	0.47	0.52	0.55	0.43	0.50
Colo	0.72	0.75	0.66	0.72	0.71	0.61	0.65		0.39	----	0.01	0.46	0.48	0.58	0.44	0.58
EKan	0.70	0.69	----	----	0.69	0.66	0.69	0.74		----	----	0.68	0.66	0.61	0.45	0.54
WKan	0.71	----	0.66	0.60	0.66	0.63	----	----	----		0.34	0.49	0.52	0.58	0.59	0.58
Texa	0.66	0.85	0.68	0.65	0.70	0.70	----	----	----	0.66		0.47	0.50	0.57	0.60	0.63
Ariz	0.57	0.84	0.69	0.69	0.65	0.64	0.64	0.65	0.51	0.67	0.65		0.49	0.56	0.63	----
SCal	0.70	0.80	0.69	0.71	0.66	0.64	0.65	0.65	0.51	0.67	0.65	0.51		0.56	0.64	0.63
NCal	0.67	0.67	0.67	0.66	0.70	0.69	0.68	0.69	0.73	0.71	0.70	0.61	0.63		0.61	0.58
Wash	0.70	0.68	0.60	0.64	0.61	0.60	0.61	0.60	0.58	0.55	0.52	0.65	0.66	0.58		0.49
Idah	0.69	0.59	0.57	0.61	0.56	0.54	0.53	0.49	0.55	0.56	0.53	0.53	0.66	0.55	0.48	

Table 4. Probability of No Arbitrage from Market *x* to Market *y* if the Price in Market *x* is 2.5% Below the Price in Market *y*.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	NCal	Wash	Idah
Penn		0.67	0.71	0.68	0.73	0.72	0.71	0.69	0.60	0.69	0.67	0.57	0.63	0.65	0.69	0.66
Illi	0.68		0.68	0.65	0.58	0.76	0.77	0.82	0.27	0.78	0.82	0.62	0.59	0.69	0.79	0.73
Omah	0.68	0.58		0.60	0.62	0.64	0.67	0.75	0.69	0.80	0.80	0.75	0.74	0.69	0.72	0.64
Siou	0.65	0.57	0.43		0.71	0.75	0.75	0.80	0.73	0.80	0.79	0.77	0.55	0.69	0.78	0.71
Iowa	0.70	----	0.52	0.54		0.53	0.58	0.71	0.74	0.77	0.78	0.72	0.73	0.68	0.66	0.68
ENeb	0.70	0.63	0.56	0.58	0.52		0.57	0.62	0.71	0.73	0.76	0.69	0.72	0.69	0.65	0.75
WNeb	0.70	0.59	0.59	0.58	0.56	0.48		0.52	0.52	0.61	0.66	0.68	0.71	0.70	0.62	0.78
Colo	0.72	0.67	0.62	0.65	0.62	0.54	0.59		0.52	----	0.35	0.69	0.69	0.71	0.64	0.87
EKan	0.70	0.69	----	----	0.67	0.66	0.68	0.71		----	----	0.74	0.75	0.70	0.60	0.85
WKan	0.73	----	0.61	0.61	0.60	0.56	----	----	----		0.42	0.71	0.72	0.72	0.85	0.87
Texa	0.71	0.78	0.64	0.65	0.64	0.62	----	----	----	0.59		0.70	0.70	0.76	0.87	0.91
Ariz	0.58	0.72	0.66	0.67	0.70	0.67	0.70	0.71	0.47	0.70	0.68		0.54	0.72	0.70	----
SCal	0.67	0.71	0.67	0.67	0.67	0.67	0.70	0.70	0.50	0.70	0.66	0.50		0.70	0.71	0.66
NCal	0.66	0.70	0.69	0.67	0.75	0.72	0.72	0.73	0.77	0.75	0.75	0.73	0.73		0.75	0.72
Wash	0.66	0.67	0.66	0.66	0.72	0.72	0.70	0.70	0.68	0.72	0.72	0.71	0.71	0.66		0.80
Idah	0.66	0.69	0.67	0.67	0.72	0.69	0.68	0.68	0.66	0.69	0.71	0.69	0.73	0.67	0.43	

References

Bailey, D. and B.W. Brorsen. "Dynamics of Regional Fed Cattle Prices." *Western Journal of Agricultural Economics* 10(1985): 126-133.

Elzinga, K.G. and T.F. Hogarty. "The Problem of Geographic Market Delineation in Antimerger Suits." *Antitrust Bulletin* 18(1973): 45-81.

Goodwin, B.K. and T.C. Schroeder. "Testing Perfect Spatial Market Integration: An Application to Regional U.S. Cattle Markets." *North Central Journal of Agricultural Economics* 12(1990): 173-186.

Goodwin, B.K. and T.C. Schroeder. "Cointegration Tests and Spatial Price Linkages in Regional Cattle Markets." *American Journal of Agricultural Economics* 73(1991):452-464.

Hayenga, M.L. and D. O'Brien. Packer Competition and Forward Contracting Price Impacts and the Relevant Market for Fed Cattle. Research Bulletin 5-91, Research Institute on Livestock Pricing, Virginia Tech, September 1991.

Horowitz, I. "Market Definition in Antitrust Analysis: A Regression-Based Approach." *Southern Economics Journal* 48(1981): 1-16.

Judge, G.C., W.E. Griffiths, R.C. Hill, H. Lutkepohl, and T.C. Lee. *The Theory and Practice of Econometrics,* Second Edition. New York: John Wiley & Sons, 1988.

Kiefer, N.M. "A Note on Switching Regressions and Logistic Discrimination." *Econometrica* 48(1980): 1065-1069.

Koontz, S.R., P. Garcia, and M.A. Hudson. "Dominant-Satellite Relationships Between Live Cattle Cash and Futures Markets. *Journal of Futures Markets* 10(1990): 123-136.

Lee, L-F. and R.H. Porter. "Switching Regression Models with Imperfect Sample Separation Information - With an Application on Cartel Stability." *Econometrica* 52(1984): 391-418.

Marion, B., F. Geithman, and G. Quail. Monopsony Power in an Industry in Disequilibrium: Beef Packing, 1971-1986. Food System Organization-Performance and Public Policies Working Paper WP-96, Dept. of Agricultural Economics, University of Wisconsin, December 1990.

Porter, R.H. "A Study of Cartel Stability: The Joint Executive Committee, 1880-1886." *Bell Journal of Economics* 14(1983): 301-314.

Quail, G., B. Marion, F. Geithman, and J. Marquardt. "The Impact of Buyer Concentration on Live Cattle Prices." N.C. Project 117, Working Paper 89, May 1986.

Quandt, R.E. and J.B. Ramsey. "Estimating Mixtures of Normal Distributions and Switching Regressions." *Journal of the American Statistical Association* 73(1978): 730-752.

Scheffman, D.T. and P.T. Spiller. "Geographic Market Definition Under the U.S. Department of Justice Merger Guidelines." *Journal of Law and Economics* 30(1987): 123-147.

Scherer, F.M. *Industrial Market Structure and Economic Performance*. Chicago: Rand McNally. 1970.

Schroeder, T.C. and B.K. Goodwin. "Regional Fed Cattle Price Dynamics." *Western Journal of Agricultural Economics* 15(1990):111-122.

Schultz, M.M. The Relevant Geographic Market Area for Fed Cattle and the Changing Structure of the Beef Packing Industry. Unpublished Ph.D. Dissertation, Iowa State University, Ames, Iowa, 1988.

Sexton, R.J., C.L. Kling, and H.F. Carman. Market Integration, Efficiency of Arbitrage, and Imperfect Competition: Methodology and Application to U.S. Celery." *American Journal of Agricultural Economics* 73(1991): 568-580.

Spiller, P.T. and C.J. Huang. "On the Extent of the Market: Wholesale Gasoline in the Northeastern United States." *Journal of Industrial Economics* 35(1986): 131-145.

Spiller, P.T. and R.O. Wood. "Arbitrage during the Dollar-Sterling Gold Standard, 1899-1908: An Econometric Approach." *Journal of Political Economy* 96(1988a): 882-892.

Spiller, P.T. and R.O. Wood. "The Estimation of Transaction Costs in Arbitrage Models." *Journal of Econometrics* 39(1988b): 309-326.

Stigler, G.J. and R.A. Sherwin. "The Extent of the Market." *Journal of Law and Economics* 28(1985):555-585.

Titterington, D.M. "Common Structure of Smoothing Techniques in Statistics." *International Statistical Review* 53(1985): 141-170.

White, H. "Maximum Likelihood Estimation of Misspecified Models." *Econometrica* 50(1982): 1-25.

Appendix

Table A1. Summary Statistics of the Price-Level Series.

Market	Mean	Std. Dev.	Minimum	Maximum	Obs.	Missing
Penn	67.74	6.66	49.55	84.00	3315	0
Illi	67.54	6.89	58.50	82.50	3315	0
Omah	67.82	6.80	50.00	82.88	3315	0
Siou	67.60	6.95	49.25	83.25	3315	0
Iowa	68.05	6.74	49.75	82.00	3315	0
ENeb	68.17	6.77	50.00	82.25	3315	0
WNeb	68.08	6.81	49.25	82.00	3315	0
Colo	68.31	6.75	49.25	81.88	3315	0
EKan	64.07	4.52	50.75	75.12	1785	3
WKan	68.65	6.67	50.25	82.50	3315	0
Texa	68.70	6.60	50.25	82.00	3315	0
Ariz	68.13	6.28	49.75	80.00	3300	15
SCal	68.08	6.24	50.00	80.50	3315	0
NCal	67.60	6.56	50.75	80.25	3186	129
Wash	67.59	6.70	50.25	81.75	2926	389
Idah	67.68	6.87	49.50	82.00	3139	176

Table A2. Summary Statistics of the Difference Between Price Series.

Market 1	Market 2	Mean	Std Dev	Minimum	Maximum	Obs
Penn	Illi	0.195	1.712	-5.25	6.25	3315
	Omah	-0.084	1.841	-6.25	6.12	3315
	Siou	0.130	1.962	-6.00	6.25	3315
	Iowa	-0.315	1.843	-7.25	5.00	3315
	ENeb	-0.433	1.935	-7.25	5.00	3315
	WNeb	-0.347	1.961	-6.50	5.75	3315
	Colo	-0.571	2.086	-7.62	5.17	3315
	EKan	-0.811	2.131	-7.50	4.25	1782
	WKan	-0.919	2.096	-8.00	4.62	3315
	Texa	-0.970	2.091	-7.87	4.62	3315
	Ariz	-0.364	2.506	-9.50	8.00	3300
	SCal	-0.349	2.508	-10.45	7.25	3315
	NCal	0.226	2.278	-9.00	7.30	3186
	Wash	-0.171	2.200	-7.95	6.80	2926
	Idah	0.136	2.119	-8.50	6.80	3139
Illi	Omah	-0.279	0.878	-5.75	2.50	3315
	Siou	-0.064	0.937	-3.75	3.00	3315
	Iowa	-0.509	0.808	-5.25	2.00	3315
	ENeb	-0.628	0.955	-7.25	2.75	3315
	WNeb	-0.542	1.080	-8.25	4.00	3315
	Colo	-0.766	1.271	-8.75	3.50	3315
	EKan	-1.045	1.242	-4.75	2.50	1782
	WKan	-1.114	1.317	-8.75	3.00	3315
	Texa	-1.162	1.395	-8.50	2.75	3315
	Ariz	-0.559	2.501	-12.25	6.75	3300
	SCal	-0.544	2.486	-10.25	6.75	3315
	NCal	0.020	2.152	-9.50	7.00	3186
	Wash	-0.370	1.677	-7.25	4.50	2926
	Idah	-0.095	1.554	-7.25	4.75	3139

Market 1	Market 2	Mean	Std Dev	Minimum	Maximum	Obs
Omah	Siou	0.214	0.662	-2.00	3.00	3315
	Iowa	-0.230	0.674	-2.88	2.75	3315
	ENeb	-0.349	0.741	-3.00	4.75	3315
	WNeb	-0.263	0.880	-3.25	3.75	3315
	Colo	-0.487	1.057	-4.00	3.00	3315
	EKan	-0.570	1.036	-3.87	2.25	1782
	WKan	-0.835	1.142	-4.25	3.25	3315
	Texa	-0.883	1.198	-4.37	2.75	3315
	Ariz	-0.278	2.302	-11.50	7.12	3300
	SCal	-0.265	2.305	-9.25	5.75	3315
	NCal	0.295	1.955	-6.25	7.25	3186
	Wash	-0.109	1.389	-5.99	4.00	2926
	Idah	0.169	1.295	-5.75	4.25	3139
Siou	Iowa	-0.445	0.820	-3.75	2.50	3315
	ENeb	-0.563	0.910	-4.50	3.50	3315
	WNeb	-0.477	1.044	-5.75	3.00	3315
	Colo	-0.701	1.189	-5.75	2.75	3315
	EKan	-0.885	1.189	-4.75	2.00	1782
	WKan	-1.050	1.292	-6.50	3.00	3315
	Texa	-1.098	1.378	-6.25	2.75	3315
	Ariz	-0.492	2.490	-12.50	7.25	3300
	SCal	-0.480	2.485	-10.00	5.50	3315
	NCal	0.085	2.115	-7.50	7.00	3186
	Wash	-0.294	1.554	-6.62	4.00	2926
	Idah	-0.030	1.457	-6.50	3.75	3139
Iowa	ENeb	-0.119	0.614	-3.25	2.50	3315
	WNeb	-0.032	0.853	-3.25	3.75	3315
	Colo	-0.257	1.012	-4.00	3.00	3315
	EKan	-0.302	1.003	-4.00	2.25	1782

Market 1	Market 2	Mean	Std Dev	Minimum	Maximum	Obs
	WKan	-0.605	1.045	-4.00	2.25	3315
	Texa	-0.653	1.137	-4.75	2.25	3315
	Ariz	-0.049	2.266	-11.50	7.25	3300
	SCal	-0.035	2.250	-9.25	5.75	3315
	NCal	0.529	1.998	-7.50	7.25	3186
	Wash	0.141	1.478	-5.87	4.75	2926
	Idah	0.397	1.378	-5.75	5.00	3139
ENeb	WNeb	0.086	0.674	-3.25	4.75	3315
	Colo	-0.138	0.813	-3.50	3.50	3315
	EKan	-0.272	0.889	-3.50	2.25	1782
	WKan	-0.486	0.862	-4.00	2.25	3315
	Texa	-0.535	0.987	-4.25	2.75	3315
	Ariz	0.067	2.201	-11.50	7.25	3300
	SCal	0.084	2.183	-8.50	5.25	3315
	NCal	0.658	1.940	-9.50	7.00	3186
	Wash	0.236	1.387	-5.25	4.75	2926
	Idah	0.509	1.259	-4.50	4.50	3139
WNeb	Colo	-0.224	0.648	-3.00	3.50	3315
	EKan	-0.470	0.725	-3.25	2.75	1782
	WKan	-0.572	0.721	-3.75	2.75	3315
	Texa	-0.621	0.849	-4.50	2.00	3315
	Ariz	-0.018	2.169	-10.50	7.00	3300
	SCal	-0.002	2.170	-7.75	5.13	3315
	NCal	0.573	1.863	-6.25	8.00	3186
	Wash	0.184	1.318	-5.75	5.00	2926
	Idah	0.462	1.182	-4.25	4.25	3139
Colo	EKan	-0.191	0.579	-2.50	1.75	1782
	WKan	-0.348	0.553	-3.50	1.75	3315
	Texa	-0.396	0.648	-3.25	1.75	3315
	Ariz	0.206	2.050	-10.50	7.25	3300

Market 1	Market 2	Mean	Std Dev	Minimum	Maximum	Obs
	SCal	0.222	2.038	-7.75	4.50	3315
	NCal	0.801	1.786	-6.50	7.50	3186
	Wash	0.405	1.250	-5.00	5.00	2926
	Idah	0.676	1.146	-3.50	4.50	3139
EKan	WKan	-0.230	0.437	-3.00	1.50	1782
	Texa	-0.399	0.551	-3.50	2.25	1782
	Ariz	-0.377	2.107	-12.25	8.00	1767
	SCal	-0.330	2.047	-7.87	4.50	1782
	NCal	0.864	1.866	-5.25	7.75	1689
	Wash	0.200	1.161	-5.88	5.50	1550
	Idah	0.686	1.147	-3.75	5.00	1609
WKan	Texa	-0.048	0.493	-2.75	2.25	3315
	Ariz	0.552	1.966	-9.75	8.00	3300
	SCal	0.570	1.957	-7.00	5.00	3315
	NCal	1.147	1.774	-6.00	7.50	3186
	Wash	0.758	1.254	-5.25	6.75	2926
	Idah	1.009	1.192	-3.00	5.50	3139
Texa	Ariz	0.602	1.754	-8.75	7.75	3300
	SCal	0.618	1.758	-5.75	5.00	3315
	NCal	1.199	1.626	-5.25	7.75	3186
	Wash	0.762	1.168	-4.75	6.00	2926
	Idah	1.028	1.131	-2.75	5.00	3139
Ariz	SCal	0.017	0.770	-5.50	5.00	3300
	NCal	0.582	1.624	-7.50	8.00	3171
	Wash	0.049	1.752	-7.00	6.50	2911
	Idah	0.337	1.839	-7.00	8.75	3124
SCal	NCal	0.583	1.667	-6.50	8.00	3186
	Wash	0.026	1.815	-6.00	6.50	2926
	Idah	0.313	1.879	-4.75	7.75	3139

Market 1	Market 2	Mean	Std Dev	Minimum	Maximum	Obs
NCal	Wash	-0.439	1.504	-7.00	6.50	2797
	Idah	-0.189	1.484	-6.00	7.50	3010
Wash	Idah	0.310	0.833	-3.63	3.75	2926

Table A3. Parameter Estimates, P-Values, Arbitrage Cost Estimates, Probabilities of No Arbitrage, and Log-Likelihood Values.

Market 1 Market 2	Penn Illi	Penn Omah	Penn Siou	Penn Iowa	Penn ENeb	Penn WNeb	Penn Colo	Penn EKan	Penn WKan	Pen Tex
α	0.176 0.001	-0.239 0.001	0.142 0.045	-0.556 0.001	-0.747 0.001	-0.637 0.001	-0.968 0.001	-1.285 0.001	-1.353 0.001	-1.39 0.00
σ	1.471 0.001	1.764 0.001	1.810 0.001	1.780 0.001	1.917 0.001	1.935 0.001	2.102 0.001	2.158 0.001	2.086 0.001	2.07 0.00
α_1	1.730 0.001	1.702 0.001	1.848 0.001	1.477 0.001	1.350 0.001	1.454 0.001	1.282 0.001	1.067 0.201	1.138 0.001	1.15 0.00
$ß_1$	0.907 0.001	1.007 0.724	0.976 0.245	1.112 0.001	1.118 0.001	1.090 0.001	1.100 0.001	1.070 0.068	1.064 0.005	0.99 0.78
α_2	1.593 0.001	1.583 0.001	1.780 0.001	1.457 0.001	1.451 0.001	1.448 0.001	1.301 0.001	1.207 0.001	1.206 0.001	1.23 0.00
$ß_2$	0.978 0.377	0.876 0.001	0.914 0.001	0.823 0.001	0.868 0.001	0.904 0.001	0.966 0.157	0.952 0.144	0.947 0.031	0.97 0.19
λ_1	0.258 0.001	0.239 0.001	0.264 0.001	0.219 0.001	0.197 0.001	0.208 0.001	0.186 0.001	0.163 0.001	0.149 0.001	0.14 0.00
λ_2	0.251 0.001	0.196 0.001	0.238 0.001	0.171 0.001	0.173 0.001	0.180 0.001	0.173 0.001	0.160 0.001	0.142 0.001	0.14 0.00
$E(T_1)$	1.53	1.69	1.78	1.62	1.49	1.56	1.40	1.15	1.20	1.[illegible]
Std Dev(T_1)	1.17	1.30	1.31	1.34	1.29	1.30	1.24	1.10	1.13	1.[illegible]
$E(T_2)$	1.56	1.39	1.63	1.20	1.26	1.31	1.26	1.15	1.14	1.2
Std Dev(T_2)	1.24	1.10	1.22	1.00	1.05	1.09	1.10	1.05	1.04	1.[illegible]
Prob{1 / 2}	0.617	0.624	0.646	0.649	0.681	0.674	0.698	0.671	0.720	0.72
Prob{2 / 1}	0.627	0.698	0.678	0.747	0.729	0.721	0.724	0.702	0.710	0.65
LnL	-6748.4	-6997.7	-7232.2	-6985.8	-7142.2	-7194.1	-7385.2	-3996.6	-7381.9	-7373
LnL Null	-6800.7	-7019.9	-7248.5	-6991.9	-7166.4	-7220.2	-7418.5	-4009.3	-7409.8	-7400

Table A3. Continued. Page 2 of 10.

Market 1 Market 2	Penn NCal	Penn Wash	Penn Idah	Illi Omah	Illi Siou	Illi Iowa	Illi ENeb	Illi WNeb	Illi Colo	 EKa
α	0.356 0.001	-0.396 0.001	0.157 0.077	-0.350 0.001	-0.174 0.001	-0.446 0.001	-0.652 0.001	-0.575 0.001	-0.841 0.001	-1.19 0.00
σ	1.963 0.001	2.165 0.001	1.960 0.001	0.736 0.001	0.761 0.001	0.737 0.001	0.793 0.001	0.858 0.001	1.091 0.001	1.16 0.00
α_1	1.550 0.001	1.465 0.001	1.459 0.001	1.155 0.001	1.431 0.001	1.179 0.001	1.064 0.008	1.187 0.001	1.138 0.001	0.92 0.06
$ß_1$	1.202 0.001	1.188 0.001	1.215 0.001	0.986 0.596	0.828 0.001	1.025 0.163	1.180 0.001	1.190 0.001	1.251 0.567	1.01 0.33
α_2	1.717 0.001	1.514 0.001	1.657 0.001	1.193 0.001	1.506 0.001	0.001 0.001	0.828 0.003	1.034 0.274	1.016 0.001	0.94 0.26
$ß_2$	1.113 0.001	0.994 0.799	1.024 0.323	0.708 0.001	0.700 0.001	0.179 0.001	0.952 0.024	0.930 0.010	0.851 0.001	0.84 0.00
λ_1	0.275 0.001	0.238 0.001	0.269 0.001	0.118 0.001	0.161 0.001	0.001 0.001	0.061 0.001	0.087 0.001	0.094 0.001	0.06 0.00
λ_2	0.287 0.001	0.216 0.001	0.267 0.001	0.097 0.001	0.145 0.001	0.075 0.001	0.053 0.001	0.070 0.001	0.071 0.001	0.05 0.00
$E(T_1)$	1.84	1.72	1.75	1.13	1.15	1.20	1.26	1.42	1.43	0.9
Std Dev(T_1)	1.48	1.43	1.45	1.05	0.97	1.11	1.22	1.30	1.34	0.9
$E(T_2)$	1.90	1.51	1.70	0.84	1.05	0.01	0.79	0.96	0.86	0.8
Std Dev(T_2)	1.46	1.22	1.32	0.77	0.86	0.01	0.86	0.94	0.85	0.8
Prob{1 / 2}	0.640	0.675	0.630	0.365	0.440	0.007	0.365	0.420	0.481	0.11
Prob{2 / 1}	0.673	0.703	0.686	0.696	0.579	1.000	0.719	0.665	0.754	0.69
LnL	-7434.7	-6706.3	-7081.4	-4447.8	-4696.8	-4040.5	-4634.8	-5045.4	-5670.5	-3000
LnL Null	-7477.2	-6726.9	-7118.7	-4454.8	-4791.1	-4099.8	-4709.3	-5143.3	-5688.5	-3037

Table A3. Continued. Page 3 of 10.

Market 1 Market 2	Illi Ariz	Illi SCal	Illi NCal	Illi Wash	Illi Idah	Omah Siou	Omah Iowa	Omah ENeb	Omah WNeb	Oma Co
α	-1.176 0.001	-1.179 0.001	0.662 0.001	-0.386 0.001	0.017 0.580	0.108 0.001	-0.303 0.001	-0.407 0.001	-0.340 0.001	-0.62 0.00
σ	2.805 0.001	2.774 0.001	1.296 0.001	1.359 0.001	1.051 0.001	0.438 0.001	0.585 0.001	0.637 0.001	0.746 0.001	0.96 0.00
α_1	1.384 0.001	1.357 0.001	1.616 0.001	1.392 0.001	1.468 0.001	0.935 0.280	0.892 0.055	0.969 0.438	1.210 0.001	1.11 0.00
$ß_1$	0.952 0.262	0.910 0.025	1.307 0.001	1.313 0.001	1.198 0.001	0.873 0.001	0.948 0.001	0.967 0.001	0.921 0.001	0.96 0.00
α_2	1.655 0.001	1.600 0.001	2.094 0.001	1.519 0.001	1.771 0.001	1.558 0.001	1.002 0.947	0.882 0.001	1.143 0.001	1.14 0.00
$ß_2$	0.758 0.001	0.819 0.001	0.881 0.001	0.803 0.001	0.842 0.001	0.609 0.001	0.775 0.001	0.894 0.001	0.764 0.001	0.75 0.00
λ_1	0.226 0.001	0.217 0.001	0.262 0.001	0.193 0.001	0.191 0.001	0.184 0.001	0.080 0.001	0.068 0.001	0.119 0.001	0.11 0.00
λ_2	0.219 0.001	0.224 0.001	0.257 0.001	0.135 0.001	0.168 0.001	0.168 0.001	0.074 0.001	0.066 0.001	0.104 0.001	0.09 0.00
$E(T_1)$	1.30	1.22	2.19	1.85	1.78	0.80	0.84	0.93	1.10	1.0
Std Dev(T_1)	1.11	1.05	1.70	1.56	1.47	0.83	0.89	0.95	1.01	1.0
$E(T_2)$	1.27	1.32	1.80	1.21	1.47	0.97	0.78	0.79	0.87	0.8
Std Dev(T_2)	0.98	1.04	1.25	0.98	1.11	0.77	0.76	0.84	0.81	0.8
Prob{1 / 2}	0.680	0.690	0.494	0.569	0.481	0.486	0.441	0.423	0.395	0.45
Prob{2 / 1}	0.838	0.800	0.668	0.680	0.594	0.498	0.588	0.598	0.645	0.66
LnL	-7921.1	-7957.3	-7184.1	-5832.1	-5972.8	-3515.5	-3536.4	-3851.5	-4452.2	-5064
LnL Null	-7991.9	-8001.3	-7258.4	-5888.9	-6080.3	-3614.0	-3609.8	-3864.9	-4507.1	-5141

Table A3. Continued. Page 4 of 10.

Market 1 Market 2	Omah Texa	Omah Ariz	Omah SCal	Omah NCal	Omah Wash	Omah Idah	Siou Iowa	Siou ENeb	Siou WNeb	Siou Colo	Siou EKan	Siou WKan
α	-1.042 0.001	-0.175 0.073	-0.236 0.202	0.595 0.001	-0.118 0.001	0.185 0.001	-0.524 0.001	-0.624 0.001	-0.547 0.001	-0.809 0.001	-0.866 0.001	-1.209 0.001
σ	1.119 0.001	1.858 0.001	1.934 0.001	1.370 0.001	1.018 0.001	0.860 0.001	0.717 0.001	0.787 0.001	0.875 0.001	1.0633 0.001	0.182 0.001	1.203 0.001
α_1	0.981 0.586	1.391 0.001	1.416 0.001	1.976 0.001	1.379 0.001	1.609 0.001	1.017 0.616	1.063 0.027	1.196 0.001	1.147 0.001	1.223 0.001	0.957 0.073
$ß_1$	1.009 0.359	1.542 0.001	1.480 0.001	1.049 0.034	1.139 0.001	0.955 0.053	0.980 0.059	1.056 0.001	1.072 0.001	1.113 0.001	0.981 0.240	1.010 0.707
α_2	0.972 0.317	1.563 0.001	1.678 0.001	1.979 0.001	1.520 0.001	1.723 0.001	1.046 0.153	0.939 0.129	1.177 0.001	1.097 0.001	0.001 0.001	0.956 0.188
$ß_2$	0.818 0.001	1.010 0.698	1.013 0.554	0.923 0.001	0.860 0.001	0.783 0.001	0.846 0.001	0.930 0.001	0.849 0.001	0.805 0.001	0.167 0.001	0.897 0.001
λ_1	0.074 0.001	0.233 0.001	0.215 0.001	0.266 0.001	0.189 0.001	0.235 0.001	0.068 0.001	0.065 0.001	0.098 0.001	0.096 0.001	0.001 0.723	0.065 0.001
λ_2	0.067 0.001	0.187 0.001	0.188 0.001	0.232 0.001	0.160 0.001	0.207 0.001	0.064 0.001	0.060 0.001	0.082 0.001	0.077 0.003	0.092 0.001	0.062 0.001
$E(T_1)$	0.99	2.17	2.10	2.06	1.57	1.49	0.99	1.12	1.28	1.28	1.19	0.96
Std Dev(T_1)	1.00	1.83	1.77	1.47	1.34	1.18	0.98	1.09	1.17	1.19	1.08	0.99
$E(T_2)$	0.79	1.56	1.68	1.80	1.30	1.35	0.88	0.87	0.99	0.88	0.01	0.86
Std Dev(T_2)	0.81	1.26	1.30	1.29	1.05	1.03	0.86	0.90	0.92	0.84	0.01	0.88
Prob{1 / 2}	0.553	0.658	0.675	0.548	0.480	0.440	0.454	0.423	0.445	0.480	0.402	0.623
Prob{2 / 1}	0.678	0.694	0.691	0.672	0.600	0.573	0.586	0.632	0.633	0.721	1.000	0.602
LnL	-5466.0	-7694.6	-7782.6	-6950.6	-5273.6	-5460.7	-4201.3	-4549.6	-5033.0	-5463.7	-2901.3	-5716.1
LnL Null	-5534.3	-7736.8	-7799.6	-6951.1	-5315.6	-5492.0	-4254.3	-4573.0	-5051.8	-5507.2	-2910.3	-5776.7

Table A3. Continued. Page 5 of 10.

Market 1 Market 2	Siou Texa	Siou Ariz	Siou SCal	Siou NCal	Siou Wash	Siou Idah	Iowa ENeb	Iowa WNeb	Iowa Colo	Iowa EKan	Iowa WKan	Iowa Texa
α	-1.281 0.001	-0.282 0.170	-1.078 0.001	0.591 0.001	-0.292 0.001	0.044 0.134	-0.165 0.001	-0.085 0.001	-0.354 0.001	-0.430 0.001	-0.741 0.001	-0.807 0.001
σ	1.295 0.001	1.924 0.001	2.730 0.001	1.363 0.001	1.196 0.001	1.012 0.001	0.499 0.001	0.647 0.001	0.876 0.001	0.897 0.001	0.968 0.001	1.055 0.001
α_1	0.994 0.820	1.266 0.001	1.452 0.001	1.651 0.001	1.383 0.001	1.532 0.001	1.048 0.238	1.469 0.001	1.371 0.001	1.303 0.001	1.058 0.015	1.119 0.001
$ß_1$	1.101 0.577	1.754 0.001	0.832 0.001	1.265 0.001	1.276 0.001	1.114 0.001	0.893 0.001	0.838 0.001	0.934 0.001	0.898 0.001	0.963 0.001	0.988 0.304
α_2	0.969 0.322	1.682 0.001	1.581 0.001	1.874 0.001	1.523 0.001	1.683 0.001	1.087 0.003	1.457 0.001	1.344 0.001	1.392 0.001	1.135 0.001	1.124 0.001
$ß_2$	0.863 0.001	1.020 0.484	0.967 0.093	0.942 0.006	0.825 0.001	0.791 0.001	0.757 0.001	0.657 0.001	0.674 0.001	0.671 0.001	0.747 0.001	0.760 0.001
λ_1	0.072 0.001	0.206 0.001	0.203 0.001	0.281 0.001	0.184 0.001	0.220 0.001	0.089 0.001	0.170 0.001	0.153 0.001	0.138 0.001	0.091 0.001	0.097 0.001
λ_2	0.067 0.001	0.179 0.001	0.235 0.001	0.250 0.001	0.136 0.001	0.173 0.001	0.082 0.001	0.138 0.001	0.118 0.001	0.115 0.001	0.080 0.001	0.083 0.001
$E(T_1)$	1.00	2.27	1.20	2.14	1.78	1.72	0.93	1.20	1.27	1.16	1.01	1.10
Std Dev(T_1)	1.00	2.00	1.00	1.65	1.51	1.38	0.91	1.00	1.08	1.01	0.99	1.04
$E(T_2)$	0.83	1.69	1.53	1.73	1.24	1.31	0.82	0.95	0.90	0.93	0.84	0.85
Std Dev(T_2)	0.85	1.31	1.22	1.27	1.01	1.01	0.79	0.79	0.78	0.79	0.79	0.80
Prob{1 / 2}	0.647	0.687	0.702	0.520	0.520	0.447	0.420	0.369	0.367	0.438	0.471	0.486
Prob{2 / 1}	0.652	0.689	0.706	0.663	0.645	0.609	0.595	0.644	0.709	0.691	0.664	0.695
LnL	-5936.5	-7963.8	-8001.8	-7137.8	-5602.4	-5777.9	-3238.4	-4383.6	-4946.6	-2642.4	-5023.1	-5308.0
LnL Null	-6001.9	-8020.4	-8005.6	-7192.7	-5658.4	-5869.1	-3297.3	-4437.7	-5014.6	-2685.9	-5102.1	-5387.3

Table A3. Continued. Page 6 of 10.

Market 1 Market 2	Iowa Ariz	Iowa SCal	Iowa NCal	Iowa Wash	Iowa Idah	ENeb WNeb	ENeb Colo	ENeb EKan	ENeb WKan	ENeb Texa	ENeb Ariz	ENeb SCal
α	0.521 0.001	0.397 0.001	0.821 0.001	0.191 0.001	0.351 0.001	-0.001 0.894	-0.214 0.001	-0.372 0.001	-0.569 0.001	-0.635 0.001	-0.668 0.001	0.530 0.001
σ	1.372 0.001	1.529 0.001	1.312 0.001	1.036 0.001	0.929 0.001	0.490 0.001	0.659 0.001	0.758 0.001	0.770 0.001	0.887 0.001	1.240 0.001	1.362 0.001
α_1	1.524 0.001	1.585 0.001	2.050 0.001	1.644 0.001	2.069 0.001	1.075 0.076	1.238 0.001	1.194 0.001	1.025 0.367	1.109 0.001	1.559 0.001	1.594.0 0.001
β_1	1.429 0.001	1.401 0.001	1.022 0.369	0.998 0.935	0.896 0.001	0.867 0.001	0.885 0.001	0.887 0.001	0.977 0.086	1.013 0.389	1.358 0.001	1.376 0.001
α_2	1.927 0.001	1.818 0.001	2.217 0.001	1.758 0.001	1.843 0.001	1.443 0.001	1.302 0.001	1.384 0.001	1.049 0.096	1.057 0.029	1.825 0.001	1.745 0.001
β_2	0.987 0.579	1.001 0.945	0.940 0.001	0.861 0.001	0.857 0.001	0.642 0.001	0.724 0.001	0.757 0.001	0.799 0.001	0.778 0.001	0.978 0.307	1.026 0.167
λ_1	0.245 0.001	0.254 0.001	0.248 0.001	0.223 0.001	0.235 0.001	0.151 0.001	0.128 0.001	0.107 0.001	0.075 0.001	0.091 0.001	0.287 0.001	0.273 0.001
λ_2	0.237 0.001	0.222 0.001	0.259 0.001	0.208 0.001	0.178 0.001	0.137 0.001	0.114 0.001	0.103 0.001	0.068 0.001	0.078 0.001	0.258 0.001	0.232 0.001
$E(T_1)$	2.26	2.28	2.01	1.61	1.73	0.91	1.08	1.05	1.00	1.12	2.18	2.24
Std Dev(T_1)	1.81	1.80	1.42	1.26	1.23	0.88	0.97	0.96	0.99	1.06	1.73	1.76
$E(T_2)$	1.87	1.79	2.08	1.50	1.59	0.93	0.94	1.04	0.84	0.82	1.75	1.76
Std Dev(T_2)	1.35	1.33	1.40	1.14	1.17	0.77	0.82	0.89	0.82	0.80	1.30	1.34
Prob{1 / 2}	0.542	0.582	0.544	0.469	0.487	0.435	0.418	0.495	0.429	0.403	0.494	0.538
Prob{2 / 1}	0.654	0.659	0.695	0.612	0.562	0.565	0.606	0.663	0.634	0.703	0.638	0.645
LnL	-7605.8	-7671.1	-7037.1	-5518.1	-5721.6	-3572.0	-4199.6	-2419.9	-4369.0	-4828.7	-7444.9	-7537.3
LnL Null	-7691.2	-7703.4	-7038.9	-5519.5	-5740.4	-3649.7	-4277.8	-2461.2	-4432.5	-4894.6	-7578.5	-7591.7

Table A3. Continued. Page 7 of 10.

Market 1 Market 2	ENeb NCal	ENeb Wash	ENeb Idah	WNeb Colo	WNeb EKan	WNeb WKan	WNeb Texa	WNeb Ariz	WNeb SCal	WNeb NCal	WNeb Wash	WNeb Idah
α	0.825 0.001	0.263 0.001	0.384 0.001	-0.254 0.001	-0.532 0.001	-0.559 0.001	-0.594 0.001	0.689 0.001	0.560 0.001	0.788 0.001	0.209 0.001	0.302 0.001
σ	1.289 0.001	0.929 0.001	0.924 0.001	0.540 0.001	0.655 0.001	0.699 0.001	0.821 0.001	1.162 0.001	1.306 0.001	1.242 0.001	0.921 0.001	0.914 0.001
α_1	2.274 0.001	1.773 0.001	2.473 0.001	1.100 0.006	0.778 0.038	0.919 0.050	1.057 0.031	1.486 0.001	1.539 0.001	2.370 0.001	1.590 0.001	2.571 0.001
$ß_1$	0.968 0.173	0.963 0.100	0.876 0.001	0.922 0.001	0.998 0.918	0.974 0.064	0.985 0.301	1.382 0.001	1.400 0.001	0.915 0.001	0.945 0.009	0.867 0.001
α_2	2.072 0.001	1.822 0.001	1.940 0.001	0.884 0.008	0.821 0.014	0.001 0.001	0.001 0.001	2.023 0.001	1.990 0.001	2.096 0.001	1.749 0.001	1.971 0.001
$ß_2$	0.983 0.361	0.808 0.001	0.782 0.001	0.860 0.001	0.883 0.001	0.212 0.001	0.185 0.001	0.911 0.001	0.948 0.002	0.931 0.001	0.774 0.001	0.751 0.001
λ_1	0.264 0.001	0.235 0.001	0.250 0.001	0.074 0.001	0.051 0.001	0.001 0.892	0.001 0.849	0.262 0.001	0.245 0.001	0.264 0.001	0.247 0.001	0.236 0.001
λ_2	0.228 0.001	0.198 0.001	0.120 0.001	0.070 0.001	0.048 0.001	0.055 0.001	0.074 0.001	0.269 0.001	0.240 0.001	0.215 0.001	0.224 0.001	0.100 0.001
$E(T_1)$	2.08	1.64	1.98	1.01	0.78	0.89	1.04	2.14	2.22	2.09	1.45	2.05
Std Dev(T_1)	1.40	1.25	1.30	0.97	0.88	0.93	1.01	1.73	1.77	1.37	1.16	1.31
$E(T_2)$	2.04	1.47	1.51	0.76	0.73	0.01	0.01	1.79	1.84	1.94	1.35	1.47
Std Dev(T_2)	1.42	1.09	1.09	0.81	0.80	0.01	0.01	1.27	1.31	1.34	1.02	1.05
Prob{1 $\underline{/}$ 2}	0.555	0.443	0.495	0.370	0.263	0.01	0.03	0.470	0.520	0.548	0.428	0.503
Prob{2 $\underline{/}$ 1}	0.688	0.604	0.543	0.646	0.695	1.00	1.00	0.640	0.650	0.680	0.607	0.527
LnL	-6946.9	-5323.2	-5467.7	-3407.2	-2023.1	-3703.1	-4258.2	-7395.1	-7529.6	-6815.8	-5173.6	-5277.6
LnL Null	-6951.2	-5339.1	-5469.4	-3451.1	-2054.7	-3714.6	-4268.6	-7533.3	-7580.0	-6816.9	-5188.3	-5315.6

Table A3. Continued. Page 8 of 10.

Market 1 Market 2	Colo EKan	Colo WKan	Colo Texa	Colo Ariz	Colo SCal	Colo NCal	Colo Wash	Colo Idah	EKan WKan	EKan Texa	EKan Ariz	EKan SCal
α	-0.220 0.001	-0.348 0.001	-0.341 0.001	0.743 0.001	0.714 0.001	0.846 0.001	0.353 0.001	0.431 0.001	-0.228 0.001	-0.399 0.001	-0.618 0.017	-0.592 0.001
σ	0.496 0.001	0.552 0.001	0.594 0.001	1.137 0.001	1.206 0.001	1.230 0.001	0.884 0.001	0.961 0.001	0.431 0.001	0.548 0.001	2.004 0.001	2.007 0.001
α_1	0.958 0.512	0.001 0.001	1.140 0.001	1.720 0.001	1.709 0.001	2.631 0.001	2.095 0.001	3.068 0.001	0.007 0.001	0.001 0.001	1.172 0.001	1.419 0.001
$ß_1$	0.902 0.001	2.738 0.001	0.942 0.001	1.269 0.001	1.253 0.001	0.837 0.001	0.833 0.001	0.903 0.001	2.301 0.001	0.348 0.001	1.445 0.001	1.291 0.001
α_2	0.848 0.018	0.001 0.001	0.001 0.001	2.166 0.001	2.084 0.001	2.100 0.001	1.820 0.001	1.952 0.001	0.001 0.001	0.001 0.001	1.557 0.001	1.637 0.001
$ß_2$	0.824 0.001	2.954 0.001	0.196 0.001	0.857 0.001	0.888 0.001	0.970 0.110	0.758 0.001	0.777 0.001	0.359 0.001	0.346 0.001	0.807 0.001	0.736 0.001
λ_1	0.068 0.001	0.001 0.001	0.001 0.815	0.258 0.001	0.265 0.001	0.261 0.001	0.276 0.001	0.263 0.001	0.001 0.001	0.001 0.001	0.224 0.001	0.235 0.001
λ_2	0.067 0.001	0.001 0.001	0.066 0.001	0.245 0.001	0.250 0.001	0.203 0.001	0.190 0.001	0.060 0.001	0.001 0.001	0.001 0.001	0.183 0.001	0.173 0.001
$E(T_1)$	0.86	0.01	1.07	2.20	2.15	2.04	1.60	2.53	0.02	0.01	1.68	1.80
Std Dev(T_1)	0.88	0.01	1.01	1.67	1.64	1.29	1.13	1.49	0.19	0.01	1.55	1.52
$E(T_2)$	0.70	0.01	0.01	1.81	1.81	2.05	1.38	1.51	0.01	0.01	1.26	1.21
Std Dev(T_2)	0.76	0.01	0.01	1.24	1.26	1.41	1.02	1.08	0.01	0.01	1.01	0.95
Prob{1 / 2}	0.388	1.000	0.01	0.458	0.483	0.576	0.438	0.580	0.001	1.000	0.679	0.660
Prob{2 / 1}	0.743	0.71	1.00	0.649	0.649	0.690	0.599	0.488	1.000	0.999	0.508	0.511
LnL	-1624.4	-2759.5	-3333.1	-7196.2	-7288.3	-6697.8	-5046.8	-5213.6	-1061.9	-1486.1	-3950.7	-3944.3
LnL Null	-1663.6	-2759.5	-3360.5	-7360.7	-7369.0	-6735.4	-5071.1	-5283.5	-1062.5	-1486.2	-3968.8	-3957.9

Table A3. Continued. Page 9 of 10.

Market 1 Market 2	EKan NCal	EKan Wash	EKan Idah	WKan Texa	WKan Ariz	WKan SCal	WKan NCal	WKan Wash	WKan Idah	Texa Ariz	Texa SCal	Texa NCal
α	0.838 0.001	0.144 0.001	0.450 0.001	-0.064 0.001	0.882 0.001	0.844 0.001	1.006 0.001	0.537 0.001	0.734 0.001	0.844 0.001	0.839 0.001	0.926 0.001
σ	1.308 0.001	0.675 0.001	0.969 0.001	0.400 0.001	1.182 0.001	1.221 0.001	1.258 0.001	0.976 0.001	0.982 0.001	1.111 0.001	1.152 0.001	1.238 0.001
α_1	2.700 0.001	1.818 0.001	3.014 0.001	1.017 0.763	2.155 0.001	2.219 0.001	2.908 0.001	3.060 0.001	3.323 0.001	2.278 0.001	2.359 0.001	3.024 0.001
$ß_1$	0.811 0.001	0.903 0.001	0.881 0.001	0.875 0.001	1.095 0.001	1.067 0.001	0.831 0.001	0.907 0.001	0.944 0.004	0.970 0.196	0.925 0.001	0.896 0.002
α_2	2.165 0.001	1.845 0.001	1.851 0.001	0.832 0.001	2.203 0.001	2.126 0.001	2.230 0.001	1.944 0.001	2.033 0.001	2.221 0.001	2.107 0.001	2.210 0.001
$ß_2$	1.012 0.690	0.733 0.001	0.758 0.001	0.799 0.001	0.871 0.001	0.917 0.001	0.999 0.965	0.848 0.001	0.830 0.001	0.808 0.001	0.851 0.001	0.977 0.194
λ_1	0.241 0.001	0.184 0.001	0.300 0.001	0.076 0.001	0.275 0.001	0.271 0.001	0.257 0.001	0.261 0.001	0.291 0.001	0.284 0.001	0.295 0.001	0.251 0.001
λ_2	0.207 0.001	0.154 0.001	0.069 0.001	0.075 0.001	0.218 0.001	0.209 0.001	0.195 0.001	0.069 0.001	0.064 0.001	0.213 0.001	0.214 0.001	0.151 0.001
$E(T_1)$	2.02	1.57	2.41	0.89	2.27	2.29	2.15	2.55	2.82	2.09	2.07	2.39
Std Dev(T_1)	1.26	1.18	1.43	0.88	1.57	1.55	1.31	1.50	1.60	1.41	1.37	1.43
$E(T_2)$	2.20	1.43	1.40	0.66	1.89	1.93	2.28	1.64	1.70	1.77	1.78	2.21
Std Dev(T_2)	1.49	1.05	1.03	0.73	1.28	1.33	1.52	1.18	1.19	1.19	1.23	1.48
Prob{1 / 2}	0.608	0.449	0.540	0.341	0.488	0.516	0.584	0.587	0.583	0.474	0.504	0.571
Prob{2 / 1}	0.725	0.583	0.547	0.664	0.665	0.665	0.715	0.553	0.559	0.651	0.649	0.702
LnL	-3694.5	-2721.0	-2672.4	-2488.1	-7084.0	-7183.6	-6703.8	-5121.6	-5360.3	-6721.3	-6831.7	-6431.8
LnL Null	-3729.6	-2726.5	-2697.2	-2568.7	-7240.6	-7258.7	-6797.6	-5152.3	-5438.6	-6860.0	-6895.2	-6578.4

Table A3. Continued. Page 10 of 10.

Market 1 Market 2	Texa Wash	Texa Idah	Ariz SCal	Ariz NCal	Ariz Wash	Ariz Idah	SCal NCal	SCal Wash	SCal Idah	NCal Wash	NCal Idah	Wash Idah
α	0.518 0.001	0.731 0.001	-0.049 0.001	0.520 0.001	-0.048 0.001	-0.063 0.037	0.570 0.001	-0.098 0.052	0.303 0.001	-0.623 0.001	-0.343 0.001	0.104 0.001
σ	0.936 0.001	0.950 0.001	0.500 0.001	1.095 0.001	1.519 0.001	1.637 0.001	1.140 0.001	1.580 0.001	1.525 0.001	1.325 0.001	1.251 0.001	0.622 0.001
α_1	3.136 0.001	3.494 0.001	1.249 0.001	2.375 0.001	1.817 0.001	0.001 0.001	2.304 0.001	1.782 0.001	1.935 0.001	1.459 0.001	1.509 0.001	2.652 0.001
$ß_1$	0.905 0.001	0.990 0.473	0894 0.001	0.880 0.001	0.917 0.001	0.121 0.001	0.874 0.001	0.992 0.703	0.877 0.001	0.997 0.904	0.973 0.221	0.916 0.001
α_2	1.920 0.001	2.059 0.001	1.423 0.001	1.746 0.001	1.657 0.001	1.747 0.001	1.855 0.001	1.679 0.001	1.727 0.001	1.437 0.001	1.497 0.001	1.660 0.001
$ß_2$	0.827 0.001	0.827 0.001	0.799 0.001	1.025 0.293	0.976 0.349	1.128 0.001	0.997 0.894	0.988 0.601	1.081 0.001	0.919 0.003	0.958 0.079	0.709 0.001
λ_1	0.269 0.001	0.284 0.001	0.114 0.001	0.252 0.001	0.214 0.001	0.181 0.001	0.248 0.001	0.206 0.001	0.237 0.001	0.138 0.001	0.161 0.001	0.205 0.001
λ_2	0.059 0.001	0.047 0.001	0.113 0.001	0.167 0.001	0.202 0.001	0.001 0.001	0.193 0.001	0.190 0.001	0.249 0.001	0.127 0.001	0.157 0.001	0.048 0.001
$E(T_1)$	2.60	3.13	1.09	1.96	1.64	0.01	1.88	1.73	1.65	1.44	1.45	2.20
Std Dev(T_1)	1.51	1.73	0.98	1.30	1.22	0.01	1.27	1.31	1.20	1.20	1.18	1.40
$E(T_2)$	1.58	1.72	1.14	1.81	1.62	1.97	1.86	1.65	1.87	1.32	1.43	1.16
Std Dev(T_2)	1.14	1.19	0.96	1.36	1.26	1.49	1.36	1.28	1.42	1.10	1.17	0.91
Prob{1 / 2}	0.599	0.628	0.493	0.55	0.633	0.944	0.556	0.639	0.633	0.607	0.581	0.488
Prob{2 / 1}	0.517	0.525	0.508	0.608	0.649	0.527	0.634	0.657	0.660	0.579	0.546	0.480
LnL	-4915.5	-5209.4	-3856.6	-6327.3	-6004.7	-6495.5	-6443.3	-6142.6	-6710.9	-5306.7	-5675.4	-4033.6
LnL Null	-4965.8	-5303.6	-4004.7	-6327.3	-6034.8	-6504.3	-6460.9	-6201.8	-6764.6	-5322.6	-5709.0	-4067.7

PART II

FED CATTLE GEOGRAPHIC MARKET DELINEATION: SLAUGHTER PLANT PROCUREMENT AREAS, FIRM AND PLANT SUPPLY RESPONSE ANALYSIS

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Introduction

The purpose of this study is to determine the relevant geographic procurement markets for fed cattle in the U. S. Relevant market determination is essential for proper analysis of the structure of the industry and its performance. Market boundaries identify separate economic markets within which partial equilibrium analyses are valid. It is within the context of an economic market that, if the exercise of market power is possible, a firm may impose significant and nontransitory changes in price through noncompetitive conduct. There is a long history of relevant market determination in court cases which can be found in antitrust casebooks. The relevant geographic market for industrial organization and antitrust analysis is often based on the trade areas of firms currently dealing in closely related products. In addition, other firms may be included in the relevant market if their probable supply response to small, but significant and nontransitory price changes would likely cause them to become a market participant. This language serves as the basis for market definition in the merger guidelines by the Department of Justice and the Federal Trade Commission, though court decisions may not follow that definition.

One method of determining relevant geographic markets is by mapping the trade areas of all firms currently producing or selling relevant goods in the same area. The location of entities in active competition with a firm are plotted on a geographical map. The extent of the area covered is then said to be the trade area or relevant market. This method is frequently used because of the availability of data and the ease with which the resulting mapping can be understood by observers.

Others such as Papandreou have proposed demand cross elasticities for product market definition. Essentially, the cross elasticity of demand at the firm level (<u>not</u> the more typical market level of aggregation) measures the responsiveness of the quantity purchased of a firm's product by customers in response to the change in price by a potentially competing firm. However, this has been difficult to do at the firm level because of data inadequacy.

The general objective of this research is to gain insights into the geographic fed cattle procurement market behavior for beef packing plants (and firms). To determine the trade areas of each plant, and the overlap with other plants, the locations of cattle purchased by 43 large fed cattle slaughter plants in the United States are mapped using ARC/INFO, a geographic mapping software package, and the percentage of cattle that were procured within 75, 150, and 250 miles during April 1992 through March 1993 are determined. In addition, the distances that plants went to procure 95 % of their cattle, their maximum procurement distances, and the extent of procurement area overlaps among plants are determined.

The strength of the interactions between plants and firms--namely, the changing flows of cattle in response to changes in relative prices paid--is another focus of this analysis. After adjusting for differences in cattle characteristics, the effect of prices paid by processing plants (firms) on the same-day flows of cattle to each plant (firm) is estimated using econometric methods. In conjunction with studies of price responsiveness among plants or publicly reported fed cattle markets being completed at collaborating universities (Oklahoma State University and

Kansas State University), this study should provide information useful in delineating the relevant procurement geographic market for general studies of beef industry structure and performance, and specific merger and acquisition or related antitrust cases.

Literature Review

The determination of the relevant market is vitally important in all antitrust analysis. Unfortunately, it is very difficult to define geographic markets with any measure of precision. Industrial organization textbooks and antitrust casebooks have devoted countless chapters to the relevant market question, but often make little distinction between the product market and the geographic market.

The relevant market is usually defined as the smallest group of producers which could hypothetically form an effective cartel (Boyer; Scheffman and Spiller). Firms may be included in the relevant market if their probable supply response to small, but significant and nontransitory price changes would likely cause them to become a market participant (Department of Justice and the Federal Trade Commission). Scheffman and Spiller propose that cross elasticities of demand be used to test whether a firm or cartel has potential market power. Boyer, on the other hand, rejects the use of cross elasticities of demand to define industry boundaries, citing identification, model misspecification, and data availability problems. It is often difficult to obtain accurate price and volume data from all potentially relevant firms, both of which are necessary to compute cross elasticities.

The relevant product market is usually handled by the courts by testing for the substitutability of the products in question. First, the court must determine whether or not the two goods are functionally interchangeable. Two inputs which are functionally interchangeable can be substituted for each other in the production process without fundamentally changing the finished product. Two finished products which are functionally interchangeable technically should also have cross elasticities of demand which are positive and significantly greater than zero. Determination of functional substitutability is generally not enough to define a product market. Two goods must also be reasonable substitutes. Functional substitutes are also reasonable substitutes when the goods which are technical substitutes also compete on the basis of price. If they did not, consumers would always choose the lower priced alternative. This can be tested formally if the appropriate data is available.

Some antitrust literature discusses the problem of geographic market delineation apart from the discussion of the product market. Unfortunately, most of these discussions are brief and incomplete. Greer mentions several factors which affect the courts' definition of the geographic market. These factors include the extent to which local demand is met by outside supply, and the extent to which outside demand is met by local production. Greer discusses the critical importance of transportation costs in determining geographic markets. Markets which are characterized by very low transportation costs are likely to be much larger than those with extremely high transportation costs. If two producers are producing the same product in different areas, they will not ship the product to the competitor's region if high transportation costs make the strategy unprofitable. The means of transportation available may shape a geographic market. For example, two cities which are located 200 miles apart, but that both lie along the same river, may be in the same market, while two towns, 50 miles apart connected by a poorly maintained gravel road, may be in different markets.

Elzinga and Hogarty discuss the weaknesses in the approaches to geographic market definition used in the courts prior to 1973, and propose a simple (but very arbitrary) 75% of a firm trading area as encompassing the primary supply and demand forces affecting a firm at a reasonable cost of substitution. If there were overlaps with other merger partners, they propose that the entire overlap and nonoverlap areas for both firms would be the relevant geographic market.

Larner and Meehan, Fisher and others also mention tests for including other firms in a market. The Federal Trade Commission/Department of Justice (FTC/DOJ) Merger Guidelines propose the "5% test" in which a 5% increase in price in the original geographic area is postulated, and the likely entry of other firms is assessed. This test, though, is fraught with problems. First, how quick must the reaction by a firm be to warrant inclusion in the relevant market? Also, it is very difficult to figure out where to stop after beginning this type of analysis. If the new firm is deemed a market participant, should one then include additional firms interacting competitively with it in the relevant geographic market? Before long, an analysis of the Greater Pittsburgh market for a given product may become an analysis of the entire U. S. market for that product.

Concerns about the practicality and accuracy of the cross elasticity approach to relevant market determination led to the development of price-based methods for defining industry boundaries. Stigler and Sherwin argue that the appropriate test for a market is the similarity of price movements within a geographic region. They propose the use of correlation analysis of direct or differenced time series to determine relevant geographic and product markets. While this approach is often more practical than a cross elasticity approach, it may lead the researcher to hasty conclusions about the extent of the market. Prices in two areas may move in a parallel fashion due to the effects of common changes in the costs of production inputs and not because the firms are competing in the same geographic market.

Residual demand analysis can also be used in market determination. A firm's residual demand is the amount of market demand remaining to be satisfied by other firms in the relevant market. Residual demand elasticities of two premerger firms are compared with the postmerger elasticity of the combined firm to determine market power gain. Sufficiently large residual demand elasticity for a firm would cause a price increase to be unprofitable and inclusion of more firms in the market would be necessary. Kamerschen and Kohler found residual demand analysis to be less powerful than proponents claim. Residual demand analysis cannot prove the existence of prior collusion in a situation where a firm in a highly concentrated industry would not gain market power as a result of a merger. The additional information required to apply this method also makes it difficult to implement.

Early studies on livestock procurement markets used several geographic market definitions in their analysis. During the 1970s, Willard Williams split the country into 14 procurement regions which were based on his and market reporters' observations of packer operating practices. Williams sums up his discussion of the relevant geographic market by stating that the breakdown was employed because "it is logical and solves some problems" (Williams, p. 155). These small regional markets which Williams delineated were used with little modification in recent cattle procurement market power studies by Quail et al., and Marion et al.

Several recent studies have examined the geographic market for fed cattle using the theoretical framework put forth by Stigler and Sherwin. Hayenga and O'Brien examined contemporaneous and lagged price relationships in cattle feeding states using correlation, vector autoregression, and bivariate and multivariate cointegration analyses. Their results generally suggest that the relevant geographic market may include all cattle feeding states. The authors point out that this type of analysis is best used as a preliminary test and not as the final word on geographic market delineation. Schroeder and Goodwin analyzed geographic price lead-lag relationships in the fed cattle market using Granger causality tests. They identified Omaha, eastern Nebraska, and Iowa-southern Minnesota as the leading price discovery locations, and found that regional price adjustments generally took 1-3 weeks to complete. In terms of geography, the larger volume markets located in the heart of cattle feeding country reacted quickly to price changes at the leading price discovery locations while small markets in "fringe" states took significantly longer to adjust. Later, Goodwin and Schroeder tested whether regional cattle prices adhere to the law of one price. Integration was tested between 10 regional markets and the eastern Nebraska direct market for the periods 1980-83 and 1984-87. Many of the series were found to be integrated. They also found a shift in regional cattle feeding and marketing patterns, with the dominant area moving from the corn belt and traditional terminal markets to the Western and Southwestern direct markets.

Margaret Schultz used four approaches in attempting to define the relevant geographic market for fed cattle in the United States. Two of these approaches were the trade area approach and the cross-elasticity approach. The trade area was estimated using data pertaining to the origin and destination of the cattle bought. This was done by circumscribing all sellers that a particular plant buys from on a map, and noting the overlapping trade areas of plants and firms for which data were available.

Schultz also attempted to define the relevant market for fed cattle using the classic cross-elasticity approach. She estimated a series of univariate transfer functions with market share at plant I as the dependent variable and price at plant j as the independent variable. This particular functional form led to several serious statistical problems which were dealt with through the ARMA process. She modified her model to use a generalized least squares procedure on pooled time series from pairs of plants, sorted the plants according to the results from factor analysis, and estimated cross elasticity coefficients. Schultz was unable to reject the hypothesis that most of the plants in the survey were in the same relevant geographic market.

Due to data problems, Schultz was unable to estimate cross elasticity using multivariate analysis. She did suggest the procedure of estimating a matrix of equations with market share of plant I as the dependent variable and relative prices at the other plants as the independent variables. The models that we propose to use in this project are similar to the approach proposed by Schultz.

It is important to mention the procedure that Schultz used for standardizing prices over a wide range of types of cattle. She first chose the characteristics which have the most impact on cattle prices at the plant level. These were contract type, sex, and quality. She then estimated a regression equation with price per hundredweight as the dependent variable, and the characteristics listed above as the independent variables. Average daily prices standardized with respect to lot size, sex, and quality were then estimated by adjusting the prices paid to those which would have been paid if the lot had the standardized characteristics established as a basis for comparison (e.g., 100% steers, 80% choice, etc.).

Data

An integral part of this study is the data. A significant contribution of this study is that actual transaction data are used from a broad spectrum of packing plants. The data were obtained from the Packers and Stockyards Program, GIPSA, U. S. Department of Agriculture. Use of actual transaction data provides a rich data set for analyses which helps ensure that the results accurately represent reality. However, with actual transaction data also come a number of issues to be dealt with.

The original data set consists of transaction data for a total of 200,616 pens of cattle procured from March 23, 1992, through April 3, 1993, by 43 U. S. fed cattle slaughter plants. Data from five other plants slaughtering cows and bulls are not considered in this study. Each transaction contains information on 39 variables which include plant location, seller location, purchase method, cost/cwt, etc. The list of data used in our analyses and the definitions employed are shown in table 1.[15]

For geographic mapping of fed cattle procurement patterns, the 43 plants dealing in fed cattle were the focus of the analysis. Since we were concerned with feedlot locations serving each plant, only the lots which had county locations of origin specified could be included in the analysis (consequently, Canadian cattle were excluded). Further, since the mapping analyses serve as a preliminary analysis for cross elasticity estimation, and spot market fed cattle movements are the focus of that analysis, only spot market fed steer, heifer, fed Holstein or mixed lots are analyzed.

For our cross elasticity estimation, a joint Iowa State University, Kansas State University, and Oklahoma State University effort developed procedures to provide a consistent series of comparable prices for each transaction date and plant. There, quality, yield, sex and weight data were essential, since otherwise the value mix of cattle could vary a lot from day to day, or plant to plant. Raw prices paid for each lot would not be comparable prices. As a result of numerous

[15]The authors would like to acknowledge the contributions of Gary Stampley in the initial stages of managing this very large and complex set of data.

missing data, unreconcilable differences in data, differences in data available from different plants, or obvious data errors, the original data set was condensed down to 103,442 lots of cattle slaughtered in 28 plants for the time series estimation. All data from 15 fed cattle plants as well as numerous transactions from the 28 retained plants are not used in the econometric analysis. Many data problems resulted in multiple and intersecting deleted transactions. The number of observations deleted at each step is not reported, as the number of observations removed by each problem is highly conditional on the order of deletion. Reasons for excluding data from the econometric study include the following:

1. Only pens containing steers, heifers, fed Holsteins, or mixed sexes are retained. These cattle represent the bulk of fed cattle slaughter and represent reasonably the same product market in terms of cattle type. Pens containing cows, bulls, and stags represent a different market whose prices would be difficult to compare with fed cattle and adjust to a comparable value relative to fed cattle.
2. Only pens that had kill and purchase dates recorded are retained. Also, transactions with dates outside the period of data collection are deleted. Purchase dates are needed to identify the days the cattle were bought. Without these, the transaction price cannot be matched with the appropriate date, which is essential for our time series analyses.
3. Only pens that indicated the number of head contained in the pen and had 35 or more head are retained. This represents the minimum number of head per pen the Packers and Stockyards Program stipulated collecting in the original data collection. Therefore, any pens containing less than 35 head were either erroneously collected or reported incorrectly, and are deleted.
4. Only lots that were purchased in the cash (spot) market are retained. The time series analysis involves plant or firm price-volume relationships at the same point in time for relatively immediate delivery. Prices for forward contract or marketing agreement cattle are not relevant in that temporal comparison since they represent purchases made for delivery at a later date.
5. Only pens with a recorded carcass weight (hot or cold) are retained. All carcass weights are converted to a hot weight basis. Prices per cwt. are based on this standard weight.
6. Only pens with an average carcass yield recorded and a yield greater than or equal to 50% and less than or equal to 70% are retained. This represents the vast majority of the fed cattle in the original data set. Truncating the data at some reasonable range is necessary to remove obvious erroneous entries, because the original data set had yields recorded ranging from 13% to 80.4%, which are outside any reasonable range.
7. Only pens with a yield grade separated into at least yield grade 1-3 and greater than 3 are retained. Yield grade is necessary to adjust the prices to a comparable value. Because a large number of plants only separated yield grades into 1-3 and greater than 3, this is the least restrictive classification to use.
8. Only pens with quality grades which allowed separation of Choice and above from Select and below quality grades are retained. Lots without yield or quality grades have insufficient information to allow estimation of comparable prices for use in econometric analyses.
9. Only pens purchased within 14 days of slaughter are retained (except at three plants where the maximum allowed was 30 days, because these plants specifically indicated that

cattle purchased that far in advance were part of their normal cash market procurement). Any other cattle purchased in advance of 14 days from slaughter are not considered cash purchases.

10. Only lots whose carcass price is greater than or equal to 80% of the USDA Select boxed beef cutout equivalent price and less than 120% of the USDA Choice boxed beef cutout equivalent price on the same date are retained.

Numerous plants do 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 number of observations and data comparability. Our general rule is to use data that had "standard" industry specifications that can be used to compare prices across plants. As rules are relaxed, the size of the data set increases, but the confidence in results declines associated with comparing increasingly heterogenous prices. Descriptive statistics for the original data set, the data set used for the geographic mapping, and the data set used for the econometric analysis are included in table 2. The 43 plants involved in the geographic mapping analyses are listed in table 3.

Geographic Mapping

One method of determining the relevant market is the trade area approach. In this approach, geographic mapping graphically shows the extent of each plant's trade or procurement area. If the overlap between trade areas is economically significant, clearly the two plants are in the same relevant market. The maps allow identification of the maximum distance plants go for cattle; this may be useful in assessing the potential procurement areas for others. The basic unit for the mapping is the county where the seller is located.

The data set for the geographic mapping includes fed cattle procured on a spot basis from U. S. feedlots. Only cattle purchased from U. S. sellers are included in the geographic mapping, as specific locations of Canadian cattle feedlots are not provided.

Several descriptive measures are calculated to provide insights into the spot market procurement behavior of various groups of plants during the year. The county locations of the plants included in the study are shown in appendix A. The percentage of cattle purchased within comparable distances from each plant--75 miles, 150 miles, and 250 miles--is calculated using ARC/INFO search routines. This share of spot cattle purchases includes all cattle purchased from any county entirely or partially within the given radius. As a result, the actual distance traveled would be greater, and it would depend on the size of the counties at the extreme edge of the procurement area, the position of the most distant feedlot suppliers located in the county, the size of the county where the packer is located, and the packer's location within the county.

To provide useful descriptive measures and obscure individual plant behavior, the plants are grouped according to their location in the U. S. Five groupings are used: East--East of the Mississippi River, including 7 plants; West--West of Colorado, including 7 plants; MidNorth--North of Kansas, including 14 plants; MidSouth--South of Nebraska, including 12 plants; and Middle--including all MidNorth and MidSouth plants. The Middle Region includes 10 of the largest cattle feeding states. Table 3 lists the plants found in each region.

The total number of cattle purchased within each of the three distances from the plant is calculated and expressed as a percent of the total cattle purchased by a particular plant. The maximum distance that cattle are hauled to each plant and the distance that each plant goes to purchase at least 95 % of its cattle are also determined (to eliminate the effects of outliers which may be atypical or attributable to data errors).

On average, plants obtained 63.92% of their U. S. cattle from within 75 miles of the plant, 81.76% from within 150 miles, and 91.79% from within 250 miles of the plant. The average distance containing 95% of total cattle purchased on the spot market is 270 miles, though 4 plants went more than 500 miles to acquire 95% of their spot market purchases. The maximum distance cattle were hauled is 1140 miles, with an average maximum distance of 655 miles. Nine plants hauled a small number of cattle more than 900 miles. More detailed procurement distance information is summarized in tables 4 and 5.

The average distance plants go to obtain 95 % of their cattle is greatest in the East region of the U. S., where the average distance is nearly 100 miles greater for those plants than for plants in other areas of the country. The maximum distance cattle are hauled is least in the West region with the MidNorth region showing the greatest average distance. Since Canadian cattle are excluded from this analysis, the distances for all spot cattle market purchases would be slightly greater than shown here, with the greatest increases likely in the areas adjacent to Canada.

Nearly one-half of the plants obtain cattle from Canadian sources. Since the distance that these cattle are brought to the plant is not available, they are not included in the summary statistics above. For the majority of these plants the number of cattle obtained is not significant since it is less than 1% of the plant's procurement. Four plants purchased more than 5 percent of their cattle from Canadian sources (table 6).

Public data on Canadian cattle slaughtered in the U. S. in 1992 (see figure 1) provide some perspective on where Canadian plants and U. S. plants have a competitive overlap. The large beef slaughter plants in Alberta and Ontario are very likely to be effective competitors for cattle moving into Washington, Idaho, Colorado, and Michigan, especially if border restrictions and costs decline under NAFTA. In 1992 the state of Washington received 27% of the live cattle exported by Canada and 40% of the western Canada cattle exports.

Procurement Area Overlaps

Significant procurement area overlaps exist for many large slaughter plants included in the USDA sample. Overlaps are determined as the percent of a packer's total cattle procurement that came from an area where cattle are also bought by another plant. The fewest overlaps for any plant is 2 and the most overlaps for a single plant is 40 (the maximum possible was 43, see table 7).

What could be considered a significant overlap with another plant is debatable. For our descriptive purposes, we arbitrarily define an area comprising 10% or more of a packer's total procurement of U. S. origin spot market fed cattle during the 1992-93 study period as a significant overlap with another plant. We expect that the cost consequences of losing that volume, or something close to it, would be likely to put a plant at a significant competitive disadvantage. Ward's 1988 study estimates that a 10% change in capacity utilization in an industry with downward sloping cost curves would lead to increased average slaughter cost of $2.96 per head going from 90 to 80 percent capacity, and an additional $1.81 per head going from 80 to 70 percent of capacity. Duewer and Nelson's 1991 USDA study estimated reduced revenues per head of $1.97 going from 40 to 36 hours of plant operation per week, with a sharply larger reduction of nearly $5 per head going from 36 to 32 hours of operation in double shift, fast- line-speed plants. Thus, relatively small changes in plant volumes due to maverick or fringe firms not cooperating in cartel-like actions could stimulate the breakup of a fed cattle purchasing cartel, and cause a larger relevant geographic market to be defined.

The number of 10 percent overlaps for the 43 plants range from 1 to 22. Plants in the West region of the country have fewer overlaps as well as fewer significant overlaps than in other parts of the country. Most of these plants are small and the distance between plants is much greater when compared to those in the main cattle feeding areas--the MidNorth and MidSouth regions. Plants in the East region have fewer overlaps as well, but their closer proximity to the MidNorth and MidSouth plants brings them into competition with many of those plants as well as those in the East region. Not all of the overlaps are necessarily competitive in nature. Plants with common ownership would not be expected to compete. In the MidNorth and MidSouth regions of the country there are several companies that own from two to eight plants. There, the overlaps may simply reflect central purchasing managers shifting cattle from intermediate feedlot locations to different plants sometime during the year.

There are a large number of plants competing for fed cattle in many parts of the U. S., with some plants exhibiting 10-percent overlaps with more than 15 other plants; however, there are a few plants and areas where the number of overlaps greater than 10 percent are relatively small (1-4). Note that smaller plants not included in the Packers and Stockyards Program survey are not included in this summary set of statistics--they would add an additional competitive dimension. Table 7 contains summary information on the trade area overlaps. Plants under the same ownership were excluded in one column, resulting in little change in results.

In analyzing the overall pattern of plant procurement overlaps, a large number of double digit overlaps occur among plants in each region. In addition, the overlaps between MidNorth region plants and MidSouth region plants are numerous and often large. In the East region, a large number of double digit overlaps are noted with plants in the MidNorth region, though hardly any with the MidSouth region. The West region has a few large overlaps with plants in the MidSouth region, very few with the MidNorth region and none with the East region. We also note a lack of overlaps by MidSouth and MidNorth plants with the West region plants. Based on figure 1, Western plants are most strongly competing for cattle with Canadian plants, though some smaller influences are found in the East and MidNorth.

Geographic Mapping Conclusions

The regions established earlier for discussion purposes serve as a beginning point for our analysis of relevant geographic markets. We can seek to determine what plants would have to be included in a hypothetical buyer's cartel to effectively depress cattle prices. The FTC/DOJ Guidelines use a figure of 5% price enhancement in product markets in assessing firms to include in the market. With slaughter firm profits typically one percent of sales, or less, a 5% purchase price reduction would dramatically increase profits, since cattle costs are a majority of total costs for meat packers. Perhaps a lower standard, such as a 2% purchase price depression, might be more reasonable for this hypothetical analysis.

For example, what would be the effects if a cartel were formed in the MidSouth Region and this cartel were able to artificially depress prices enough to receive monopsony profits. The procurement area overlaps between plants in Southwestern MidSouth Region and some plants in the West Region suggest that an artificial depression of prices by the MidSouth plants would result in cattle that nominally go to plants in the MidSouth Region being diverted to the nearest plant in the West Region paying a higher price. If that plant's capacity were large enough to divert enough cattle and cause the MidSouth's plant cost structure and market share to be significantly impacted, the Western plant would have to be included in an effective cartel. If we continue this line of reasoning, most of the plants in the Southwest probably would have to be included. Since there are a significant number of overlaps among the plants of the MidSouth and MidNorth regions, a similar price depression would result in cattle moving from the MidSouth to the MidNorth region. It could be argued that the MidNorth region would also be included. Using similar logic, a cartel formed in the Northwestern MidNorth Region would have to include the nearest plants in the West in order to be effective.

The plants that purchase Canadian cattle present a slightly different situation. Since some plants in the West Region purchase a significant number of cattle from Canada, it would be necessary to include Western Canada in the geographic market when Northwestern plants might be the focus of antitrust inquiries.

The East Region includes plants in Illinois, Wisconsin, Michigan, and Pennsylvania. Significant overlaps are found between the Eastern MidNorth plants and the closest plants in the East. Public data discloses that several plants in the East Region are purchasing some cattle from Canadian sources. While the number of cattle crossing the border might be considered marginal influences unlikely to break up a cartel in 1992-93, the reduction of border barriers or changes in number of slaughter plants competing for cattle North of the border may lead to Canada becoming a greater competitive influence in the late 1990s. Following our previous line of reasoning, in order for a cartel formed in the Northeastern MidNorth Region to be effective, it might have to include these Canadian plants today, though perhaps not in 1992-93. Several of the Eastern region plants have significant overlaps with the MidNorth, and each other, so it is difficult to isolate the Eastern region as a separate geographic market.

For general industry competitive market analysis, the relevant geographic procurement market for fed cattle appears to be the entire United States and Canada. However, the shortrun competitive linkages among plants clearly grow more tenuous with increasing distance. We expect that the competitive interplay is strongest and most immediately felt among plants with current procurement area overlaps of 10% or more. As the competitive impacts are filtered through intermediate competitors, the strength of the impacts and the reaction speed would be dissipated. Individual mergers of plants located 1500 miles apart would not be expected to have the strength or speed of competitive impacts to consider them part of the same market.

Beyond the shortterm (1992-93) procurement areas observed in normal market environments, an analyst also needs to consider the ease of competitors (or feedlots) shipping cattle a few hundred miles further to take advantage of depressed prices. Nine plants acquired cattle over 900 miles away, and the maximum distance shipped was approximately 1140 miles. More conservatively, four plants acquired more than 5 percent of their cattle from a distance greater than 500 miles. The incremental cost of shipping 50,000 pounds of live cattle is approximately 45-60 cents/cwt. (carcass) per 100 miles for transportation (according to a few trucking companies), plus any carcass tissue shrink which incrementally is probably quite small (Raikes et al., p. 9). Thus, cartels formed in one part of the country would be susceptible to predatory behavior by more distant plants, to ensure that the cartel-forming plants had no cost advantage. A 2% change in carcass prices is approximately \$2.40/cwt., which could warrant an extension of a plant's procurement area radius by 400 miles or more. Considering both actual procurement areas in 1992-93 and the incremental costs of extending those areas if cartel-like activity offered lower cost opportunities for nonmembers, the areas east of the Rockies and west of Pennsylvania appear to have sufficiently strong direct, indirect, or potential competitive interplay to be considered part of the relevant geographic market for almost all analytical purposes. Further, plants on the edges of that area have a sufficiently strong competitive interplay with other plants near them--on the western edge, to the far west; in the north, to Canada; in the east, to the far east. Plants within 1000 miles in proximity would likely be in the same relevant geographic market. Plants in the most distant parts of the U. S. or Canada might be excludable from a current competitor analysis for other distant plants on the other side of the continent, although their potential for building a competing plant in the area might lead to their inclusion in the relevant market.

Procurement Volume Response to Relative Prices
Basic Approach

If, in the short run, a plant's volume is significantly affected by a competing plant's price (or relative price), conceptually they both should be in the relevant market for competitive or antitrust case analysis. Following Papandreou and others, model 1--the quantity purchased by a plant as a function of its potential competitors' prices--is proposed to address the basic question of appropriate market boundaries. The volume response to price model can be expressed as:

$$(1)\ \ q_{i,t} = f(\ p_{i,ts}\ p_{j,ts} \ldots p_{k,ts}\ x_t\ )$$

where q_i and p_i are the quantity procured and the price of the i^{th} plant, p_j, ...,P_k are procurement prices of potentially competing plants j through k. The subscribes t and t-s stand for same day and previous day (if s=1), respectively. The null hypothesis of a non-negative coefficient relating a plant's procurement volume to a potential competing plant's price (or relative price) suggests there is no significant competitive relationship with that plant. This can be tested by a one-tail t test. Since feedlot supplies vary, affecting overall slaughter levels, an additional variable x (total procurement by all the plants on each day) is incorporated into the model to account for non-competitive behavioral factors affecting the aggregate quantity and price relationship. Since there are several multiplant firms, and behavior observed for individual plants may be conditioned by arbitrage possibilities in other plants and geographic areas in which the firm operates, model 1 is also estimated for firms (as aggregates of plants) to determine the aggregate responsiveness to other firms' prices, and compare the results with individual plant behavioral estimates.

Since multicollinearity is expected to be a problem, an alternative model is also postulated, in which a plant's volume share in a particular geographic region is a function of relative prices paid by that plant and potential competitors. Using plant price ratios is expected to eliminate common correlation effects, and putting the dependent variables in the form of a market share should minimize problems caused by overall changes in the volume of cattle coming from feedlots throughout the year. This model--plant market share response to relative

$$(2)\ \ q_{ir} = f(\frac{p_{ir}}{p_{jr}}, \ldots, \frac{p_{ir}}{p_{kr}})$$

price--can be specified as follows:

where the subscript r stands for an arbitrarily selected geographic region r from which cattle originated. Negative and significant relative price relationships will indicate plants with significant competitive interaction on a daily basis.

Price Standardization Procedure

A necessary step to conduct the time series analysis is to obtain a daily price series for each plant. These daily price series must be quality-adjusted to be comparable over time and across plants. Therefore, the transaction prices need to be converted to a quality-adjusted daily price quote for each plant. This process involves estimating a hedonic price model using cash market transaction data for each plant over all useable observations. These plant-specific models are then used to estimate the price that plant would have been expected to pay 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.; Schultz) and data availability. The price adjusting equation (3), developed in conjunction with Ted Schroeder at Kansas State University, is:

$$(3)\ \ p_{ilt} = f(type_{ilt}, yield_{ilt}, head_{ilt}, weight_{ilt}, difday_{ilt}, valueidx_{ilt}, avgprice_{t})$$

where the subscript ilt stands for the i^{th} plant and the l^{th} transaction on day t.

Different types of fed cattle (dummy or binary variables for heifers, fed Holsteins, or mixed sexes) are each expected to receive lower prices than steers. Perfect collinearity requires a default pen be specified which consisted of steers. The percentage of cattle grading yield grade 3 or better is expected to positively influence price. Price is expected to increase with increasing number of head in a lot, but at a declining rate (a quadratic functional form is specified). Similarly, price is expected to increase, then decline with increasing average carcass weight. The number of days (difday) between purchase and kill dates could be either positive or negative depending upon how this variable is expected to influence packer pricing (Jones et al.). The price paid would be expected to be positively related to the delivery lag if longer delivery time was reflective of packers desires for feedyards to hold cattle longer than normal and packers were willing to pay for this service. Alternatively, shorter delivery time could indicate a need by the packer for cattle to meet slaughter capacity and, given economies of scale, the packer may be willing to pay more to fill short-term slaughter needs. Wholesale value is expected to be positively related to price; as the wholesale value of the beef (valueidx) related to the quality grade of cattle in a lot increases, the packer would pay more. A weighted average plant price for all 28 plants 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 (see T. Schroeder's market definition study for additional information).

The empirical model described in equation (3) is estimated separately for each plant and for all plants combined. This model includes data from 28 plants, consisting of 103,442 pens of cattle, comprising 12.3 million head. The model estimated for all plants combined explains 89 percent of the variability in transaction price, with all parameter estimates significant at the 0.001 level with the expected signs (reported in Ted Schroeder's market definition study). The plant- specific models also generally had significant parameters with the anticipated signs. The R^2s of the plant-specific models range from 0.714 to 0.967, with most between 0.85 and 0.95. The Root Mean Square Error (RMSE's) range from $1.097/cwt. to $3.401/cwt., or from about 1% to 2.8% of the mean price. These are important because the accuracy or representativeness of the predicted daily plant prices are contingent on the explanatory power of these models. Accurate models will result in high levels of confidence in the daily price estimates, whereas models that are unable to explain much of the price variability will result in suspect daily price estimates.

The plant-specific models are used to calculate a daily carcass beef price at each plant. The selected pen standard characteristics are: a 150-head pen of steers, graded 60% choice or better, 95% yield grade 1-3, average carcass weight of 730 pounds, and purchased 7 days prior to slaughter. For each day that cattle were purchased in the cash market by the plant, the actual price paid for each pen is adjusted for quality, and the simple average of these quality-adjusted prices is used as the plant price for that day.

A slightly different approach is used to estimate this equation and to generate the quality-adjusted price series for share response models. In the volume response model (1), the average daily price paid for all the transactions within the nation for each plant is used. In contrast, the average price paid in the selected small geographic region by each plant is used in the share response model (2). To standardize the price series used in estimating model 2, equation 3 estimated parameters for each plant are applied to each lot of cattle procured from the selected geographic areas (such as Texas and Nebraska), to calculate the average adjusted price paid by each plant for cattle from that area.

By adding individual plant dummy intercepts to model 3 for all 28 plants combined, and reestimating it, the plant dummy variable coefficients reflect the constant price differences not accounted for by other factors influencing purchase price specified in the equation. The range of adjusted plant carcass weight prices for the 28 plants was $2.53 per cwt. The highest adjusted purchase prices are found in the western Nebraska, Colorado and Kansas area; as the distance from this area increased, prices tended to decline. Unfortunately, exploring further possible explanations for these differences is beyond the scope of this project.

Another modification to model 3 involves substituting firm dummy variables for the plant dummy variables described above. This allows one to determine whether firms differ in adjusted prices paid for cattle, though not reasons for the differences. The fit is quite good (R^2=.89), and the average adjusted carcass price differences are as much as $2.14 per cwt. for the high and low firms. The general tendency is for the largest firms to pay higher than average adjusted prices for fed cattle, while the smaller firms pay less than average. While this does not directly address the issue of overall market price movements in response to increasing concentration, the larger firms are not capturing lower procurement prices relative to their smaller competitors in this sample of firms in 1992-93. This is not what one would expect to find if high concentration in this industry is allowing large firms to reduce prices paid for cattle.

Estimation Procedure

Price series for all plants show a trend over the time period studied. In general, they decrease from March 1992 to the end of July and then move upward. This trend exists for the original price series as well as the quality-adjusted price series. Figure 2 illustrates this trend. Using both simple and augmented Dicky-Fuller (D-F) unit root tests, the null hypothesis of a unit root cannot be rejected for all the price series studied (either adjusted or unadjusted series). The quantity procurement data series are stationary. To deal with nonstationary prices, a detrending procedure for the price series is utilized in estimating the volume response model. The weighted average adjusted price of all 28 plants is calculated for each day, then the price series of each plant is divided by this average price. The price series after this detrending are stationary according to D-F tests. The null hypothesis of nonstationarity is also rejected at the 1% significance level for the price ratios used in share model (2).[16]

Geographic regions for share response feed model (2) are arbitrarily selected to be state boundaries for convenience. Two of the largest cattle feeding states (Nebraska and Texas) are chosen to illustrate the analysis of this model specification.

The volume response model (1) is estimated by Ordinary Least Squares (OLS) in the log-linear form for the detrended price series, and the share response model (2) in log-linear form also is estimated by OLS. SUR is also used to estimate the equations as a system, in consideration of the likely correlation of errors across equations of different plants, especially those within the same geographical region. SUR cannot be successfully applied in estimating volume response model (1) for all 28 equations together due to an inadequate number of common purchase dates across all 28 plants.

Various approaches could be used to select the appropriate independent variables in each plant's volume response model. One alternative is to include prices from all other plants in each plant's volume response model. Due to overlapping data gaps, that results in an inadequate number of observations. Another alternative is to sequentially add other plants' prices in the order of the extent of overlap with that plant, but this could cause bias due to the ordering of plants added to the equation. As the preferred, though not perfect, procedure, we include the prices for each plant with at least 10% overlap in cattle procurement with the plant serving as the dependent variable, though other plants owned by that plant's owner are excluded. To test whether excluding other plants from the same firm or all plants with little or no overlap would potentially bias our results, joint F tests are conducted separately on the competitive impact of all plants with less than 10% overlap, and all other plants owned by the same packer. We fail to reject the null hypothesis that all less than 10% overlap plants are jointly not significantly different from zero (at the 5% level) for only 2 of 28 plants. Also, only 2 plants' volumes are

[16] An alternative method suggested by W. Enders to make the price time series stationary is also used. All the price series of 28 plants are found to be cointegrated. Longrun equilibrium relationships for one price with all other prices in each equation are established by regressing this price on all other prices in the equation. The longrun equilibrium price for this dependent price is the predicted value from the regression. The same procedure produces the longrun equilibrium prices for all other prices in the equation. The new price series used in estimation of equation 1 are the daily deviations of the adjusted prices from the longrun equilibrium prices. These deviation price series are stationary by the D-F test. The estimation results of equation 1 using these deviation price series are not reported here, since the results have many signs inconsistent with expectations (signs for own price and cross price elasticities are always the same, all positive or negative).

significantly impacted by prices of other plants owned by the same packer (at 5% level). That low frequency of significant results could be due to chance. Thus, eliminating from the equations prices paid by other plants owned by the same packer and other plants with little or no procurement overlaps should not bias the resulting estimates.

Autocorrelation is not found to be a problem by the Durbin-Watson (D-W) tests. However, heteroscedasticity exists in volume response model (1) for some plants and firms, based on simple residual plots and the Breusch-Pagan (B-P) test. Out of 28 plant volume response models, 8 exhibit heteroscedasticity according to the B-P test at the 5% significance level. In the firm response models, the null hypothesis of homoscedasticity is not rejected for all 9 firms' equations at 5% significance level. When heteroscedasticity is present, White's procedure is used to re-estimate the variance of coefficient estimates, and the t values are re-calculated based on the corrected standard errors. Multicollinearity is also tested by the variance inflation factor (VIF) and is not found to be a problem (only two independent variables in two equations have VIF greater than 10).

Volume Response Estimation Results and Interpretation
Model 1, Plant Volume Response

The results of the volume response to price models show that plants sometimes are very responsive to price changes in the same day. Since the model is estimated in log-linear form, the coefficient estimates are elasticities themselves. They can be interpreted as the percentage change in a plant's volume (or share) associated with a 1-percent change in the independent variable. Generally, the proportions of the variation in the daily plant volume explained by these models range from 5% to 77%, with most equations (22 out of 28) in the 42% to 77% range.

A one-tailed t test is used to test the significance of all own price and potential competitor's price coefficients (elasticities). The null hypotheses for model 1 are: $b_{ij} \geq o$ and $b_{ii} \leq o$; for model 2: $b_{ijr} \geq o$ and $b_{iir} \leq o$. For the 28 plants analyzed, the total number of estimated model 1 price elasticities which are significant with the expected sign at the 10% significance level are 17 and 39 for their own price and cross prices respectively (at the 5% level, they are 16 and 20, respectively).

There are not a large number of statistically significant coefficients on same day that volume responds to prices. A little more than half of the own price effects are significant at the 5 % level with the expected sign (16 out of 28 plants); 11 plants' volumes are not significantly related to their own price changes (at 10% significance level). The total number of significant (at 5 %) negative cross price elasticities in 28 equations is only 20, with an additional 19 at the 10% significance level. Most plants' volume are significantly impacted (10% level) by prices at one or two other plants; the maximum noted is three. There are 4 plants without a significant negative cross price coefficient at least at 10% significance level (and 12 at the 5% significance level). The small number of valid observations (the average is 76) and related degrees of freedom in estimation due to the overlapping data gaps in individual plant price series may be a small influence on the small number of significant relationships observed.

A high price elasticity suggests that a plant's cattle procurement volume is very sensitive to price changes. For example, a plant may have an own price elasticity of 58.99 and cross price elasticities of -22.4, -28.52 and -31.85 with three other plants. That means, all other things equal, that the plant's purchase of cattle will increase 59 percent for a 1 percent increase in its own price; likewise, its daily purchases decline 22.4, 28.52, and 31.85 percent respectively, with a 1-percent increase in the price of its significant competitors.

The estimated significant negative cross price elasticities were very large, with a mean value of -31.8, and a range of -8.13 to -82.62. While these high elasticities seem initially to be quite extreme (relative to demand elasticities, for example), the variability in plant daily transaction volumes is quite high relative to the variability in prices or relative prices. Daily plant price standard errors are typically 4 percent of the mean price for the year, while quantity variability is dramatically higher (with standard deviations as low as 30 percent to many over 100 percent of the mean daily transaction volume). Recall that many plants only purchase cattle a few days each week. Consequently, slight variations in the number of days of purchase during a week could contribute to the large size of the measured standard errors and elasticities. Further, we expect that plants offering a price 50 cents per cwt. lower than neighboring plants (a small percentage change) would experience sharp volume declines in a competitive setting, and that certainly is consistent with estimated large cross elasticities. In addition, since some plants may not be attempting to buy cattle on the same day, the competitive reaction time for them may be longer than the 1 day specified in this model.

Most significant cross price elasticity coefficients are within the roughly defined regions where plants are in closer proximity and display more procurement area overlaps. There are few significant coefficients outside these regional blocks, and they are usually only significant at the 10% level. In studying these "outsiders" more closely, four of the significant relationships involve geographically close plant pairs, though not defined in the same region. Therefore, there is some evidence from these estimates that some limited intraregional or interregional interplay among nearby fed cattle slaughter plants does occur. However, the small number of significant plant volume and price relationships may also be related to the nature of the procurement behavior of multiplant firms. Only 5 plants included in this analysis are not owned by the top four firms. The largest packers may arbitrage cattle procurement across multiple plants in such a way that individual daily plant volume and price relationships would not behave as one might expect. However, the estimated small number of competitive interrelationships are also found for firms with only one plant. Since daily reaction functions may be too short, adding lagged prices would seem desirable to allow slight extensions to the competitive reaction timeframe in our analysis; however, the great loss of observations makes estimation impractical with this data set.

Model 1, Firm Volume Response

Weighted average adjusted daily prices are calculated for the nine firms with sufficient procurement records, and model 1 is estimated for each firm. Since multiplant firms have more daily price observations than individual plants, we are able to slightly expand the time period for competitive response in our econometric estimation, adding 1-day lags in both own and other firms' prices. The fits of these models are substantially better than the individual plant models. The R^2s range from .37 to .94, with eight of nine above .50. The top four firms have nine significant negative cross elasticities on the same day or day earlier, with six of the nine with other top four firms. The five smaller firms in the sample have 13 significant negative cross elasticities, with 11 of the 13 with other small firms. Nine of the significant negative cross price elasticities are for the prior day. Only one small firm has no significant cross elasticities. All other firms have one to four significant cross elasticities in the same day or one day earlier. Overall, the number of significant cross elasticities with other firms averaged slightly more than 2 per firm, and the average number of significant negative cross price relationships are similar for big and small firms in the sample. While the number of significant firm price and volume relationships is not great, the firms' aggregate procurement volumes are sometimes significantly related to other firms' prices on the same day or 1 day earlier. When they are significant, the cross price elasticities are large. Significant negative cross price elasticities ranged from -6.68 to -42.3, with an average of -27.91. While the number of significant cross price elasticities in the same or prior day is not large, the magnitude of the volume shifts in response to small relative price changes seems likely to prompt other plant or firm responses over a longer time period.

Model 2, Plant Share Response

The share response to relative price model (2) is estimated at the plant level for two states individually, and groupings of states. On average, there is approximately one significant price ratio for each plant buying cattle in each state studied (Texas and Nebraska). The R^2s of the models are mostly below 0.40. Alternative estimates using seemingly unrelated regression for the several plant equations in each state also provide a relatively small number of significant coefficients. The daily market share of each plant in a particular state probably does not appropriately reflect overall plant competitive behavior, as it is only a partial measure of volume going to a plant. Consequently, perhaps it should not be surprising that the simultaneous daily response of each plant to price changes of other plants was weak. One other problem is lack of observations. No plant buys cattle in a particular state every day, and some plants make purchases less frequently than others. As a result, the number of observations in the regression are sharply reduced as more plants are added to the equation. When similar models are estimated for other larger geographic regions, such as NE and IA together, TX and KS together, etc., similar results are found.

Summary, Plant and Firm Volume Response to Price

In general, the significant price elasticities found in this study are quite high for both own price and cross prices. High price elasticities suggest small price changes relative to others significantly affect plant or firm volume. Typically, only 1-2 significant and negative daily cross price relationships are found in the plant volume response model. When the same model is estimated at the firm level, firms are more frequently found to be responsive to other firms' prices (an average of two firms) on the same day or 1 day earlier. Allowing an additional day for competitive response in the firm models does result in more significant competitive interactions being found. Firm rather than plant behavioral models logically are more attractive to model competitive interrelationships in situations where multiplant firms have centralized purchasing and cattle allocation operations, though no major differences in the comparative results emerge from our analyses.

From the analysis of share response to relative prices (model 2), little responsiveness to nearby plant prices is noted in several arbitrarily selected states or combinations of states. Since the share response in an arbitrarily selected geographic area is only a part of the overall competitive response, these results may be the result of a weak modeling approach, rather than an accurate indication of plant competitiveness.

The main problems encountered in this statistical analysis are related to the data. The data set covers only 1 year, and many plants do not purchase cattle on the spot market on many days within this period. While conceptually the idea of using cross price elasticities to identify significant competitors has appeal, that approach has significant limitations in the fed cattle procurement market analysis. Trending, nonstationary prices, heteroskedasticity, and data gaps create obstacles to effective estimation of these relationships. Allowing a slightly longer timeframe for competitive response in our models beyond 1 day lags was impractical due to the data gaps in the single year of data provided.

An Integrated Analysis

The objective of this study is to determine relevant geographic procurement markets for fed cattle in the United States. The Packers and Stockyards Program, GIPSA, U. S. Department of Agriculture, provided daily transactions data for all lots greater than 35 head purchased by the 43 largest fed cattle slaughter plants in the United States. Geographic mapping of cattle movements to slaughter plants and econometric modeling of the plant (and firm) volume responsiveness to prices paid by potentially competing plants (firms) are the analytical methods employed.

Geographic mapping of cattle flows to plants (bought during March 23, 1992, through April 3, 1993) generally shows significant overlapping of procurement areas for many plants in the same region and bordering regions, especially in the major cattle feeding areas in the U. S. Overlaps in procurement areas were much more limited in the extreme western and eastern areas of the U. S., but still substantial enough that the plants in those areas should be considered part of the relevant market for general industry competitive market analysis. Some plants in the northern part of the U. S. purchased sufficient cattle from Canadian sellers to warrant inclusion of Canada in the relevant geographic market for general industry analyses. The average maximum distance which cattle were shipped is approximately 655 miles, with the maximum distance shipped over 1000 miles for four plants. In addition, the out-of-pocket cost for shipping cattle further is near 45-60 cents/cwt. (carcass) for a fed steer or heifer. If prices were depressed artificially by 2 percent ($2.40/cwt., carcass) in a cattle feeding area, other firms would find it profitable to ship cattle 300-500 miles further than usual. The potential procurement range for many plants could reach 1,000-1,500 miles.

Econometric analysis of daily supply responsiveness sometimes indicates high price elasticities, which suggest that small price changes by others significantly affect plant or firm volume. Only a small number (typically 1-2) of significant negative cross price relationships among plants are found. Firms are more frequently found to be responsive to other firms' prices (an average of two firms) on the same day or 1 day earlier. Top four and smaller firms exhibit a similar amount of competitive interaction, though most frequently within their own size class. The fits of the firm models were generally better than those of the plant models. Firm rather than plant behavioral models logically are more attractive to model competitive interrelationships in situations where multiplant firms have centralized purchasing and cattle allocation operations, though no major differences in the comparative results emerge from our analysis.

Analysis of the plant market share response to relative prices in small geographic areas finds few significant competitors; this may be due to the small number of observations where many plants are considered potential competitors, and the fact that procurement behavior in a small area like one or two states is only part of an individual plant's overall competitive procurement behavior (most plants buy cattle in several states).

While conceptually the idea of using cross price elasticities to identify significant competitors has appeal, that approach in the fed cattle procurement market analysis has significant limitations. Trending, nonstationary prices, and data gaps create obstacles to effective estimation of these relationships. Partly as a consequence of data limitations, restricting the timeframe for a competitive response to the same day or even 2 days undoubtedly is overly restrictive. While a longer period for competitive response would be more appropriate, the volume responsiveness of large firms to small changes in price by some competitors in the same day or a day earlier indicates some very shortterm competitive behavior is present. The longer term behavior reflected in the geographic mapping analysis may more accurately reflect competitive interrelationships among plants (and firms).

The results of this study indicate that the relevant geographic procurement market for fed cattle for general-purpose competitive analysis includes the entire United States and southern Canada. Significant plant procurement area overlaps within and between plants in many parts of the country make it nearly impossible for a cartel formed in one region of the country to artificially lower prices without a firm outside the cartel being able to offer a higher price for enough cattle to make it difficult for any hypothetical cartel to be effective. The long distances that some cattle are or can be shipped to plants tend to argue for a relatively large geographic market. In specific merger and acquisition cases, however, the competitive effects of distant plants may be sufficiently small that a smaller regional market area would be appropriate.

References

Blair, Roger D. and David L. Kassennan, Antitrust Economics, Richard D. Irwin, Inc., Homewood, IL, 1985.

Boyer, Kenneth D., Industry Boundaries, in Economic Analysis and Antitrust Law, second edition, T. Calvani and J. Siegfried, editors, Little, Brown, and Company, Boston, 1988, pp. 70-77.

Chatterjee, Samprit and Bertram Price, Regression Analysis by Example, John Eiley & Sons, Inc., New York, 1991.

Duewer, L.A. and K.E. Nelson, Beef Packing and Processing Plants: Computer Assisted Cost Analysis, Staff Report AGES 9115, Economic Research Service, USDA, April, 1991.

Elzinga, K.G. and T.F. Hogarty, "The Problem of Geographic Market Delineation in Antitrust Suits", Antitrust Bulletin, vol. 18, no. 1, Spring, 1973, pp. 45-81.

Goodwin, Barry K., and Ted C. Schroeder, "Testing Perfect Spatial Market Integration: An Application to Regional U.S. Cattle Markets," North Central Journal of Agricultural Economics, Vol. 12, No. 2, 1990, pp. 173-186.

Greene, William H. Econometric Analysis, Macmillan Publishing Co., Inc., New York, 1993.

Greer, Douglas F., Industrial Organization and Public Policy, Macmillan Publishing Co., Inc., New York, 1980.

Hayenga, Marvin and Dan O'Brien, Packer Competition, Forward Contracting Price Impacts, and the Relevant Market for Fed Cattle, Research Bulletin 5-91, Research Institute on Livestock Pricing, Agricultural Economics, Virginia Tech, Blacksburg, VA, September, 1991.

Kamerschen, David R. and Johames Kohler, "Residual Demand Analysis of the Ready-to-Eat Breakfast Cereal Market," The Antitrust Bulletin, Winter, 1993, pp. 903-942.

Lamer, Robert J. and James W. Meehan, Jr., editors, Economics and Antitrust Policy, Quorum Books, New York, 1989.

Marion, Bruce, Frederick Geithman, and Gwen Quail, Monopsony Power in an Industry in Disequilibrium: Beef Packing, 1971-1986, Food System Organization-Performance and Public Policies Working Paper WP-96, Dept. of Agricultural Economics, University of Wisconsin, December, 1990.

Papandreou, Andreas G., "Market Structure and Monopoly Power," The American Economic Review, September, 1949, pp. 883-897.

Quail, G., B. Marion, F. Geithman, and J. Marquardt, The Impact of Packer Buyer Concentration on Live Cattle Prices, NC Project 117 Working Paper WP-89, May, 1986.

Raikes, Ronald, Gail M. Sieck, H. L. Self, and M. Peter Hoffman, Weight Loss of Fed Steers and Marketing-Decision Implications, Iowa Agriculture and Home Economics Experiment Station Special Report 82.

Schroeder, Ted C. and Barry K. Goodwin, An Examination of Regional Fed Cattle Price Dynamics, Working Paper No. 90-3, Dept. of Agricultural Economics, Kansas State University, 1988.

Scheffman, David T. and Pablo T. Spiller, "Geographic Market Definition under the U. S. Department of Justice Merger Guidelines, "The Journal of Law and Economics, April, 1987, pp. 123-147.

Schultz, Margaret M., The Relevant Geographic Market Area for Fed Cattle and the Changing Structure of the Beef Packing Industry, Unpublished Ph. D. dissertation, Iowa State University, 1988.

Stigler, G. J., and R. A. Sherwin, "The Extent of the Market," Joumal of Law and Economics, Vol. 28, October, 1985, pp. 555-585.

U. S. Department of Justice and the Federal Trade Commission, Horizontal Merger Guidelines, April 2, 1992.

Ward, Clement E., Meatpacking Competition and Pricing, Research Institute on Livestock Pricing, Blacksburg, Virginia, July, 1988.

White, Kenneth J., S. Donna Wong, Diana Whistler, and Shirley A. Haun, Shazam User's Reference Manual Version 6.2, McGraw Hill, New York, 1990.

Williams, Willard F., "The Changing Structure of the Beef Packing Industry," in Small Business Problems in the Marketing of Meat and Other Commodities (Part 4-Changing Structure of the Beef Packing Industry), Hearings before the Subcommittee on SBA and SBIC Authority and General Small Business Problems, Committee on Small Business, House of Representatives, 96th Congress, June 25-26, 1979, U. S. Govt. Printing Office, Washington, D.C., 1979, pp. 59-216.

Tables and Figures

Table 1--Transaction data variables and descriptions

Packer ID	Plant name and location--county and state
Kill Date	Date cattle recorded as slaughtered
Seller City	Address of the feedlot where cattle were fed
Seller State	State location of the feedlot where cattle were fed
Seller County	County location of the feedlot where cattle were fed
FIPS Code	Federal Information Processing Standard code(for seller county)
No hd	Number of head in lot
Cattle Type	Type of cattle in lot (dairy, fed holsteins, heifers, steers, mixed, unknown/not recorded, or other)
Pro Meth	Purchase method for lot (forward contract, packer fed/owned, marketing agreement, spot market, unknown, or other)
Price Meth	Pricing method for lot (carcass weight--grade and yield, carcass weight fixed price, formula, grade/yield and formula, live weight, custom kill, or unknown)
Purch Date	Date lot purchased by packer
Live Wt	Net live or actual purchase weight for lot
Hot Wt	Total hot weight for lot; same as carcass or dressed weight
Yld	Lot yield (carcass weight as % of live weight)
Cost	Total delivered cost of lot
Cost/cwt	Average total delivered cost per cwt of hot/carcass weight for lot
QG Code	Number of carcasses in each quality grade
Prime	Portion of lot graded prime
Choice	Portion of lot graded choice
Select	Portion of lot graded select
Other	Portion of lot graded as other than prime, choice, or select
YGl	Portion of lot graded yield grade 1
YG2	Portion of lot graded yield grade 2
YG3	Portion of lot graded yield grade 3
YG4	Portion of lot graded yield grade 4
YG5	Portion of lot graded yield grade 5
Ship	Total transportation cost for lot
Comm	Total commissions paid for lot

Table 2 -- Descriptive statistics

Variable	Data Set	Number	Mean	Std. Dev.	Min	Max
No head	A	200615	115.21	96.3	1	1916
	B	141960	115.27	94.5	35	1916
	C	103442	118.55	94.0	35	1055
Cost/cwt	A	186885	120.14	7.37	0	818.09
	B	131557	120.96	6.23	0	255.43
	C	103442	121.61	6.05	91.47	148.58
Choice/Prime	A	193237	54%			
	B	135941	55%			
	C	103442	62%			
Select/Other	A	193227	46%			
	B	135941	45%			
	C	103442	38%			
YG1-3	A	180290	91%			
	B	114922	92%			
	C	103442	96%			
YG4-5	A	180290	9%			
	B	114922	8%			
	C	103422	4%			

Average transaction frequency by day of week

Mon	Tue	Wed	Thu	Fri	Sat	Sun
21.3%	37.4%	21.8%	12.4%	6.5%	.5%	.1%

Type of cattle by percent

Steers	Heifers	Mixed	Fed Holsteins
55.1%	34.5%	8.7%	1.7%

Per plant transaction frequency ranged from 12-10,558

Geographic mapping includes: 16,364,282 cattle fed in the U.S.
122,782 cattle fed in Canada
43 plants owned by 20 different companies

Data Set A--The original data set gathered by P&SA--43 plants
Data Set B--Data used for mapping--43 plants
Data Set C--Data used for econometric analysis--28 plants

Table 3 -- Plant locations

West region

Name	Location
Sunland Beef Co.	Tolieson, AZ
Shamrock Meats, Inc.	Vernon, CA
Harris Ranch Beef Co.	Selma, CA
E. A. Miller Company, Inc.	Hyrum, UT
Washington Beef Co.	Toppenish, WA
IBP, Inc.	Pasco, WA
IBP, Inc.	Boise, ID

East region

Name	Location
IBP, Inc.	Geneseo,IL
Green Bay Dressed Beef, Inc.	Green Bay, WI
Murco, Inc.	Plainwell, MI
Moyer Packing Co.	Souderton, PA
Packerland Packing Co., Inc.	Green Bay, Wl
Taylor Packing Co., Inc.	Wyalusing, PA
Aurora Packing Co., Inc.	North Aurora, IL

MidSouth region

Name	Location
Excel Corporation	Friona, TX
Monfort, Inc.	Garden City, KS
Excel Corporation	Plainview, TX
Hyplains Dressed Beef	Dodge City, KS
IBP, Inc.	Amarillo, TX
IBP, Inc.	Holcomb, KS
Excel Corporation	Dodge City, KS
National Beef Packing	Liberal, KS
IBP, Inc.	Emporia, KS
Sam Kane Beef Processors, Inc.	Corpus Christi, TX
Booker Custom Packing Co.	Booker, TX
Monfort, Inc.	Dumas, TX

MidNorth region

Name	Location
Excel Corporation	Schuyler, NE
IBP, Inc.	West Point, NE
Monfort, Inc.	Greeley, CO
IBP, Inc.	Dakota City, NE
Excel Corporation	Fort Morgan, CO
IBP, Inc.	Lexington, NE
Excel Corporation	Sterling, CO
Beef America	Omaha, NE
Monfort, Inc.	Grand Island, NE
IBP, Inc.	Denison, IA
Monfort, Inc.	Des Moines, IA
Caldwell Packing Co.	Windom, MN
Packerland Packing Co., Inc.	Hospers, IA
IBP, Inc.	Luverne, MN
Beef America	Norfolk, NE
Greater Omaha Packing Co., Inc.	Omaha, NE
Beef America	Omaha, NE

Table 4--Regional plant procurement pattern

A. Percent of U.S. cattle procured within 75-mile radius

Region	Range	Mean	Std. Dev.
West	16.04-94.06	72.05	28.86
East	11.88-60.08	31.88	17.74
MidNorth	29.85-90.59	64.94	15.98
MidSouth	35.39-94.07	76.42	16.34

B. Percent of U.S. cattle procured within 150-mile radius

Region	Range	Mean	Std. Dev.
West	65.94-100.00	90.46	11.34
East	31.46-89.53	52.24	20.91
MidNorth	62.07-98.77	83.93	11.99
MidSouth	80.97-98.56	90.84	6.43

C. Percent of U.S. cattle procured within 250-mile radius

Region	Range	Mean	Std. Dev.
West	72.59-100.00	93.20	9.78
East	39.65-99.74	78.06	18.89
MidNorth	80.97-100.00	94.65	5.57
MidSouth	83.09-99.94	95.29	5.18

Table 5--Regional plant maximum and 95 % plant procurement distances (Distances in miles)

Region	95 % Ave.	Range	Ave. Max. Distance	Range
West	241.43	80-460	480.00	100-1000
East	369.29	200-575	621.43	470-1100
MidNorth	235.59	125-500	737.06	180-1140
MidSouth	278.33	100-975	660.42	400- 975
Middle	259.83	100-975	705.34	180-1140
Overall	270.23	80-975	655.00	180-1140

95 % Distance	No. of plants	Maximum Distance	No.of plants
0-99	1	100-299	3
100-149	9	300-499	7
150-199	3	500-699	15
200-249	10	700-899	9
250-299	7	900-1199	9
300-399	6		
400-499	3		
500 plus	4		

Table 6--Percent of Cattle Procured from Canada

Percent	No. of plants
Less than 1	34
1-4	5
5-100	4

Table 7--U.S. Plant Trade Area Overlaps

		Number of Overlaps	
Region	Total	10% or more overlap	Competitive overlap*
West	2-19	1-7	1-7
East	10-30	4-16	3-16
MidNorth	21-40	13-22	9-20
MidSouth	12-35	3-20	3-17

* 10% or more and excluding same-owner plants

Figure 1. Canada Live Bovine Exports to the U.S. 1992 Value

Figure 2. A Typical Price Trend

PART III

SPATIAL FED CATTLE TRANSACTION PRICE RELATIONSHIPS

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SPATIAL FED CATTLE TRANSACTION PRICE RELATIONSHIPS

Introduction

Determining the relevant market for fed cattle is important for monitoring market prices. Which plants compete with each other and the extent of spatial price integration is an important indicator of market performance. Spatial price integration refers to prices across plants that do not diverge widely from each other. If prices across plants diverge from each other, this suggests the plants are not competing with each other for cattle purchases. Rational choices by market participants of sellers selling to the highest bidders and buyers buying from willing sellers make prices spatially linked. Inadequate market information or inability to trade cattle with plants in a particular location may reduce the strength of spatial price relationships. In addition, identification of spatial price differences may not occur instantaneously. That is, it takes time to recognize the 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 prices across location adjust to price changes at other locations, the stronger the spatial competition. Strong spatial competition for slaughter cattle procurement is the essence of plants operating in the same geographic market.

Testing for price leadership is also 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 have insufficient activity to generate much new information. Plants that are price followers may be in the same market as those that serve 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 addresses three primary issues. First, Granger causality of daily prices at 28 beef packing plants is determined. The purpose of this is to determine the extent to which price leadership and dominant price discovery plants exist. If strong causality or feedback in prices is present across plants, then the plants interact with each other in discovering price and the plants can be considered in the same market. Alternatively, lack of price causality suggests the plants do not react to price changes of each other, implying that the plants are discovering prices independently of each other. This suggests the plants are not in the same market.

Second, cointegration is used to determine whether long-run price relationships across plants are stationary. This provides evidence of whether a long-run equilibrium spatial price parity is present. Longrun spatial price parity suggests that over time cattle sellers are receiving prices for cattle that are similar across location. In other words, spatial price discrimination is not present. 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 that the plants are not in the same relevant market. Plants with cointegrated prices maintain a stable spatial, equilibrium suggesting that the plants are in the same relevant cattle procurement market.

Third, error correction models are estimated and used to determine the 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 from spatial equilibrium at other plants are more likely in the same relevant fed cattle procurement market than plants that respond slowly or not at all.

All price data analyzed in this report are cash market transactions. No forward contracts or alternative captive supply marketed cattle are considered here. This study focuses on the spatial interaction of temporally consistent prices. As such, prices for cattle purchased on a particular day for slaughter in the same general time period best represent comparable prices on a daily basis. To the extent plants may contract for cattle in different locations than they secure their cash purchases from, this study would understate the relevant geographic market. If alternatively, cash and contract cattle are purchased from similar market regions, this study will accurately reflect the plants' competitors.

Previous Research

Several studies have examined price leadership and cointegration in spatial fed cattle markets. All of the published studies have used Agricultural Marketing Service weekly or monthly prices. Bailey and Brorsen examined dynamics of weekly slaughter steer prices from 1 January 1978 through 4 June 1983 in four major 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 pair-wise Granger causality in eight weekly slaughter cattle markets from 1973 through 1984. They concluded that, in general, the Nebraska direct market reacted fastest to evolving information though some markets exerted feedback to this market. 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. They concluded that the leading price discovery locations tended to be Iowa-Southern Minnesota, Eastern Nebraska, and Omaha. The Western Kansas market became more dominant over the time period. Regional price adjustments took from 1 to 3 weeks to complete. Larger volume markets, located near concentrated cattle feeding and slaughtering regions, fully reacted to price changes at other markets usually within 1 or 2 weeks. However, small volume markets, located on the fringes of the major cattle feeding regions, took 2 to 3 weeks to fully respond to price changes in larger markets.

Goodwin and Schroeder examined cointegration in fed cattle markets using weekly price data from 11 markets over the January 1980 through September 1987 period. They reported cointegration test results between the Nebraska direct market and 10 other regional and terminal markets. Overall, cointegration was somewhat limited with about half of the tests indicating cointegrated markets. They further determined that 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 important ways. Plant-level transaction prices from 28 plants located across the country are analyzed. Transaction prices are aggregated into daily plant level prices for analysis. This rich data set allows for analysis of daily pricing strategies and market dynamics in the fed cattle markets. No previous study has examined the spatial price dynamics of such detailed and disaggregated slaughter cattle transaction prices. Vector autoregression models, cointegration, and error correction vector autoregression models are all examined and compared in this analysis. This provides a comprehensive examination of these different techniques for determining market dynamics and degrees of spatial price integration.

Empirical Models

Several time series techniques are used here to investigate daily price relationships across packing plants. When investigating spatial price relationships, either bivariate or multivariate (referring here to 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, for example (i.e., prices may actually be correlated in a multi-variate fashion that may not surface in bivariate comparisons). Multivariate analysis, on the other hand, accounts for the joint effects of all regions being studied. The problem encountered with multivariate analysis, however, is that if the price series are highly correlated, degrading multicollinearity in the multivariate model quickly becomes 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 (see data discussion below). This large number of plants, with highly correlated prices, would not yield informative conclusions using multivariate time series. Therefore, bivariate time series models are used.

Vector Autoregression Models

Several time series analyses are conducted of the daily plant prices. The first method employed is vector autoregression models (VAR). The simple bivariate VAR can be specified as:

$$(1)\quad Y_{1t} = \beta_0 + \sum_{i=1}^{k} \beta_{1i} Y_{1t-i} + \sum_{i=1}^{kbeta_{2i}} Y_{2t-i} + \varepsilon_{1t}$$

$$Y_{2t} = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} Y_{1t-i} + \sum_{i=1}^{k} \alpha_{2i} Y_{2t-i} + \varepsilon_{2t}$$

where *t* refers to day, Y_i refers to price at plant *i*, α's and β's are parameters, and ε are random errors. The lag length of the VAR (*k*) can be determined using numerous methods. The method used here was the Schwartz Bayesian criterion (SBC) (Enders, p. 88)[17]:

$$(2)\quad SBC = T \ln(residual\ sum\ of\ squares) + n \ln(T)$$

where T is the number of observations and n is the number of parameters estimated including the intercept. The lag length was determined by selecting the largest lag length of subsequent lags starting from one, that minimized the SBC statistic. The same number of observations were used to estimate equations for each lag length.

Causality in price adjustments is tested using standard Granger F-tests. The procedure involves testing the null hypothesis for the parameters in equation (1) that $\Sigma\beta_{2i}=0$, which if rejected implies price at plant 2 Granger causes price at plant 1, and $\Sigma\alpha_{1i}=0$, which if rejected implies price at plant 1 causes price at plant 2.[18] If Granger causality is bi-directional, this indicates price information flows both directions and the prices at each plant react to price changes at the other plant. This is evidence of the plants competing with each other and that they operate in the same geographic market. Price leadership, on the other hand, where one plant simply responds to price changes at the other plant, suggests the leading plant may be able to operate somewhat independent of the other plant. Finally, lack of Granger causality in either direction does not support the plants being in the same relevant geographic slaughter cattle market.

[17] The Schwartz Bayesian criterion is superior to the standard Akaike information criterion (AIC) often used. Enders indicates that the AIC is biased toward selecting an overparameterized model.

[18] In its purest sense, Granger causality testing requires out-of-sample forecasting. Given the large number of markets being considered, and the relatively short time series available, out-of-sample forecast performance of the VAR models was not tested here.

Disagreement has existed over time regarding whether to estimate such a VAR model with prices in levels or in first differences. The typical reason suggested for differencing is to make the data stationary. If the price data are nonstationary, then standard statistical measures are not reliable. However, first-differencing the data result in mis-specified models if the data are cointegrated (Enders). In the analysis conducted here three types of VAR models are reported: 1) using prices in levels, 2) using first-differenced prices, and 3) using error correction models with first-differenced price data. Using all three provides opportunity for comparison with each other and with previous studies. If the data are cointegrated, Enders argues that using the error correction model is the most appropriate.

Cointegration Model

The daily plant price data are also tested for cointegration. In particular, consider two nonstationary series that by themselves 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:

$$(3)\quad Y_{1t} = \beta_0 + \beta_1 Y_{2t} + e_t$$

The two series are said to be cointegrated of order (1,1) if *e* is stationary.[19]

Essentially, spatial market integration is brought about by arbitrage between market locations or by sellers and buyers trading in overlapping market 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 costs, transaction costs, 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. Two tests proposed by Engle and Granger are used here. These are the Dickey-Fuller (DF) and the augmented Dickey-Fuller (ADF) tests. The DF stationarity test for a particular series, *y*, is:

$$(4)\quad \Delta y_t = -\phi y_{t-1} + \varepsilon_t$$

The null hypothesis is φ=0, that the series contains a unit root. Failure to reject the null suggests that the series is nonstationary. The test statistic is φ divided by its standard error. Critical values for the statistic are provided by Engle and Granger. The ADF is similar to the DF and is:

[19] 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).

$$(5)\quad \Delta y_t = -\phi y_{t-1} + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \varepsilon_t$$

The choice of lag length is selected using the SBC criterion discussed earlier. The test statistic is similar to that used for the DF test. The ADF test is more general and is preferred if the residual in (4) is not white noise.

Once nonstationarity of the prices in levels is established (and stationarity in first-differences is present) the parameters of the cointegrating regression are estimated using standard OLS regression. Estimates of the parameters of the cointegrating regression are then

$$(6)\quad \hat{e}_{1t} = Y_{1t} - \hat{\beta}_0 - \hat{\beta}_1 Y_{2t}$$

used to calculate estimates of the residual errors, $\hat{e}$, where
Testing for cointegration involves testing the stationarity of the residual series using the DF and ADF tests where the DF test is:

$$(7)\quad \Delta \hat{e}_{1t} = -\phi \hat{e}_{1t-1} + \varepsilon_t$$

$$(8)\quad \Delta \hat{e}_{1t} = -\phi \hat{e}_{1t-1} + \sum_{i=1}^{k} \beta_i \Delta ehat_{1t-i} + \varepsilon_t$$

and the ADF is:
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 (7) or (8) is significantly different from zero.

If two economic time series are cointegrated, then VAR models of the series should be estimated using an error correction model (Enders). Otherwise, the model will suffer from

$$(9)\quad \Delta Y_{1t} = \alpha_1 + \alpha_{1y} \hat{e}_{1t-1} + \sum_{i=1}^{kalpha_{11}} (i) \Delta Y_{1t-i} + \sum_{i=1}^{k} \alpha_{12}(i) \Delta Y_{2t-i} + \varepsilon_{1t}$$

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

misspecification error. The error correction model is specified as:
where the models in (9) are similar to standard VARs using differenced data, though, the lagged error correction term (the error from the cointegrating regression in (6)) is added to the VAR. The α_{1y} and α_{2y} coefficients are referred to as speed of adjustment estimates. These parameters provide an estimate of 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[20] indicates a 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 price at plant 2 does not Granger cause price at plant 1. Likewise if α_{2y} is zero and all $\alpha_{21}(i)$=0 in the second equation, then price at plant 1 does not Granger cause price at plant 2.

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

Degree of cointegration, levels of causality present, and the speed of price adjustment to longrun equilibrium are all continuous variables that provide means for economic analysis. Economic factors are expected to be related to the strength of these market conditions. The ability to develop generalizations requires conceptualization of factors affecting these spatial price relationships. The strength of the cointegration present can be measured by the size of the ADF cointegration test statistic (test statistic on φ in equation (8)). Larger ADF test statistics indicate higher levels of cointegration suggesting stronger tendencies for prices at the two plants in question to move together and not diverge from each other, suggesting they are in the same geographic market.

Similarly, causality is also present to a degree. Plants that have large pair-wise Granger causality F-statistics (using equation (9)) have strong directional price causality. Finally, the size of the speed of adjustment parameter (estimates of α_ys in equation (9)) indicates how rapidly prices at a particular plant adjust to price changes at another plant (given that the two series are cointegrated). Large speed of adjustment parameters (close to 1.0) suggest rapid information flow and reaction and small parameters (close to 0.0) reflect slow reactions.

Economic factors are expected to be related to all of these test statistics. In particular, the following models are designed to test the relationships between several factors and the strength

$$(10)\quad ADF_{ij} = \beta_{10} + \beta_{11} Distance_{ij} + \beta_{12} Distance_{ij}^2 + \beta_{13} Procurement\ Overlap_{ij} + \beta_{14} Cash\ Purchas$$
$$+ \beta_{15} Slaughter_i + \beta_{16} Slaughter_i^2 + \beta_{17} Price\ Data_i + \beta_{18} Same\ Firm_{ij} + \varepsilon_1$$
$$(11)\quad FSTAT_{ij} = \beta_{20} + \beta_{21} Distance_{ij} + \beta_{22} Distance_{ij}^2 + \beta_{23} Procurement\ Overlap_{ij} + \beta_{24} Cash\ Purcha$$
$$+ \beta_{25} Slaughter_i + \beta_{26} Slaughter_i^2 + \beta_{27} Price\ Data_i + \beta_{28} Same\ Firm_{ij} + \varepsilon_2$$
$$(12)\quad SPEED_{ij} = \beta_{30} + \beta_{31} Distance_{ij} + \beta_{32} Distance_{ij}^2 + \beta_{33} Procurement\ Overlap_{ij} + \beta_{34} Cash\ Purcha$$
$$+ \beta_{35} Slaughter_i + \beta_{36} Slaughter_i^2 + \beta_{37} Price\ Data_i + \beta_{38} Same\ Firm_{ij} + \varepsilon_3$$

of cointegration, significance of causality, and speed of adjustment. The models are:

[20] 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.

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 (equation (8)), *FSTAT* is the significance of the Granger F-statistic from the error correction model (equation (9)), and *SPEED* is the estimated speed of adjustment parameter (α_y) from the error correction model (equation (9)). The independent variables are *Distance*, which is the number of miles between plant *i* and plant *j*; *Distance-squared* is the squared mileage; *Procurement Overlap* is the percentage of plant *i*'s cattle purchased from a region overlapping with plant *j*'s procurement area; *Cash Purchases* is the percentage of cattle purchased in the cash market by the plant over the estimation time period; *Slaughter* is the total number of cattle slaughtered by the plant during the period; *Slaughter-squared* is the slaughter variable squared; *Price Data* is the percentage of days over the time period that daily price data were available (as discussed later); and *Same Firm* is a binary variable equal to 1 if the two plants are owned by the same parent firm and equal to 0 otherwise.

The expected signs of the various independent variables are discussed below. The strength of spatial price relationships is expected to be related to the costs and risks associated with spatial arbitrage. Some of the variables in these models are especially 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, the strength of spatial price relationships is expected to decline. Therefore, *Distance* is expected to be negatively related to the ADF cointegration test statistic. In addition, as distance increases, the speed of price adjustment back to long run spatial equilibrium as prices change would be expected to decline. Therefore, *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. That is, 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 significance level value, 0.01 is less than 0.05 though of greater statistical significance). Thus, the F-statistic significance level is expected to be positively related to *Distance* between plants. The effect of distance was allowed to be nonlinear by including a squared term.

Procurement Overlap is expected to have a similar effect as the distance variable. That is, plants in close proximity to each other would also be expected to have large procurement overlaps. To some extent this is true. However, *Procurement Overlap* measures actual trade activity, whereas *Distance* is a rough measure of 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. A simple regression of the *Procurement Overlap* variable against *Distance* and *Distance squared* gave an R-squared of 0.60. Thus, although related, the two variables are not perfectly correlated.

Cash Purchases was included in the models to determine whether the packer's procurement method was related to the strength of spatial cash prices. Conceptually the sign of this variable could be either positive or negative. If the plant uses the cash market more heavily this could imply that the local cash price is more liquid and therefore the local market has more opportunity for quick and complete spatial arbitrage. This would suggest 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 frequently, 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 some other market than to discover locally. This would suggest a negative relation between the percentage of cattle purchased in the cash market and *ADF* and *SPEED*, and a positive relation with *FSTAT*.

Slaughter volume is intended to capture the relation between plant size and spatial market integration. This variable is expected to be negatively related to the strength of spatial price relationships. If larger plants discover price somewhat independently and have influence on local market price, then prices at larger plants would be expected to be less cointegrated, be slower to respond to price changes at other markets, and be less likely to be significantly influenced by prices at other locations. This would suggest negative signs in the *ADF* and *SPEED* equations and a positive sign in the *FSTAT* equation. In examining cointegration in regional markets using aggregate Agricultural Marketing Service (AMS) prices, Goodwin and Schroeder found that large-volume markets tended to be less cointegrated with small-volume markets supporting this position. Similarly, using the same (AMS) data set, Schroeder and Goodwin found that large volume markets were more likely to cause prices at smaller volume markets than the reverse, supporting the anticipated signs. The effect of plant size is also allowed to be nonlinear by including a squared term.

Price Data was included in the models to adjust for statistical effects of having to replace missing daily price data. As detailed later, missing price data were estimated by using the predicted values of a regression equation of the plant's daily prices on the contemporaneous, single-day-lagged, and two-day-lagged overall plant average prices over the entire data period. This would tend to smooth the individual plant price series more in situations with more missing data. This would suggest that the more missing data (the smaller the value of *Price Data*), the more likely the plant price series would falsely be considered cointegrated, the faster the price will react to other plants' prices, and the greater the *FSTAT* significance. That is, a plant's price series with a large number of missing prices is forced to be related to prices in the other markets through the method used to proxy these missing prices. Important to note is that larger plants tended to have fewer days containing missing prices, therefore, *Price Data* is negatively correlated with *Slaughter* and the two variables capture part of the same phenomenon of plant size.

Finally, the *Same Firm* variable was used to capture different spatial price adjustments associated with plants that are owned by the same firm relative to those owned by different firms. Plants owned by the same firm in different locations would have lower costs and lower risks associated with spatial arbitrage than plants owned by different firms. In addition, plants owned by the same firm share information more directly and may rely on each other to help schedule cattle procurement and slaughter. Thus, this variable was expected to be positive for the *ADF* and *SPEED* equations and negative in the *FSTAT* equation.

Data

A significant contribution of this study is that actual transaction data are used from a broad spectrum of packing plants. The data were obtained from the Packers and Stockyards Programs. Use of actual transaction data provides a rich data set for analyses which helps ensure that the results are accurate representations of reality. However, the data also presented some analytical problems.

Useable Data

The original data set consisted of transaction data for a total of 200,616 pens of cattle slaughtered in 48 U.S. plants procured from March 23, 1992 through April 3, 1993. As a result of numerous missing data, unreconcilable differences in data, incompatibilities to compare data across plants, or obvious data errors, this data set was condensed down to 103,442 pens of cattle slaughtered in 28 plants for the time series estimation. Plants were represented from the states of Texas, Kansas, Colorado, Nebraska, Iowa, Minnesota, northwestern states, and eastern states. Plants located in southeastern and southwestern states were not included. Data representing all transactions from 20 plants as well as numerous transactions from the 28 retained plants were not used in this analysis. Many data problems resulted in multiple and intersecting numbers of deleted transactions making the number of observations removed by each problem highly conditional on the order of deletion. Therefore, the number of observations deleted at each step is not reported. Reasons for excluding data included the following:

1. Only pens containing steers, heifers, fed Holsteins, or mixed sexes were retained. These cattle represent the bulk of fed cattle slaughter and represent reasonably the same market in terms of cattle type. Pens containing cows, bulls, and stags represent a different market whose prices would be difficult to compare with fed cattle and adjust to a standard comparable quality to fed cattle for analysis.
2. Only pens that had kill and purchase dates recorded were retained. Also, transactions with dates outside the period of data collection were deleted. Purchase and kill dates were needed to identify the day the cattle were procured and slaughtered. Without these, the transaction could not be matched with the appropriate date, which is necessary to conduct time series analysis.
3. Only pens with 35 or more head were retained. This represented the minimum number of head per pen the Packers and Stockyards Programs stipulated collecting in the original data collection. Therefore, any pens containing less than 35 head were either erroneously collected or reported incorrectly and were deleted.
4. Only pens that were purchased in the cash (spot) market were retained. The time series analyses involved examination of prices for pens of cattle purchased at the same point in time for slaughter in the same period. As such, prices for forward-contracted or

marketing agreement cattle were not relevant in the temporal comparison since they represent purchases made for delivery at a later date.

5. Only pens that had a recorded carcass weight (hot or cold) were retained. All carcass weights were converted to a hot weight basis. This was necessary because carcass weight was needed to adjust prices for weight in calculation of a daily plant price used in the time series estimation. No pens were deleted that could have been assigned an estimated carcass weight.
6. Only pens that had an average carcass yield (carcass weight / live weight) recorded and had yield greater than or equal to 50% and less than or equal to 70% were retained. This represented the vast majority of the fed cattle in the original data set. Truncating the data at some reasonable range was necessary because the original data set had yields recorded ranging from 13% to 80.4%. Identifying precisely which recorded yields were erroneous and which were accurate was not always possible. Therefore, the truncation was necessary to remove potentially erroneous entries.
7. Only pens that had a yield grade separated into at least yield grade 1-3 and greater than 3 were retained. Yield grade was necessary to accurately adjust the prices to a plant level daily price. Because a large number of plants only separated yield into 1-3 and greater than 3, this was the least restrictive measure to use while still maintaining this relevant pricing variable. Again, pens without a yield grade have insufficient quality information to discern the nature of their price makeup.
8. Only pens containing a quality grade which separated Choice and above from Select and below quality grades were retained. Quality grade was necessary to accurately adjust the prices to a plant level daily price. Because several plants only separated quality grade into Choice and above and Select and below, this was the least restrictive measure to use while still maintaining this relevant pricing variable. Pens without a quality grade have insufficient information to explain price.
9. Only pens that were purchased within 14 days of slaughter were retained except at three plants where the maximum allowed was 30 days because these three plants specifically indicated that cattle purchased that far in advance were in their normal cash market procurement. Any cattle purchased in advance of 14 days from slaughter are not considered cash purchases and as noted earlier would not be included in the same temporal market.
10. Only pens whose carcass price was greater than or equal to 80% of the USDA Select boxed beef cutout equivalent price and less than 120% of the USDA Choice boxed beef cutout equivalent price were retained. This resulted in deletion of only three pens of cattle in the final step of deletions. Thus, this cleaning had virtually no impact on results, but again removed potentially erroneous entries from the data.

These rules resulted in 20 plants that were not retained in the final data. 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 heterogeneous prices rapidly becomes suspect.

Daily Plant Prices

A necessary step to conduct the time series analysis is to obtain a daily price series for each plant. These daily price series must be quality-adjusted to be comparable over time and across plants. Therefore, the transaction prices need to be converted to a quality-adjusted daily price quote for each plant. This process involved estimating a hedonic price model using cash market transaction data for each plant over all useable observations. These plant-specific models were then used to estimate the price that plant would have been expected to pay 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:

$$\begin{aligned}(13)\ Price = {} & \beta_0 + \beta_1 Heifer + \beta_2 Holstein + \beta_3 Mixed + \beta_4 Yield\ Grade\ 3 + \beta_5 Pen\ Size \\ & + \beta_6 Pen\ Size\ Squared + \beta_7 Average\ Hot\ Weight + \beta_8 Average\ Hot\ Weight\ Squared \\ & + \beta_9 Purchase\ to\ Kill\ Days + \beta_{10} Wholesale\ Value + \beta_{11} Average\ Plant\ Price + \varepsilon.\end{aligned}$$

All variables are defined in table 1. Perfect collinearity required a default pen be specified which consisted 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. The number of days between purchase and kill dates could be either positive or negative depending upon how this variable is expected to influence packer pricing (Jones et al.). The price paid would be expected to be positively related to the delivery lag if longer delivery time was reflective of packers desires for feedyards to hold cattle longer than normal and packers were willing to pay for this service. Alternatively, shorter delivery time could indicate a need by the packer for cattle to meet slaughter capacity and, given economies of scale, the packer may be willing to pay more to fill short-term slaughter needs. Wholesale value is expected to be positively related to price; as the wholesale value of the beef from a pen increases, the packer would pay more. 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.

The empirical model described in equation (13) is estimated separately for each plant and for all plants combined. The parameter estimates for data from all plants combined are reported in table 3. This model includes data from 28 plants, consisting of 103,442 pens of cattle, comprising 12.3 million head. The model explains 89 percent of the variability in transaction 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 Weight) are difficult to casually interpret; therefore, they are illustrated in figures 1 and 2.

Premiums and discounts reported in table 3 are comparable with those found in previous work (Ward 1992; Schroeder et al.; and Jones et al.).

The parameter estimates from the plant-specific models are not reported to conserve space. They generally had significant parameters with the anticipated signs. The R-squareds of the plant-specific models range from 0.714 to 0.967, with most between 0.85 and 0.95. The RMSE's range from $1.097/cwt to $3.401/cwt or from about 1% to about 2.8% of the mean price. These are important because the accuracy or representativeness of the predicted daily plant prices are contingent on the explanatory power of these models. Accurate models will result in high levels of confidence in the daily price estimates, whereas models that are unable to explain much of the price variability will result in suspect daily price estimates.

The plant-specific models were used to calculate a daily carcass beef price at each plant. The selected standard pen characteristics were: a 150-head pen of steers, graded 60% choice or better, 95% yield grade 1-3, average carcass weight of 730 pounds, and purchased 7 days prior to slaughter. For each day that cattle were purchased in the cash market by the plant, the 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 (i.e., no transaction prices exist to be adjusted for quality). This was necessary in order to estimate the standard time series models used here. The total number of days having at least one plant with at least one transaction was 364. The number of days that plants had at least one transaction ranged from 84 to 314 (23% to 86% of the 364 days).

Plant prices during days without transactions could be estimated in several ways. For example, the same equations used to adjust the transaction prices for quality (equation (13)) could be used. This would essentially make the price change from day to day only with the current price across all plants (Average Plant Price) and the wholesale prices. An alternative is to estimate the missing daily prices by regressing the average daily plant prices on days data are available on current and lagged average plant prices. The advantage of using this method is that if time lags are present between the particular plant's price and the average price across all plants, this would help maintain some of that lag structure. This latter method was employed here. Daily prices were regressed 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 during days that a plant did not have any cash cattle purchases. This process resulted in 28 plants having a total of 364 days with quality-adjusted comparable carcass prices. These data are used in the time series analyses reported.

The time series models cannot be estimated without complete time series data, so determining the precise impact on results of replacing missing data is not possible. However, one method that can be used 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, the correlations between the original series and the series with missing data replaced are essentially the same with most correlations differing by less than 0.05. Thus, pair-wise correlations of the plants' prices over time were generally not affected much by replacing missing prices with proxies. This provides confidence in the results derived from these data series.

Additional data were needed to estimate equations (10)-(12). 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 (rounded to the nearest percent) of cattle purchases by a plant that overlaps the other plant's procurement area. The percentage of cattle purchased in the cash market and the slaughter number were calculated from the original Packers and Stockyards Programs data set.

Results

VAR Estimates

The VAR models are estimated first with prices in levels. Selected lag orders are all 2 to 4 days in length. The Granger causality F-statistics are generally significant across most all plants. Plants located in Texas, Kansas, Nebraska, and northwestern states tended to Granger cause prices at approximately 90% of the other plants.

However, a few plants in these same regions are primarily price followers as they Granger cause prices at less than 30% of the remaining plants. All but three of the plants Granger cause prices at half or more of the other plants. This suggests that price causality is strong with considerable information flowing across plants. The number of significant Granger F-statistics as a percentage of pair-wise comparisons indicates strong causality as additional regions are considered. For example, in Texas, 75% of the total pair-wise Granger F-statistics are statistically significant. Adding Kansas and Texas together, 85% of the F-statistics are significant. Adding plants from Colorado and Nebraska results in 80% being significant, and all plants together have 77% of Granger statistics significant.

The Granger causality results of first-difference prices result in fewer significant causalities than with prices in levels. In addition, the plants leading price discovery changed as no plants cause prices at 90% of the other plants, but four plants located in Kansas and Nebraska cause prices at 80% of the other plants. On the other extreme, in first differences, 12 of the 28 plants Granger cause less than 30% of the remaining plants' prices. This analysis suggests Kansas and Nebraska tend to be the geographic price leaders, with less national influence compared to the results of the VAR models on price levels. Performing a similar comparison of significance of F-statistics as was done in the price-level models, plants in Texas have only 33% of their F-tests significant; adding Kansas plants results in 54% significant F-tests; adding Colorado and Nebraska results in 43% significant; and all regions together had 43% significant.

Which is more appropriate, the price level or first-differenced price results? The Kansas-Nebraska geographic area is a price leader in both model specifications. Relevant to this discussion is also the issue of stationarity of the underlying price series. As will be discussed in the next section, the price series are nonstationary. Some have argued that the data should be stationary prior to estimating a VAR to avoid biased standard errors, whereas others argue that this is not an issue as one should let the nonstationarity in one series describe the nonstationarity in the other series (Sims 1972 and 1994). However, with nonstationarity, the F-statistics are not reliable. Therefore, inferences drawn from these results may not be robust. They are reported here because these methodologies have had considerable use in previous studies and, therefore, serve as a basis for comparison.

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.

Similar to the VAR Granger causality results, 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. In other words, 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 that the data are nonstationary and prices at the various plants are generally cointegrated, an error correction model specification of the VAR is most appropriate. Similar tests to the other VAR models are used to analyze these results. The Granger causality F-statistic results from the error correction VAR support plants in Nebraska as price leaders.

Performing the same analysis of the F-statistics as was done for earlier results provides additional insights. 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 at 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 tend to follow prices discovered in Nebraska. Plants in the other regions have less strong links to prices at plants in Nebraska or other regions.

An important observation is that the VAR Granger causality test results are sensitive to the modeling method. Price-level models, first-differenced price models, and error correction models provide different individual plant results, but are more consistent in identifying regions of price leadership. Enders and others argue the error correction model is the most appropriate of the three. Perhaps the weakness associated with the power of the causality F-test (as compared to out-of-sample forecasting, for example) reduces the relative importance of these concerns.

The speed-of-adjustment parameters indicate how rapidly price in the plant reacts to get back to longrun cointegrated spatial equilibrium when price changes at another plant. A value of 1.0 would suggest immediate reaction within the same day. A value close to zero would suggest 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 1 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 1 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 that operate in the same market would be expected to have rapid adjustments to price changes at other plants 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 (10)-(12) are estimated to provide generalizations of the results. Equations (10), (11), and (12) 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 regression. The residuals from this model 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. The final parameter estimates are calculated as the means of the stored parameters across all estimation interactions. Similarly, 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 bootstrapped 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.

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. 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. In addition, and perhaps most 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.

Procurement Overlap is an important determinant of spatial price relationships. Cointegration increases as expected for plants whose trade areas overlap. Similarly, firms having 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 disequilibrium (although this variable is only significant at the 0.10 level).

Plants that have high percentages of cattle purchased in the cash market are less 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 (other spatial) markets as sources of market information to determine their cash market 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 regarding relative prices leading to greater pricing independence. This could also be a result of larger plants simply having a larger burden of price discovery than their smaller counterparts. That is, larger plants have higher total costs associated with prices that do not accurately reflect local market conditions (since their purchases are greater). Larger plants also naturally have more influence on prices because they purchase cattle over larger areas. This also 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, as noted earlier, correlations between the plant prices without missing data replaced and plant prices containing proxies for missing data were very similar, the need to supplant missing prices with proxy prices appeared to affect 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 of prices back to long-run spatial equilibrium, and were less likely to have price changes caused by price changes at other plants. This indicates, that replacing missing prices using the method used here could have somewhat biased upward the amount of cointegration, and increased the speed of price adjustment, relative to what would likely be the case had actual prices been available throughout the time period. This is not surprising in that prices used to proxy for missing data likely had less variability than actual data. However, an important alternative interpretation is that the number of missing observations was correlated with plant size; smaller plants had more days without a price quote. Thus, this result could be additional evidence of large plants operating somewhat independently in price discovery relative to smaller plants as discussed above.

Plants owned by the same firm were more likely to have cointegrated prices. This indicates that firms having plants in different locations can more easily ship cattle across plant locations or can make purchases at the fringe of each plant's trade area that could be shipped to either plant. This is consistent with Goodwin and Schroeder's findings that as beef packer concentration over time increased, regional cattle price cointegration also 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. The significance of *FSTAT* was not significantly related to whether the plants were owned by the same firm.

To further interpret the 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:

$$(14)\ \ Procurement\ Overlap = 67.46 - \underset{(-27.84)}{0.109}\ (Distance) + \underset{(19.49)}{0.000038}(Distance\ squared)$$

$$R\text{-}squared = 0.60,\ t\text{-}statistics\ are\ in\ parentheses.$$

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. A graph of this relation between *Procurement Overlap* and *Distance* is provided in figure 3. *Procurement Overlap* on average reaches zero as distance increases to about 900 miles. Figures 4, 5, and 6 illustrate how *ADF*, *FSTAT*, and *SPEED* change as distance between plants increases using the 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 5). 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 4). Plants also become much slower to react to new information in other locations as the distance between them increases. Plants within 200 miles of each other on average adjust fully to price changes from spatial equilibrium on average within 2.5 days; however, plants separated by 900 miles or more take approximately 4 days to adjust (figure 6).

Limitations

Analysis presented in this report has several limitations that deserve elaboration. Results rely critically on quality and representativeness of the data. Undoubtedly, data omission has affected the results. Data from only 28 of 48 original plants were retained in the analysis presented. Many of the smaller plants or plants that slaughtered mixed maturities and varieties of cattle were removed from the data set. In addition, plants that did not maintain cattle quality, yield, and other records consistent with the majority of plants were removed (this was not exclusively the smallest plants). Thus, results do not necessarily represent all cattle markets near these plants. Certain regions of the country that have beef slaughter plants are not represented, including Arizona, California, Wisconsin, Utah, and Georgia.

Only spot market transactions were analyzed here. Significant percentages of cattle were procured through means other than the spot market. To the extent that prices of these cattle differ from those of cattle purchased in the cash market, results could be affected.

Data needed to be converted to daily, quality-adjusted prices for the analysis conducted. This included estimating plant level quality models and finding proxy prices for a substantial number of days at numerous plants. Although efforts were made to ensure data integrity at each step, such data transformations induce error and reduce the confidence of results. However, comparisons of correlations indicate the series containing missing price proxies have similar relations with each other as those series without missing prices replaced. Thus, using proxies for missing prices is not expected to have significantly altered conclusions of this study.

Only approximately 1 year of price data were available for this study. Time series techniques such as cointegration are longrun phenomenan. To the extent daily prices for 1 year are representative of typical time periods, and to the extent this can be considered long run in the sense that plants have ample time to make adequate adjustments to market conditions, results are valid. If these conditions do not hold, results could be less robust.

Conclusions

Spatial price relationships among beef packing plants have important implications in defining geographic markets for live cattle markets. Plants whose prices are not integrated may convey inaccurate price information that could distort producer 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 in order to discern information regarding relevant spatial markets for slaughter cattle. Strengths of market price relationships vary continuously; therefore, relevant markets are also continuous measures.

VAR models estimated in price levels indicate considerable causality and feedback in daily plant prices. VAR models using first-differenced prices suggest less causality, but generally support the price-level results. Plants located in Kansas and Nebraska tended to be price discovery leaders.

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 generally tended to move together and did not generally diverge from each other. In other words, daily prices tended to maintain a longrun spatial equilibrium, 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 1 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 purchased large percentages of cattle through noncash means tended to have cash prices that were less cointegrated, had less causality, and were slower to react to other plants' price changes than plants that purchased all of their cattle in the cash market. Larger plants also tend to react more slowly to price changes from equilibrium and tend to have lower degrees of price causality from other plants. This indicates that plants with relatively small percentages of cattle being purchased in the cash market and large plants act 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 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 tend to 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.

References

Bailey, D. and B.W. Brorsen. "Dynamics of Regional Fed Cattle Prices." *West. J. Agr. Econ.* 10(1985):126-33.

Dickey, D.A. and W.A. Fuller. "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root." *Econometrica* 49(1981):1057-72.

Efron, B. "Bootstrapping Methods: Another Look at the Jacknife." *Ann. Statist.* 7(1979):1-26.

Enders, W.E. *Applied Econometric Time Series*. New York: John Wiley & Sons Inc. 1995.

Engle, R.F. and C.W.J. Granger. "Cointegration and Error Correction Representation, Estimation, and Testing." *Econometrica* 55(1987):251-76.

Engle, R.F. and B.S. Yoo. "Forecasting and Testing in Co-Integrated Systems." *J. of Econometrics* 35(1987):143-59.

Goodwin, B.K. and T.C. Schroeder. "Cointegration Tests and Spatial Price Linkages in Regional Cattle Markets." *Amer. J. Agr. Econ.* 73(1991):452-64.

Granger, C.W.J. "Investigating Causal Relationships by Econometric Models and Cross-Spectral Methods." *Econometrica* 37(1969):424-38.

Hamilton, J.D. *Time Series Analysis.* Princeton, New Jersey: Princeton University Press. 1994.

Hayenga, M.L., R.D. Hook, and B. Jiang. "Fed Cattle Geographic Market Delineation: Slaughter Plant Procurement Area and Supply Response Analysis." Confidential Report prepared for the Packers and Stockyards Administration, U.S. Dept. of Agriculture, May 15, 1995.

Jones, R., T. Schroeder, J. Mintert, and F. Brazle. "The Impacts of Quality on Cash Fed Cattle Prices." *So. J. Agr. Econ.* 24(1992):149-62.

Koontz, S.R., P. Garcia, and M.A. Hudson. "Dominant-Satellite Relationships between Live Cattle Cash and Futures Markets." *J. Futures Mkts.* 10(1990):123-36.

Schroeder, T.C. and B.K. Goodwin. "Regional Fed Cattle Price Dynamics." *West. J. Agr. Econ.* 15(1990):111-22.

Schroeder, T.C., R. Jones, J. Mintert, and A.P. Barkley. "The Impact of Forward Contracting on Fed Cattle Transaction Prices." *Rev. Agr. Econ.* 15(1993):325-37.

Sims, C. Book Review of *Business Cycles: Theory, History, Indicators, and Forecasting*. By V. Zarnowitz. *J. Econ. Lit.* 32(1994):1885-88.

Sims, C.A. “Money, Income, and Causality.” *Amer. Econ. Rev.* 62(1972):540-52.

SoftKey International Inc. *Key Travel Map.* Computer Software, 1994.

Ward, C.E. “Inter-Firm Differences in Fed Cattle Prices in the Southern Plains.” *Amer. J. Agr. Econ.* 74(1992):480-85.

Ward, C.E. “Meatpacking Plant Capacity and Utilization: Implications for Competition and Pricing.” *Agribusiness and International Journal*. 6(1990):65-73.

Tables and Figures

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

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

Variable	Average	Standard Deviation	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 ($/cwt)	121.61	5.62	112.64	138.50
Observations (pens)	103,442			
Choice 5/700 Carcass Price ($/cwt)	117.92	3.90	111.48	128.10
Choice 7/850 Carcass Price ($/cwt)	117.32	4.28	110.89	128.69
Select 5/700 Carcass Price ($/cwt)	113.60	4.65	106.82	126.07
Select 7/850 Carcass Price ($/cwt)	113.26	5.18	106.49	126.87

Table 3. 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	-63.8798*
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 Squared	-9.95×10^{-6}	-7.468*
OTHER TRAITS:		
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	
Observations (head)	12,262,770	

Asterisk indicates significantly different from zero at the 0.0001 level.

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

State of Plant Location	State of Plant Location		
	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

Table 5. Summary Statistics of Variables Used in Explaining Error Correction Model 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

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. * indicates statistically different from zero at 0.05 level.

Figure 1. Estimated Price Impact of Pen Size

Figure 2. Estimated Price Impact of Weight

Figure 3. Relation between Distance between Plants and Procurement Overlap Percentage

Figure 4. Impact of Distance between Plants on Cointegration Test Statistics, with Other Variables at their Means

Figure 5. Impact of Distance between Plants on Granger F-Statistic Significance Level, with Other Variables at their Means

Figure 6. Impact of Distance between Plants on Speed of Adjustment Parameter, with Other Variables at their Means

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