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Meatpacker Conduct in Fed Cattle Pricing: An Investigation of Oligopsony Power

Stephen R. Koontz, Philip Garcia, and Michael A. Hudson

Market power in regional fed cattle markets is measured with an econometric model which links behavior of the margin between boxed beef and fed cattle prices to an economic model of conduct. A noncooperative game theoretic model suggests that for tacitly collusive pricing behavior to persist in equilibrium, oligopsonists must follow a discontinuous pricing strategy. Meatpackers pay low prices for cattle during cooperative phases and purchase cattle aggressively during noncooperative phases. Tests for cooperative/noncooperative conduct and measures of market power are presented. Fed cattle prices in four direct trade regions in the central United States are examined. Evidence of cooperative/noncooperative conduct is present in all markets but has declined over time. Varying conduct across markets and over time suggests it is important to continue monitoring fed cattle markets to assure a competitive environment.

Key words: fed cattle prices, meatpacker conduct, noncooperative game theory, oligopsony power.

Significant structural changes have occurred in the meatpacking sector, particularly in beef slaughter and boxed beef processing (Ward 1988). These changes have resulted in a highly concentrated oligopsony and have caused concern over exercise of market power in fed cattle markets (Purcell). Although research suggests that market power is being exercised, the extent varies depending on the study and procedures followed.

Most research on meatpacker market power has assessed long-run behavior, using either the traditional structure-performance paradigm (e.g., Quail et al.; Menkhaus, St. Clair, and Ahmaddaud) or the conjectural variation approach (e.g., Schroeter). The structure-performance paradigm infers the degree of competition by relating measures of market structure to measures of market performance (Bain). Recent summaries suggest that market distortions due to meatpacker concentration are between 1% and 2.5% of fed cattle prices (Connor). While informative, the structure-performance paradigm has been criticized on several grounds. The most important are that empirical models often are not derived from an economic model and that, due to aggregated data, estimated relationships reflect correlations more than cause and effect.

The conjectural variation approach measures firm conduct by incorporating the response to other firms' actions into the first-order conditions of a profit maximizing firm.[1] The basic model makes use of the following marginal revenue/marginal cost specification

$$(1) \quad r(1 - \theta/\eta) = p(1 + \phi/\epsilon) + \partial C/\partial Q$$

where r and p denote output and input prices of the commodities of interest, η and ϵ are output demand and input supply elasticities, θ and ϕ are output and input market conjectural elasticities, and $\partial C/\partial Q$ denotes other marginal input costs. Conjectures equal zero under perfect

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[1] See Geroski et al., Bresnahan, and Schmalensee for literature reviews.

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competition and one under monopoly/monopsony. An oligopoly/oligopsony is assumed to fall within the continuum. Schroeder, Azzam and Pagoulatos, Schroeter and Azzam, and others have applied this approach to the meatpacking industry. Beefpacker conjectures suggest market power distortions are 1% to 3% of fed cattle prices (Schroeter). However, conjectural variations research has shortcomings. Most important is that little attention has been given to understanding the optimal pricing strategies in oligopoly/oligopsony behavior. Specifically, no oligopoly/oligopsony model is offered to show that behavior along the continuum between pure competition and monopoly/monopsony is optimal; that is, (1) is not derived from an oligopoly/oligopsony model. Further, often because of data constraints, conjectural variation research focuses on long-run relationships, frequently groups packers of all red meat species, and has not examined regional markets, which are most relevant in fed cattle procurement.

The purpose of the present analysis is to determine if noncompetitive behavior is prevalent in short-run fed cattle pricing. A model of oligopsony meatpacker conduct is presented and tested in several regional markets, and noncooperative game theory is used to explain possible tacit collusion among meatpackers' fed cattle purchases. The economic model suggests that in order for collusive behavior to be an optimal equilibrium strategy, meatpackers will follow a pricing strategy with two actions: a cooperative phase in which below-competitive prices are paid for cattle, and a noncooperative phase in which cattle are priced aggressively at more competitive levels.

Oligopsony Model of Fed Cattle Procurement

Our economic model is a noncooperative repeated pricing game between n players with complete but imperfect information (Green and Porter). Noncooperative refers to the structure of player interaction. Players (meatpackers) cannot, because of antitrust laws, form enforceable agreements, so if any market power is exercised it must be done tacitly through self-enforcing agreements. The repeated pricing game recognizes that meatpackers procure cattle daily and consider the dynamic effect of their current actions on future actions of other players. The n-player game does not consider long-run strategies such as exit and entry; the focus is on short-run pricing behavior of existing players. Complete information implies players understand the structure of the market within which they operate. However, information is imperfect in that players do not perfectly observe pricing actions by other meatpackers.

A meatpacker produces meat (y) from fed cattle (x) and from a vector of other inputs ($\mathbf{v}$). The production process has fixed proportions between fed cattle and the other inputs

$$y = \min[x/k, h_i(\mathbf{v})] \tag{2}$$

where the proportion of live animal converted to meat is $1/k$. Leontief production is reasonable in the short run for established plants with a specific technology and limited substitution between animals and other inputs.

Given stochastic elements influencing procurement and other players' actions, profits of the ith meatpacker are

$$\pi_i(p_t^i, \mathbf{p}_t^{-i}, \mathbf{z}_t) = (r_t - p_t^i k) y_t^i(p_t^i, \mathbf{p}_t^{-i}, \mathbf{W}_t, \xi_t) - c_i(\mathbf{z}_t) \tag{3}$$

where t denotes time, p^i is the cattle price paid by the ith firm, $\mathbf{p}^{-i}$ is a vector of cattle prices paid by all other firms, r is the meat price, and $\mathbf{z}$ is a vector of other input prices. Profits equal the margin multiplied by volume, less other input costs. The volume of cattle processed is influenced by the price the ith firm offers for cattle, prices offered by other meatpackers, a vector of exogenous variables $\mathbf{W}$, and a random term ξ. The wholesale meat price is assumed exogenous; fresh beef markets are national in scope (Faminow and Sarhan) while fed cattle are procured regionally (Ward 1988).[2] The profit function incorporates a cost function which is short-run in nature. Cost is specified as a function of the number of cattle slaughtered (marginal costs) and a fixed cost component. Given the necessity of longer-term scheduling of other inputs (e.g.,

[2] The assumption simplifies model development. More importantly, assuming exogenous wholesale meat prices seems reasonable given the local nature of cattle markets, the fact that meatpacker activities in one area do not largely influence those in other areas, and the focus on daily fed cattle price behavior. Further, while large meatpacking firms may recognize the impact of slaughter levels on meat prices (i.e., endogenous meat prices), it is not clear that this knowledge influences daily procurement strategies. Procurement prices are a short-run strategic variable, whereas slaughter levels are an intermediate-run strategic variable. The knowledge that slaughter levels affect meat prices may influence the number of plants a meatpacker operates or the number of labor shifts used at individual plants, but it should not affect short-run pricing behavior.

labor), these can be considered on a daily basis as a part of fixed costs.[3]

In the repeated game, the profits of the *i*th firm are the sum of expected current and discounted expected future profits

$$(4) \quad V_i(\mathbf{s}_t) = \mathrm{E}\left[\sum_{t=0}^{\infty} \delta^t \pi_i(s_t^i, \mathbf{s}_t^{-i})\right] \quad i = 1, \ldots, n \text{ and } 0 < \delta < 1,$$

where profits depend on the firm's own pricing strategy s_t^i and on strategies $\mathbf{s}_t^{-i}$ of all other firms. The term δ equals $1/(1 + d)$ where d is the discount rate and E denotes expectations over strategies. Nash equilibrium is used to identify equilibrium strategies. It is the only reasonable equilibrium concept for a noncooperative repeated game in which players make simultaneous decisions (Friedman). Nash equilibrium is a set of strategies in which each firm, acting in its own self-interest, is not able to improve profits by changing strategy unilaterally.

For a single-period game, the Nash strategy is for all players to price so that marginal costs equal marginal revenues. If the cattle price offered (marginal cost) is less than marginal revenue from meat sold, there is an incentive for each packer to offer a higher price, secure a larger market share of the cattle procured, and sell more meat. However, when all packers respond to this incentive, cattle prices are bid up to marginal revenue and there are no pure profits earned nor market power exercised.

For a multiple-period game, Nash equilibrium can support strategies in which market power is exercised if the discounted sum of profits over time from tacitly colluding is greater than profits from continuous single-period Nash behavior. Using value function (4), denoting prices under single-period Nash behavior as p'' and prices under collusion as p', oligopsony members will cooperate if profits from doing so are greater than profits from myopically competing, i.e., if

$$(5) \quad V_i(p') > V_i(p'') \text{ for all firms.}$$

As with the single-period game, individual firms can improve profits by increasing cattle price offers. However, a punishment phase can be used to deter cheating. The punishment strategy is as follows: all firms price at cooperative level p' if, in the last period, all other firms priced at the cooperative level. However, if one firm prices at $p^* > p'$ (cheating on the tacit agreement) then all firms revert to Nash behavior p''. For collusive pricing to be an equilibrium strategy, returns from cheating followed by continuous single-period Nash behavior must be less than returns from cooperating, or

$$(6) \quad V_i(p') > \pi_i(p^*) + \delta V_i(p'') \text{ for all firms.}$$

Market power is exercised in a noncooperative game if a punishment strategy can satisfy equations (5) and (6).

Green and Porter generalize this game, recognizing that each firm may not directly observe other firms' actions. Collusive equilibria and market power continue to be possible, but the punishment strategy must be modified. With imperfect information, meatpackers maximize value function (4) subject to a trigger strategy

$$(7) \quad S_t^i = \begin{cases} p' & \text{if } \mu < m_{t-1} \\ p'' & \text{if } \mu \geq m_{t-1} \text{ in the last } T - 1 \text{ periods} \end{cases}$$

where μ is the trigger margin level, p' and p'' are cooperative and noncooperative price levels, and m_{t-1} is the margin between meat price and observable cattle price during some previous period. With a trigger strategy, if the margin in the previous period is greater than trigger level μ, the firm offers cooperative price p'. However, if the margin in the previous $T - 1$ periods is less than the trigger level, the firm offers noncooperative price p''. Like the punishment strategy, cooperation is enforced through threat of temporary high prices and low profits.

A theoretical justification for the trigger strategy is that it is one of the few strategies which supports collusive equilibria in a multiple-period game (Luce and Raiffa). The trigger strategy is discontinuous in actions, and only discontinuous strategies support Nash equilibria with collusive outcomes (Stanford). Further, a discontinuous two-phase strategy, such as a trigger strategy, Pareto dominates all other linear and nonlinear strategies (Abreu, Pearce, and Stachetti). A trigger strategy can reduce to a punishment strategy or single-period Nash behavior. With perfect information, the trigger strategy reduces to a punishment strategy. However, if information is so imperfect that collusive equilibria cannot be supported, the strategy reduces to single-period Nash behavior.

A practical justification for the trigger strat-

[3] The assumed cost function is necessary to aggregate firm cost functions into an industry cost function (Chambers) and is used elsewhere (e.g., Schroeter, and Schroeter and Azzam).

egy is that it is presented as a management option in business school discussions of pricing. Meatpacking firms recognize the choice between pricing to maintain market share and pricing to improve profit margin (Price Waterhouse). Business school strategies for pricing homogeneous products center on price warfare. Such a strategy involves pricing at target rates of return and monitoring rival behavior. If competitors price aggressively, the recommended action is to match behavior (Porter 1980).

Substituting trigger strategy (7) into value function (4) yields a recursive equation summarizing the multiple-period optimization problem. First-order conditions derived from equation (8) reveal market power measures and this model's contribution. For a firm initially in the cooperative period, the value function is

$$(8)\quad V_i(p') = \pi_i(p') + Pr(\mu < m_t)\delta V_i(p') + Pr(\mu \geq m_t)\left[\sum_{t=0}^{T-1} \delta^t \pi_i(p'') + \delta^T \mathrm{v}_i(p')\right].$$

Value function (8) equals current period profits plus discounted expected future profits. Expected future profits are discounted returns during cooperative and noncooperative phases weighted by their probability of occurrence. Equation (8) can be rewritten as

$$(9)\quad V_i(p') = [\pi_i(p'')/(1 - \delta)] + [(\pi_i(p') - \pi_i(p''))/(1 - \delta + (\delta - \delta^T)F)]$$

where the probability of crossing the trigger margin $Pr(\mu \geq m_t)$ is written as distribution function F (Porter 1983). The expected value of current and future returns equals the discounted profits $\pi_i(p'')$ associated with Nash behavior plus discounted gains $\pi_i(p') - \pi_i(p'')$ from cooperation.

The interior solution of the first-order condition is

$$(10)\quad \partial V_i/\partial s^i = [\partial \pi_i(p')/\partial s^i][1 - \delta + (\delta - \delta^T)F] + [\pi_i(p') - \pi_i(p'')](\delta - \delta^T)(\partial F/\partial s^i)f = 0$$

where f is the density function of F.[4] In cooperative periods, marginal returns to increasing the firm's offer price $\partial \pi_i(p')/\partial s^i$ are just offset by increased chance of lower returns $\pi_i(p') - \pi_i(p'')$ from triggering the noncooperative phase.

Under perfect information, when each player observes all other players' actions, the distribution and density functions in (10) vanish. The first-order condition becomes that of an intertemporal monopsony. However, as long as actions are observed imperfectly, the optimal oligopsony strategy is bounded away from the monopsony solution. Under imperfect information, optimal oligopoly/oligopsony behavior is not on the continuum between perfect competition and monopoly/monopsony. Rather, the actions are discontinuous: Nash during noncooperative phases and bounded away from monopoly/monopsony solutions during cooperative phases.

A collusive equilibrium requires the discount parameter δ be close to one, and meatpackers must be able to discover cheating and revert to noncooperative behavior quickly (Salop). If meatpackers detect cheating the period it occurs and revert to noncooperative behavior the following period, p', p'', and δ must satisfy

$$(11)\quad V_i(p') > \pi_i(p^*) + \sum_{t=1}^{T-1} \delta^t \pi_i(p'') + \delta^T V_i(p')$$

where $p^* > p'$ is the price the cheating firm pays. Equation (11) implies collusive profits are greater than the one-period gain from cheating plus $T - 1$ periods of Nash profits.

In order for a collusive equilibrium to exist, the length of the noncooperative phase, trigger margin, and prices in the cooperative and noncooperative phases must be such that (10) and (11) are satisfied. The number of possible equilibria is large, and there are tradeoffs between levels of these endogenous variables which determine the relative competitiveness of different equilibria (Porter 1983). Given the supply and cost functions, discount rate, distribution function of stochastic supply, and number of firms, it is possible to solve for levels of the endogenous variables which maximize the value function. However, actual levels are determined by the conduct of industry players. Thus, given data on meatpacker margins, it is an empirical exercise (e.g., Iwata) to verify existence of trigger pricing conduct and to measure the degree of market power exercised if this conduct is found. A discontinuous pattern in meatpacker margins will be observed if trigger pricing is an equilibrium strategy. Strength of collusion can be measured by cooperative phase length and size of margin change between phases. The longer the cooperative phase and the larger the change in margin between cooperative and noncooperative phases, the stronger the oligopsony.

[4] An interior solution implies $1 \leq T < \infty$ and $0 < \mu < m(p'')$, where $m(p'')$ is the margin when the single-period Nash price is played.

Econometric Model of Oligopsony Pricing

The first-order condition for a profit maximizing firm is used to derive the econometric model. The first-order condition for a firm maximizing (3) through choice of price is

$$(12)\quad \partial\pi_i/\partial p_i = (r - p_i k)\left[\partial y_i/\partial p_i + \sum_{j\neq i} (\partial y_i/\partial p_j)(\partial p_j/\partial p_i)\right] - ky_i = 0$$

where p_j denotes the price offered by the jth firm, $j \neq i$. An estimable model is developed by identifying parameters, incorporating economic model structure, and considering data limitations.

The procurement response to the cattle price offered is a structural parameter. The effect on the ith firm's procurement due to a change in a jth firm's price is smaller than the own price effect:[5]

$$(13)\quad \partial y_i/\partial p_i = \gamma \text{ and } \partial y_i/\partial p_j = -\gamma/(n - 1) \quad \text{where } j \neq i \text{ and } j = 1, \ldots, n.$$

A symmetric response across all other firms is necessary; without it, the noncooperative game addresses differentiated product pricing, obscuring the oligopsony pricing focus. The first-order condition becomes

$$(14)\quad (r - p_i k)\left\{1 - [1/(n - 1)] \cdot \sum_{j\neq i} (\partial p_j/\partial p_i)\right\}\gamma - ky_i = 0.$$

The sum of conjectures has a specific structure from the economic model. In noncooperative periods, where single-period Nash behavior is prevalent, the conjecture is zero. In cooperative periods, the conjecture is positive because all firms reduce offer prices. Thus,

$$(15)\quad [1/(n - 1)] \sum_{j\neq i} (\partial p_j/\partial p_i) = \beta_i = \begin{cases} \beta_{i0} > 0 & \text{during the cooperative phase} \\ 0 & \text{during the noncooperative phase} \end{cases}$$

The conjecture measures the average change in cattle price offered by other firms as meatpackers switch between phases.

Due to data limitations, two additional steps are taken to make (14) estimable. First, because only aggregate regional price data are available, the equation is aggregated over n firms, yielding an expression in market variables

$$(16)\quad (r_t - p_t k)[1 - \beta]\gamma = ky_t$$

where y_t is total regional supply and p_t is average regional cattle price. Parameter β measures the average conjecture across firms (Bresnahan). Defining

$$(17)\quad \psi \equiv [1 - \beta] = \begin{cases} \phi = [1 - \beta_0] & \text{in the cooperative phase} \\ 1 & \text{in the noncooperative phase} \end{cases}$$

simplifies notation so that (16) becomes

$$(18)\quad m_t = [k/(\gamma\psi)]y_t$$

denoting the margin $(r_t - p_t k)$ as m_t. The margin is a function of aggregate regional supply and the state of cooperation among meatpackers.

The second step, because of data limitations, involves substituting for y_t in (18) a function expressing regional animal supply in terms of observable factors. No daily regional cattle quantity data are available. Aggregate supply is captured through the function

$$(19)\quad y_t = \mathbf{W}_t\eta + \xi_t$$

where $\mathbf{W}_t$ is the tth row of an exogenous variable matrix, η is a vector of parameters, and ξ_t an error term. Exogenous variables include current feeder cattle prices, corn prices, interest rates, and temporal variables. Daily regional aggregate fed cattle supply is not a function of fed cattle price. Rather, daily aggregate supply is influenced by season of the year; by input prices affecting the marginal decision of whether to continue feeding cattle in the feedlot or sell the cattle, making space available for replacement animals; and by random elements.[6]

Research suggests short-run fed cattle supply is unrelated to contemporaneous prices (Reutlinger; Arzac and Wilkinson). Daily fed cattle supply is most likely determined by seasonal availability of feeder animals and incentives to change rates of gain in the feedlot. Further, the

[5] This specification restricts the market supply response to be zero when a firm changes offer price, i.e., the market supply of cattle is perfectly inelastic or $\Sigma_{i=1}^{n} = \partial y_i/\partial p_j = 0$.

[6] The margin model specification would not change if cattle prices were included. The procedure involves substituting supply function (19) into margin equation (18) and generating a reduced form. If an own-price inelastic supply function is inappropriate, then the two-stage system would result in essentially the same reduced-form margin model.

price discount structure associated with under- and over-finished animals is severe. As a result, cattle feeders have little flexibility in responding to fed cattle price incentives. Rather, incentives appear to favor obtaining minimum adequate finish on cattle and evaluating the marketing decision based on economies of replacement cattle. Commercial cattle feeders' use of hedging programs reinforces this idea. Feeders do not respond to price incentives on animals which are forward priced. However, they will respond to pricing opportunities on replacement cattle. Thus, on any given day, prices paid by meatpackers likely have little impact on the aggregate number of animals available. Instead, prices divide the fixed number of animals between meatpackers.

Use of daily data focuses the model on short-run producer behavior. Feeder cattle prices, corn prices, and interest rates reflect the largest costs in cattle feeding. Cattle feeders evaluate the short-run marginal decision in which cattle with adequate finish are kept on feed (increasing sale weights at declining rates of performance) or are sold, freeing pen space and providing cash resources for replacement animals. Increases in feeder animal prices increase marginal costs of replacement cattle. Increases in corn prices or interest rates decrease marginal cost of replacement cattle relative to cattle on feed. Increases in marginal costs of replacement cattle should decrease the short-run supply of finished cattle marketed. Temporal factors also influence daily animal supply. Dummy variables are used to capture variations in supply across days of the week, weeks of the month, and months of the year. Cattle volume is largest early in the week (Ward 1990). Supply may also be large during the fourth week of the month as operators prepare to meet monthly cash demands. Monthly dummies capture supply fluctuations throughout the year due to feeder animal availability. A trend variable is also used to capture long-term changes in margins.[7]

[7] If feedlot operators respond to omitted factors (e.g., basic incentives), these factors will enter the error term. If error variations are correlated with conduct, measures of market power can be biased. However, the pattern attributable to market power is very specific. The economic model identifies a proportional shift in margin mean and error variance between phases. It is unlikely this specific pattern would also emerge because of omitted factors.

Substituting aggregate supply function (19) into (18) yields the following structural parameter model

$$m_t = [k/(\gamma\psi)](\mathbf{W}_t\eta + \xi_t) \tag{20}$$

and the following observable parameter model

$$m_t = \mathbf{W}_t\boldsymbol{\alpha}/\psi + (1/\psi)\epsilon_t \tag{21}$$

where $\boldsymbol{\alpha} = (k/\gamma)\eta$, $\epsilon = (k/\gamma)\xi$, and $\boldsymbol{\alpha}/\psi$ denotes each element of vector $\boldsymbol{\alpha}$ divided by function ψ. The margin is a conditional regression where

$$(22) \quad \begin{aligned} m_t &= \mathbf{W}_t\boldsymbol{\alpha}/\phi + (1/\phi)\epsilon_t && \text{if } m_t \text{ is in the cooperative phase and} \\ m_t &= \mathbf{W}_t\boldsymbol{\alpha} + \epsilon_t && \text{if } m_t \text{ is in the noncooperative phase.} \end{aligned}$$

In (22), cooperative/noncooperative behavior is represented by a proportional increase in parameters and error term. An equivalent form of the model in which the shift captures the proportional decrease in parameters and errors is more useful. The equivalent model is

$$(23) \quad \begin{aligned} m_t &= \mathbf{W}_t\boldsymbol{\alpha} + \epsilon_{1t} && \text{if } m_t \text{ is cooperative and} \\ m_t &= \mathbf{W}_t\boldsymbol{\alpha}\phi + \epsilon_{2t} && \text{if } m_t \text{ is noncooperative.} \end{aligned}$$

In this form, $\epsilon_{2t} = \phi\epsilon_{1t}$. assuming the first error term is distributed normally [$\epsilon_{1t} \sim N(0, \sigma^2)$], the second error has a proportional shift in variance [$\epsilon_{2t} \sim N(0, \phi^2\sigma^2)$]. The only structural parameter identified is conjecture

$$\beta_0 = (1 - \phi). \tag{24}$$

The standard error of the proportional shift ϕ is not easily calculated if the shift is measured as $1/\phi$ and the standard error of the conjecture β_0 is the same as that for the proportional shift ϕ.

A strength of our model specification is the precise nature of the margin shock implied by a change in conduct. Change in conduct implies a proportional shift in the parameter vector modeling the conditional mean of margin levels and a proportional shift in model error variance. A potential difficulty with our model is that the inference about market power comes from identifying a specific component in the margin equation error term—this component enters the model as supply shocks. The difficulty is that shocks other than changes in conduct may influence margin levels. Hence, it is important to identify time periods that are structurally stable and to specify factors such as input prices and technology that influence supply. It is important also to consider the size of margin changes which result from the shocks, and their persistence, in evaluating the market power (Bresnahan). Findings must be viewed within the context of previous research on market power in fed cattle markets.

To estimate the model, the process by which each observation is associated with the cooperative or noncooperative phase must be specified. The trigger strategy from the economic model suggests that the switching process is T-Markov. However, use of the T-Markov process in estimation has severe practical limitations. First, estimating this process requires the likelihood function to be optimized N^T times, where N is the number of observations and T is the length of the noncooperative period; this is computationally infeasible (Green and Porter). Second, while the T-Markov is useful to derive the economic model's analytical results, its use in estimation would fix the noncooperative period length. In practice, the length of these periods may be flexible; actions within the strategy may vary (Porter 1985). Also, variations of collusive strategies may not be T-Markov (Abreu, Pearce, and Stachetti). Here, we use a Bernoulli process, which has been used in all previous applications of the Green and Porter model. Under the Bernoulli approximation, cooperative and noncooperative phases occur with probabilities λ and $(1 - \lambda)$. The Bernoulli process structure is flexible enough to approximate a T-Markov process (Green and Porter) and may be robust to alternative switching processes.[8]

In the Bernoulli model, the density of observation m_t is

$$(25)\quad h(m_t|\mathbf{W}_t) = \lambda/\sigma\sqrt{2\pi}\ \exp\{-(m_t - \mathbf{W}_t\alpha)^2/2\sigma^2\} + (1 - \lambda)/\phi\sigma\sqrt{2\pi}\ \exp\{-(m_t - \mathbf{W}_t\alpha\phi)^2/2\phi^2\sigma^2\}.$$

Maximum likelihood estimates of the parameters are found via an iterative optimization routine and are denoted $\Theta^* = (\alpha^*, \sigma^*, \phi^*, \lambda^*)$. The log-likelihood function satisfies regularity conditions for consistency and asymptotic normality. The covariance matrix of estimates is constructed using the inverse of the negative Hessian matrix.

Data and Results

Price quotes from direct feedlot-to-meatpacker sales of 900-to-1100 pound choice steers in four U.S. regional markets—Iowa and Southern Minnesota, Eastern Nebraska, Western Kansas, and Texas-New Mexico—are used. Prices in these regions are reported daily and were gathered from USDA Market News' weekly LS-214 publication. A large portion of total U.S. fed cattle sales occur in these four direct market regions. As well, they represent the most important markets in the fed cattle producing regions of the southern plains and midwestern states. The meat price used is the USDA daily boxed beef cutout value series for choice 550-to-700 pound carcasses. These price series are converted to regional margins by subtracting the regional fed cattle price converted to a carcass equivalent (price/61.5%) from the boxed beef cutout value.[9] Exogenous variables used in the margin model to capture variations in fed cattle marketing include prices which influence future feeding profitability and temporal dummy variables. Daily closing price of nearby feeder cattle and corn futures contracts (excluding delivery month) and daily interest rate data (six month rate) are used to reflect future feeding profitability.

The game theoretic model requires underlying industry cost and supply function parameters to be stable (Green and Porter). The meatpacking industry does not globally possess this feature. Examination of industry structure from 1980 to 1989 indicates two periods of relative stability. These are from June 1980 through September 1982 and from July 1984 through July 1986, which we employ in the empirical analysis. Data prior to 1980 are likely dated due to the short-

[8] Attempts were made to estimate the margin model using a first-order Markov switching process. Problems with estimation made this specification suspect. Specifically, the switching process variance converged to zero during maximum likelihood estimation. Difficulty in finding optima is not an uncommon problem when estimating switching regime models (Kiefer). An *ad hoc* restriction was placed on the switching process variance and convergence was obtained; the market power findings were similar to the Bernoulli results. One interpretation of the difficulties is that the Markov model may be misspecified. Meatpackers may recognize noncooperative behavior and change pricing strategy phases within the day. In this case, the Markov specification, which uses past margin levels, is not appropriate, and the Bernoulli specification may be better. Research on the structure of conduct changes needs to be pursued (Bresnahan).

[9] USDA data supports the $1/k = 61.5\%$ assumption. We assume $y/x = 0.615$ or $\ln(y) = \ln(0.615) + \ln(x)$. The regression $\ln(y_t) = a + b\ln(x_t) + e_t$ was estimated using weekly carcass and slaughter animal data, and an F-test was conducted on the hypothesis H_0: $a = \ln(0.615)$ and $b = 1$. The F-statistic and P-value were 0.73 and 0.485, failing to reject the hypothesis. Further, there was no seasonality or trend in the regression, and the R-square was 95.4%.

run nature of the pricing model, and the demand and cattle cycle shocks of that period would characterize it as unstable. Because of the large number of mergers and acquisitions between 1987 and 1989, data after 1986 were not considered either. Discussions with industry experts and a review of trade publications also revealed that late 1981 through early 1983 was a period of instability in meatpacking due to plant closings, purchases, mergers, and refurbishing (Ward 1988; Holder; Meat Industry Magazine).

Least squares estimates were used as starting values in the maximum likelihood routine for the linear parameter vector and model error variance. Estimation was conducted using MINOS 5.0 (Murtagh and Sanders). Alternative starting values of the proportional shift ϕ and probability of cooperation λ were used, and models were robust across starting values in convergence to maximum likelihood estimates. Specification tests identified significant first-order serial correlation in all models (Kiviet). Models were corrected for serial correlation via generalized differencing, and parameters were re-estimated using the initial maximum likelihood estimates as starting values. Again, models were robust in convergence to a global optimum.

Collusive pricing behavior is present if the switching process persists in the empirical model. The switching model collapses to a single regime if there is no proportional shift, i.e., if $\phi = 1$. Table 1 presents likelihood ratio statistics testing for existence of the proportional shift. Likelihood ratio tests suggest the discontinuity in margin behavior is present at the 1% significance level in all regional markets and both time periods.

In the presence of trigger strategy conduct, collusion strength is measured by margin level in the noncooperative phase relative to that in the cooperative phase ϕ, by size of the conjecture β_0, by percentage of time the market is in the cooperative phase λ, and by expected value of gains to meatpackers through tacitly collusive behavior. The proportional shift and conjecture measure the difference between margins and fed cattle prices in cooperative and noncooperative phases, while the probability of cooperation measures the amount of time each regional market is at cooperative versus noncooperative profit levels. The gains to cooperation combine these two into an overall measure of market power.

The expected value of gains to cooperation is calculated using parameter estimates and mean values of data $\bar{\mathbf{W}}$. The expected value of the margin during cooperative periods is

$$m^c = \bar{\mathbf{W}}\alpha^*. \tag{26}$$

The noncooperative margin is the cooperation margin reduced by the proportional shift

$$m^n = m^c\phi^* = \bar{\mathbf{W}}\alpha^*\phi^* \tag{27}$$

which is the level of margins under the most competitive, Nash pricing, behavior. In the presence of a trigger strategy, the expected value of the meatpacker margin is a combination of the two margins weighted by the probability of each phase:

$$m^e = \lambda^* m^c + (1 - \lambda^*) m^n. \tag{28}$$

The expected gain to cooperation due to the equilibrium trigger pricing strategy is then the difference between the expected margin under the trigger strategy and the margin during the noncooperative period:

$$\text{Gains} = (m^e - m^n). \tag{29}$$

Table 2 presents the measures of market power: proportional shift parameters ϕ, conjectures β_0, and probabilities of cooperation λ, estimated for each regional market. The root error variances of margin models are also presented. Noncooperative margins are between 59.6% and 63.1%

Table 1. Likelihood Ratio Tests for Presence of Bernoulli Switching Regression Model of Regional Meatpacker Margins

	First period: 5/80–9/82		Second period: 7/84–7/86	
Market	Test statistic[a]	Prob > χ^2	Test statistic[a]	Prob > χ^2
Iowa	13.3080	0.0003	9.4269	0.0021
Eastern Nebraska	31.2840	0.0001	8.5534	0.0034
Western Kansas	30.7270	0.0001	32.5820	0.0001
Texas-New Mexico	16.8600	0.0001	10.0430	0.0015

[a] Test statistics are distributed χ^2 with one degree of freedom.

Table 2. Proportional Shift Parameters ϕ, Conjectures β_0, Probability of Observing Cooperative Regime λ, and Root Margin Model Error Variances σ

First period: 5/80–9/82	ϕ	β_0	λ	σ
Iowa	0.6234*	0.3766*	0.4337*	0.9341
	(0.0068)[a]	(0.0068)	(0.0639)	
Eastern Nebraska	0.6018*	0.3982*	0.5776*	0.8601
	(0.0006)	(0.0006)	(0.1931)	
Western Kansas	0.5962*	0.4038*	0.1978*	1.0509
	(0.0066)	(0.0066)	(0.0685)	
Texas-New Mexico	0.6313*	0.3687*	0.2587*	0.9512
	(0.0155)	(0.0155)	(0.1434)	
Second period: 7/84–7/86	ϕ	β_0	λ	σ
Iowa	0.5488*	0.4512*	0.0643	1.3134
	(0.0445)	(0.0445)	(0.0897)	
Eastern Nebraska	0.5887*	0.4113*	0.0593	1.3810
	(0.1198)	(0.1198)	(0.0793)	
Western Kansas	0.4657*	0.5343*	0.1039*	1.3219
	(0.0406)	(0.0406)	(0.0165)	
Texas-New Mexico	0.5870*	0.4130*	0.2243	1.0870
	(0.0124)	(0.0124)	(0.1687)	

* Significant at the 5% level.
[a] Standard errors are in parentheses.

of cooperative margins in the first period and between 46.6% and 58.7% in the second period. This suggests an increase in the exercise of market power across the two periods; when beefpackers cooperate, their margins are larger. Our conjecture estimates are between \$0.37/cwt. and \$0.40/cwt. of fed cattle prices in the first period and between \$0.41/cwt. and \$0.53/cwt. in the second. These estimates are smaller than estimates from other studies. The conjectures are 0.5% to 0.8% of the fed cattle price; previous research suggests beefpacker conjectures are between 1% and 3% of cattle prices.[10] The conjectures are also moderately larger in the two midwestern markets than in the two southern plains markets.

Results of the switching regressions vary across time period and market.[11] On balance, the autoregressive process and regime switching parameters are the most important factors in our models, the temporal variables being the next most important. Months with seasonally larger cattle supplies have smaller meatpacker margins, reflecting reductions in intermediate-run average costs. Margins earlier in the week are larger than those later in the week, reflecting decreases in short-run marginal processing costs across the week. The trend variable is in general negative and more significant in the first period, when there was a gradual increase in cattle slaughter. The trend results suggest reductions in long-term average costs. Parameters on input price variables are less significant, but the signs are consistent with expectations; the feeder cattle price, corn price, and interest rate variable parameters are in most cases negative.[12]

Our estimates of the probability of cooperation demonstrate considerable variability across markets and time periods. In the first period, the probability of observing cooperation is larger in midwestern markets than in southern plains markets. Probabilities of cooperation are 0.43 and 0.58 in Iowa and Eastern Nebraska, and 0.26 and 0.20 in Texas and Western Kansas. The ab-

[10] Care must be taken when comparing our conjecture estimates to previous research. Here, conjectures measure a discontinuous margin change as meatpackers switch between cooperative and noncooperative behavior. In previous research, conjectures measure a continuous component of industry first-order conditions (e.g., equation 1).

[11] A degree of variability across models is expected because the estimated parameters are reduced form, and there are temporal and spatial differences in the markets. This variability could also reflect difficulties in estimating short-run supply and margin dynamics. However, analyses of subperiods in the two sample periods suggest our parametric findings are very robust within each market and sample period. Complete results of the switching regression models in each of the markets, sample periods, and subsamples are available in Koontz, Garcia, and Hudson.

[12] All significant parameter estimates were negative except in the second period model of the Texas-New Mexico market; the feeder price coefficient was positive and significant. Expansion in Texas feedlot capacity between the sample periods may have resulted in this atypical response.

solute and relative sizes of the estimates change in the second period; probabilities in midwestern markets are substantially smaller. Probabilities of cooperation in Iowa and Eastern Nebraska are 0.064 and 0.059, while probabilities in Texas and Western Kansas are reduced marginally from first period estimates to 0.22 and 0.10. Smaller probabilities of cooperation in the second period suggest reduction in the exercise of market power.

Expected gains to cooperation provide a third measure of market power and reveal net effects on the total exercise of market power of the increasing conjecture sizes and declining probabilities of cooperation. Table 3 presents (*a*) expected values of regional margins during cooperative and noncooperative phases, (*b*) expected margins, and (*c*) expected gains to cooperation through the trigger strategy. In the first period, expected gains are largest in the Eastern Nebraska and Iowa direct markets. For example, expected gains to cooperation are $2.74/cwt. and $1.89/cwt. (boxed beef price) in Eastern Nebraska and Iowa, compared to $0.96/cwt. and $0.93/cwt. in Western Kansas and Texas. Depending upon region, oligopsony gains are between $5 and $19 per head. The difference in expected gains across markets and time periods is due primarily to differences in the probability of cooperation. In the first period, conjectures are somewhat larger in midwestern markets than in southern plains markets; but probabilities of cooperation are considerably larger in the midwestern markets, leading to larger expected gains in the midwestern markets. In the second period, rankings change substantially. The largest gains, $0.77/cwt., are in Texas while the smallest, $0.24/cwt., are in Eastern Nebraska. Oligopsony gains are between $2 and $5 per head. As with the first period, conjectures are moderately larger in midwestern markets; however, the probability of cooperation is smaller in these markets than in the southern plains. The difference in the size of the probability of cooperation largely determines the expected gains rankings.

Changes across the two periods in our estimates of probability of cooperation substantially influence changes in the regional expected gains. There is a uniform but small increase in the conjecture across the two periods. This is consistent with an increase in regional beefpacker market power, possibly due to increases in regional concentration. However, the decrease in probability of cooperation in each regional market outweighs the conjecture increase. The net result is a reduction in overall market power in the second period. The source of the reduction is unclear but may involve changes in industry and short-run supply conditions. In the second period, increased excess capacity relative to supply may have increased competition for fed cattle as firms attempted to spread fixed costs (USGAO). Perhaps increased contractual arrangements with boxed beef purchasers led meatpackers to break tacit agreements more often, accepting punishment to meet short-term demands. Finally, as the theoretical model suggests, uncertainty over actions of other firms can cause cooperative behavior to break down. It is possible that increased instability in short-run fed cattle supplies during the second period, reflected in the root of the model error variance

Table 3. Margin Levels in Cooperative and Noncooperative Trigger Strategy Phases, Expected Margins, and Gains to Cooperation

	Cooperative margin (m^c)	Noncooperative margin (m^n)	Expected margin (m^e)	Expected gains
First period: 5/80–9/82	Dollars per hundredweight of boxed beef			
Iowa	11.5621	7.2078	9.0963	1.8885
Eastern Nebraska	11.9172	7.1718	9.9127	2.7410
Western Kansas	12.0341	7.1747	8.1359	0.9612
Texas-New Mexico	9.7176	6.1347	7.0616	0.9269
Second period: 7/84–7/86	Dollars per hundredweight of boxed beef			
Iowa	12.3456	6.7753	7.1334	0.3582
Eastern Nebraska	12.7010	7.4771	7.7121	0.2350
Western Kansas	10.1841	4.7427	5.3081	0.5654
Texas-New Mexico	8.2799	4.8603	5.6273	0.7670

in table 2, made it more difficult for firms to evaluate competitor behavior, leading to more competitive pricing.

Summary and Conclusions

We have developed a noncooperative game-theoretic model of meatpacker behavior in daily fed cattle procurement. The economic model is incorporated into an econometric model of the daily margin between boxed beef prices and regional fed cattle prices. Because of the reduced form nature of this approach and the fact that market structure changes (cost and supply functions and firm numbers) affect the strategic conduct variables, our econometric model is estimated for two separate time periods during which market structure was relatively stable. The model and results identify short-run meatpacker pricing behavior in fed cattle markets which is consistent with trigger pricing strategies. Our approach permits a more complete development of firm and price behavior in agricultural markets.

The general finding of our analysis is that market power appears to have been exercised in fed cattle purchases during the early to mid 1980s in the regional markets examined. Behavior of daily meatpacker margins and fed cattle market prices is consistent with cooperative pricing conduct. Strongest evidence of the exercise of market power is found from June 1980 to September 1982. Maintaining cooperative strategies during the mid-1980s may have been more difficult than in the early 1980s because of changes in market structure and short-run supply conditions. Nevertheless, between July 1984 and July 1985, expected gains from cooperative pricing are estimated to be between $2 and $5 per head.

Several implications can be drawn from our findings. First, presence of cooperative pricing strategies supports the notion that market power has been exercised in fed cattle markets. Second, the magnitude of our conjectures, which are somewhat smaller than those previously estimated, indicate that longer-run analyses measure effects of quantity decisions, exit and entry, and other market structure changes, as well as the effects of cooperative pricing. Third, our findings indicate that market power is not constant over time nor uniform over space. Beefpackers operate in a dynamic environment in which they adjust pricing strategies to varying market conditions. Changing conduct across markets and over time highlights the difficulty and importance of continued monitoring for competitive performance. Changing conduct also suggests the importance of developing a more comprehensive understanding of the factors influencing changes in conduct and competition. Such an understanding would permit clearer identification of periods of cooperative breakdown and reformation and assist in the monitoring process. Finally, the noncooperative game theoretic framework appears useful for understanding short-term meatpacker pricing behavior. Nevertheless, additional research needs to focus on relaxing assumptions used here, on analyzing other time periods and markets, on identifying the factors influencing changes in pricing conduct, and on verifying our measures of market power.

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