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Regime switching and oligopsony power: the case of U.S. beef processing

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Abstract

In this article, we estimate a model of oligopsony behavior under imperfect monitoring of rival actions to analyze weekly marketing margin data for the U.S. beef packing industry. Oligopsonists are hypothesized to follow a discontinuous pricing strategy in equilibrium, and we focus on shocks in the normal throughput of supply as a potential catalyst for regime switching between cooperative and noncooperative phases. We adopt an algorithm developed by Bellone (2005) that relies on Hamilton's (1989) multivariate first-order Markov process to test for the cooperative/noncooperative switching behavior. We find strong evidence that links switching conduct by packers to disruptions in coordinating the derived demands for processed beef with the supply of live cattle. Once switched, cooperative regimes lasted an average of 21 weeks, while noncooperative regimes averaged 33 weeks. The average marketing margin for processed beef was 68% lower in the noncooperative regimes compared to the cooperative regimes. This led to an annual average increase in profits of 28 million dollars to the beef packing industry and about an 8 to 9% reduction in live cattle prices.

JEL classifications: D43, L11, L13

Keywords: Beef packing; Fed cattle prices; Margin; Markov regime switching

1. Introduction

Trends toward increased concentration in beef packing from the 1970s through the 1990s raised major public policy concerns about the potential for beef packers to use oligopsony power to lower fed cattle prices. In these decades, average plant size grew five-fold, the number of plants declined by over 70%,[1] and industry concentration, as measured by the Herfindahl–Hirschmann Index (HHI) for steer and heifer slaughter increased steadily. By 1999, the four largest beef packers accounted for 80% of the national beef slaughter, as opposed to 36% in 1980 (GIPSA, 2002). In 1992 and for the first time, the national HHI index for steer and heifer slaughter rose above the threshold of 1,800 defined by the U.S. Department of Justice as a highly concentrated industry (Whinston, 2008).

Many studies have evaluated the potential for buyer power in U.S. beef packing. Azzam and Anderson (1996), Sexton (2000), and Ward (2002) provide excellent reviews of the literature through 2001. All three summaries suggest that the evidence supporting buyer power distortions is not conclusive. However, they are also critical of the methods employed in many of these studies. In general, there was concern about the structural rigidities implicit in structure-conduct-performance analysis and conjectural variation methods. Ward (2002) points toward a greater need to focus on the dynamic interactions among firms as a way to more flexibly identify potential price impacts from buyer power.

A failure to understand how market power is manifested spatially or over time would make it difficult to identify and measure with much precision. And this may be one factor driving the supposed inconclusive results from past work. At least four past studies have evaluated the beef packing industry in ways that capture dynamic patterns in buyer power behavior. Koontz

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Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article. Please note: Wiley-Blackwell, Inc. is not responsible for the content or functionality of any supporting information supplied by the author. Any queries (other than missing material) should be directed to the corresponding author for the article.

[1] The average number of head slaughtered per plant increased from 32,383 in 1972 to 163,071 in 1998 (Ward and Schroeder, 2002). The number of beef slaughter facilities declined from over 600 in 1980 to about 170 in 1999 (Barkema et al., 2001).

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et al. (1993; hereafter KGH) used a noncooperative game model to evaluate breakdowns in oligopsony power using daily price movements. Evidence that cooperative regimes broke down and re-emerged over time, supports strongly the point made by Ward (2002). Koontz and Garcia (1997; hereafter KG) later extended the single market model in KGH to multiple markets and found that low prices were paid in all relevant markets in cooperative phases, while high prices were paid in the noncooperative phases. Azzam and Park (1993) adopted traditional Bresnahan's procedure to test for switching market conduct in the beef slaughter industry. They found the evidence of market power by identifying the starting and ending points for the two distinct regimes of noncooperative and cooperative conduct. Carlberg et al. (2009; hereafter CHW) applied a dynamic oligopsony framework to fed cattle transactions data generated in an economic experiment setting. Collusive behavior associated with a dynamic pricing game was observed in the simulated market but the extent of collusion varied across the different replications. Other studies offer findings suggestive of regime switching.[2]

In the present article, we analyze the beef procurement market relying on the regime-switching framework introduced by Porter (1983a) and Green and Porter (1984), generalized by Abreu et al. (1986), and updated by Mailath and Samuelson (2006). We employ an algorithm developed by Bellone (2005) of Hamilton's (1989) Regime-Switching model that explicitly assumes a first-order Markov process.[3] These are substantial improvements on KGH and KG that used a Bernoulli process in the empirical model, which is a special case of the Markov process used in the economic model.[4] Our model uses weekly cost, price, and slaughter data from the 1992 to 1999 period when national concentration levels were above the HHI = 1,800 DOJ threshold. KG and KGH analyze earlier periods.[5] Additionally, they use daily prices as a basis for determining regime switches. Given the institutional nature of fed cattle purchasing patterns that look to meet weekly quantity objectives, our use of weekly data may provide a superior (i.e., less noisy) platform for understanding the potential breakdowns in cooperative behavior over a long time series and should do a good job measuring accurately the length of differing regimes if such patterns are present. CHW were able to find this noncompetitive conduct that accompanies regime switching in an experimental market. While their market is artificial in that it is within an experiment, the simulated market is constructed with real-world parameters. The strength of their methodology is that it has none of the sharp or gradual structural changes that accompany all real-world markets and the parametric realism provides an opportunity to compare results.

We study one regional market, Kansas, and the national market. Our results for the national (Kansas) market show that the marketing margin in the noncooperative regime is 68% (64%) lower than that in the cooperative regime, the expected annual decrease in the marketing margin is about 46% (50%). For the national market, this translates into an increase in profits to beef packing industry of nearly 28 million 1992 dollars each year. Finally, the market distortions due to packers' cooperative behavior led to about an 8–9% decrease in the price of fed cattle for Kansas and the national markets.

2. Conceptual model

The conceptual framework is based on Abreu et al. (1986), and Mailath and Samuelson's (2006) optimal collusive model with imperfect monitoring. Both works follow Green and Porter (1984) who first introduced the imperfect competition with price uncertainties. Because market price is subject to random shocks and identical oligopolists cannot observe each others' actions, collusion can be sustained in equilibrium based on trigger prices and Nash reversion. However, Green and Porter's collusive equilibrium is suboptimal due to the limited set of strategies specified in the model. For example, there is a certain trigger price under which the firms switch to a punishment regime by producing the Cournot–Nash quantity in the stage game and the firms switch back to collusive regime after a fixed T periods of time. Abreu et al. (1986) and Mailath and Samuelson (2006) extend Green and Porter's work by relaxing those limitations and derive the optimal collusive equilibria over a broader set of strategies. Based on their models, firms switch between collusive and punishment regimes according to a set of collusive prices and a set of punishment prices. While in the collusive regime, any price in the collusive price set causes firms to select the collusive action and any observed price in the punishment set causes the firms to switch to the punishment regime. While in the punishment regime, any price in the collusive price set prompts the transition to the collusive regime, and any price in the punishment set acts to sustain the punishment regime.

Here, we begin by describing the model in the context of our analysis. We assume that n symmetric beef packers with complete but imperfect information bid for live cattle in a repeated game framework. The assumptions of the model are:

1. Beef packers purchase an undifferentiated product—fed cattle from the regional cash market;

[2] For example, Stiegert et al. (1993) found that unanticipated supply shocks led to breakdowns of average cost pricing strategies by beef packers. Xia and Sexton (2004) show that pricing contracts tied to spot markets add to the marginal cost of packers allowing them to bid lower for spot market cattle.

[3] Hamilton's method has been extensively used in a variety of macroeconomic analyses to explain regime patterns in business cycles, inflation, labor markets, and others. Google Scholar finds over 3,000 articles citing the Hamilton (1989) article. More recently, Markov regime switching method has been employed in pricing models. For a recent example, see Chen and Forsyth's (2009) application on natural gas markets.

[4] Hamilton's Markov regime switching approach assumes that the current state depends on the previous state. Practically speaking, this means the model solves for unique probabilities for switching from cooperation to noncooperation and *vice versa*.

[5] None of the 34 studies reviewed in Ward (2002) use data exclusively in the post-1992 period, and only a few used data that spanned into the early and mid 1990s.

2. No exit or entry in the long run is considered in the game;
3. Beef packers understand the market structure well;
4. Beef packers cannot observe either the pricing actions by others or the shock to the cattle supply, but can obtain a perception about the degree of price competition based on their own operating margin;
5. Beef packers are risk neutral and maximize their expected profit.

Profit of the ith beef packer is given by

$$\pi_i(p_{it}, p_{jt}, W_t, z_t, \xi_t) = (r_t - p_{it}k)y_{it}(p_{it}, p_{jt}, W_t, \xi_t) - c_i(z_t, y_{it}), \quad (1)$$

where p_{it} is the price for live cattle paid by the ith packer at time t, p_{jt} is a vector of cattle prices paid by all other packers, r_t is the price of boxed beef, k is the inverse of the proportion of live animal converted to beef (cutout ratio or dressing percentage), W_t is a vector of exogenous variables, y_{it} is the beef quantity the ith packer produces from fed cattle and other inputs, ξ_t is a random term, c_i is the variable processing cost of the ith beef packer and is a function of z_t, a vector of noncattle variable input prices, and y_{it}. Therefore, the ith beef packer's production $y_{it}(p_{it}, p_{jt}, W_t, \xi_t)$ is determined by this packer's own price offer, others' prices, some exogenous variables and a cattle supply shock. The supply shock enters the production equation additively and is assumed to be i.i.d. across periods. And the beef packer's production function is strictly increasing in the packer's own price offer, decreasing in other packers' prices, continuously differentiable in the prices, and strictly increasing in the supply shock.

The setup of the variable processing cost in Eq. (1) is fundamentally different from the one in KGH. In the KGH model, they used daily data and assumed that all costs other than the purchase of fed cattle were fixed. Our use of weekly data is suggestive of production process with flexibility in using other noncattle inputs such as energy and labor. We assume that beef production is in fixed proportion to the live cattle slaughtered each week using the conversion ratio k.

Given the packer's own pricing strategy s_{it}, other packers' strategies s_{jt} and the distribution of the cattle supply shock $F(\xi_t)$, beef packer i maximizes the sum of current and discounted expected future profits:

$$V_i(s_t) = \int_0^\infty \pi_i(p_i, p_j, y_i(p_i, p_j, W, \xi))\, dF(\xi) \qquad i \neq j, i, j = 1, \ldots, n. \quad (2)$$

For each beef packer, its price offer can be chosen from a set. Because of a limited supply of live cattle in the market and the beef packer's production capacity and cost, the packer's price offer cannot range on all of R_+, that is, $s_i \in S_i$ and S_i is a finite subset of R_+. And by having the finite set of prices, we can restrict our attention only to the bang–bang equilibria (Mailath and Samuelson, 2006, Proposition 7.5.1). Therefore, there exists an optimal symmetric sequential equilibrium where firms offer a low price $\underline{p}$ in cooperative regime and the expected value is $\overline{V_i}$, and they offer a high price $\overline{p}$ with the expected value of $\underline{V_i}$ in noncooperative regime. $\overline{V_i}$ and $\underline{V_i}$ are the maximum and minimum pure perfect equilibrium payoff for the ith packer. Since packers cannot observe either the pricing actions of their competitors or unanticipated cattle supply shocks, they choose a pricing action based only on their own marketing margins. Transitions between the two states are determined by two sets of margins $\bar{m}$ and $\underline{m}$. In the collusive regime, when the packers find their margin in the set of $\bar{m}$, they stay in the collusive regime, otherwise, the play switches to noncooperative regime. And in the noncooperative regime, when the packers find their margin in the set of $\underline{m}$, they stay in the noncooperative regime, otherwise, they switch to the cooperative regime. So, in this buying game, the ith packer's pricing strategies can be described by the following:

$$S_{it} = \begin{cases} \underline{p_i} & \text{if } m \in \bar{m} \\ \overline{p_i} & \text{if } m \in \underline{m}. \end{cases} \quad (3)$$

Suppose the conditional probability of a margin based on the packers' pricing strategy is $\theta(m|s)$ and the discount rate is $d \in (0, 1)$. The cooperative and noncooperative values are given respectively by

$$\overline{V_i} = (1-d)V_i(\underline{p_i}) + d[(1-\theta(\bar{m} \mid \underline{p}))\overline{V_i} + \theta(\bar{m} \mid \underline{p})\underline{V_i}] \quad (4)$$

$$\underline{V_i} = (1-d)V_i(\overline{p_i}) + d[(1-\theta(\underline{m} \mid \overline{p}))\overline{V_i} + \theta(\underline{m} \mid \overline{p})\underline{V_i}]. \quad (5)$$

The ith packer's equilibrium payoff is then

$$\overline{V_i} = \frac{V_i(\underline{p_i})(1 - d\theta(\underline{m} \mid \overline{p})) + dV_i(\overline{p_i})\theta(\bar{m} \mid \underline{p})}{1 - d(\theta(\underline{m} \mid \overline{p}) - \theta(\bar{m} \mid \underline{p}))}. \quad (6)$$

From Proposition 11.1.2 in Mailath and Samuelson (2006), in the cooperative regime with buyer power, the price offer $\underline{p_i}$ is less than the one-shot Nash price p^N and greater than the monopsony price offer p^m, that is, $p^m < \underline{p_i} < p^N$.[6] A collusive price greater than p^m makes deviation possible and requires punishment in equilibrium. Suppose the cooperative price is no less than p^N, then an equilibrium of playing Nash in every period always exists, collusion can no longer be on the equilibrium path. In the cooperative regime, any pricing strategy different from $\underline{p_i}$ is not chosen by the packer because of the incentive constraint below:

$$(1-d)\big(V_i\big(p_i', \underline{p_j}\big) - V_i(\underline{p})\big) \leq d\big(\theta\big(\bar{m} \mid \big(p_i', \underline{p_j}\big)\big) - \theta(\bar{m} \mid \underline{p})\big)(\overline{V_i} - \underline{V_i}), \quad (7)$$

where p_i' is any pricing action different from $\underline{p_i}$ in the cooperative regime. The above equation indicates that the gain from deviation should be no larger than the future loss resulted from the increased likelihood of noncooperation.

[6] See detailed proof in Mailath and Samuelson (2006), page 353.

In the noncooperative regime, $m \in \underline{m}$, packers choose price $\overline{p}$. In KGH, $\overline{p}$ is the one-shot Nash price. But Mailath and Samuelson (2006) point out that the optimal punishment generally is more severe to sustain a higher payoff in equilibrium, that is, $\overline{p} > p^N$. The optimal punishment satisfies the following equilibrium trade-off for any action p_i' different from $\overline{p}$:

$$(1-d)\big(V_i\big(p_i', \overline{p_j}\big) - V_i(\overline{p})\big) \\ \leq d\big(\theta\big(\underline{m} \mid \big(p_i', \overline{p_j}\big)\big) - \theta(\underline{m} \mid \overline{p})\big)(\overline{V_i} - \underline{V_i}). \tag{8}$$

It is intuitive that punishment is associated with low margins because low margins are related with raising price to obtain profitable deviations from collusion. So if a beef packer raises the price above the collusive price, the other packers' margin will decrease, and a price that is higher than the deviation price is effective to discourage the unilateral price increase. However, there is a possibility that the deviation can be toward lower prices. While this may not seem plausible (i.e., the deviator's current payoff is decreased), it is feasible and is associated with lowering the probability of switching to the noncooperative state. According to Mailath and Samuelson (2006), if the conditional density function of the cattle supply satisfies the monotone likelihood ratio property, then deviation to lower prices can be excluded because it can be deterred by attaching punishments to a large margin instead of a small one.

Suppose the cattle supply shock ξ is randomly drawn from a continuous uniform distribution F with a density function f over the range of $[\underline{\xi}, \overline{\xi}]$. $\overline{\xi}$ is the maximum possible shock and $\underline{\xi}$ is the minimum possible shock in reality. Because ξ enters the beef production function in Eq. (1) additively, it enters the margin function multiplicatively: $m(p,\xi) = \xi m(p)$. Therefore, for any $\tilde{m}$, $\theta([0,\tilde{m}] \mid p) = F(\frac{\tilde{m}}{m(p)})$, the density of $\theta(\,\cdot \mid p)$ is then $h_p(\tilde{m}) = f(\frac{\tilde{m}}{m(p)})/m(p)$.

The punishment triggering margin set is $\bar{m} = [0, \tilde{m}]$ for some $\tilde{m}$, so the payoff to firm i by choosing a different price p_i' from everyone else is then:

$$(1-d)V_i\big(p_i', \overline{p_j}\big) + d\left(1 - F\left(\frac{\tilde{m}}{m_i(p_i', \overline{p_j})}\right)\right)\overline{V_i} \\ + dF\left(\frac{\tilde{m}}{m_i(p_i', \overline{p_j})}\right)\underline{V_i}. \tag{9}$$

Take the first-order condition for the above equation, we have

$$(1-d)\frac{\partial V_i\big(p_i', \overline{p_j}\big)}{\partial p_i} + df\left(\frac{\tilde{m}}{m_i\big(p_i', \overline{p_j}\big)}\right) \\ \times \frac{\tilde{m}}{\big(m_i\big(p_i', \overline{p_j}\big)\big)^2}\frac{\partial m_i\big(p_i', \overline{p_j}\big)}{\partial p_i}(\overline{V_i} - \underline{V_i}). \tag{10}$$

Differentiating the first-order condition in Eq. (10), we obtain the following inequality based on the continuous uniform distribution of ξ, $\partial^2 V_i(p_i', \overline{p_j})/\partial p_i^2 < 0$, $\partial m_i(p_i', \overline{p_j})/\partial p_i' > 0$, and $\frac{\partial^2 m_i(p_i', \overline{p_j})}{\partial p_i} < 0$:

$$(1-d)\frac{\partial^2 V_i(p_i', \overline{p_j})}{\partial p_i^2} \\ - d\left[f'\left(\frac{\tilde{m}}{m_i(p_i', \overline{p_j})}\right)\frac{\tilde{m}}{m_i(p_i', \overline{p_j})} + 2f\left(\frac{\tilde{m}}{m_i(p_i', \overline{p_j})}\right)\right] \\ \times \frac{\tilde{m}}{(m_i(p_i', \overline{p_j}))^3}\frac{\partial m_i(p_i', \overline{p_j})}{\partial p_i}(\overline{V_i} - \underline{V_i}) \\ + df\left(\frac{\tilde{m}}{m_i(p_i', \overline{p_j})}\right)\frac{\tilde{m}}{(m_i(p_i', \overline{p_j}))^2}\frac{\partial^2 m_i(p_i', \overline{p_j})}{\partial p_i}(\overline{V_i} - \underline{V_i}) \\ = (1-d)\frac{\partial^2 V_i(p_i', \overline{p_j})}{\partial p_i^2} - d\frac{2}{\overline{\xi} - \underline{\xi}}\frac{\tilde{m}}{(m_i(p_i', \overline{p_j}))^3} \\ \times \frac{\partial m_i(p_i', \overline{p_j})}{\partial p_i}(\overline{V_i} - \underline{V_i}) \\ + d\frac{1}{\overline{\xi} - \underline{\xi}}\frac{\tilde{m}}{(m_i(p_i', \overline{p_j}))^2}\frac{\partial^2 m_i(p_i', \overline{p_j})}{\partial p_i}(\overline{V_i} - \underline{V_i}) < 0. \tag{11}$$

Therefore, the payoff function of packer i is concave. Because any p_i greater than $\overline{p_i}$ gives the packer the same payoff as $\overline{p_i}$, we can infer that the deviations to prices smaller than the cooperative price are suboptimal. Deviations toward lower prices do not occur and in the optimal equilibrium, $\bar{m} = [0, \tilde{m}]$, where $\tilde{m} = sup\{m_{p_i'} \mid p_i' > \overline{p_i}\}$.

In our game, price wars are part of the equilibrium behavior because the fed cattle supply is subject to random unobservable shocks and the packers' price offers are not observed by their competitors. When a low margin is observed, packers cannot tell if it is a consequence of a deviation from cooperative pricing by one of their rivals or if it is due to some other factor such as an unanticipated fed cattle supply shock. Thus, the model portends a market condition in which possibly lengthy periods of high margins are observed followed by possibly lengthy periods in which low margins are observed. As the imperfect collusion theory prescribes, the presence of punishment provides implicit restraints for firms to bid conservatively for live cattle so as to "not upset the apple cart."

3. Econometric model

In this section, we develop an empirical model that allows for discontinuous patterns (i.e., regime switching) between cooperative and noncooperative periods. As is discussed above, it is important to control for margin fluctuations that are both observable and not attributable to firm conduct. Beef packers are assumed to choose input prices of live cattle to maximize profits. Thus, we begin with the first-order condition of Eq. (1), which is:

$$\frac{\partial \pi_i}{\partial p_i} = (r - p_i k)\left[\frac{\partial y_i}{\partial p_i} + \sum_{j \neq i} \frac{\partial y_i}{\partial p_j}\frac{\partial p_j}{\partial p_i}\right] - k y_i - \frac{\partial c_i}{\partial y_i}\left[\frac{\partial y_i}{\partial p_i} + \sum_{j \neq i} \frac{\partial y_i}{\partial p_j}\frac{\partial p_j}{\partial p_i}\right] = 0. \tag{12}$$

Assume that the effect of the jth firm's price on the ith firm's fed cattle purchase is smaller than the effect of its own price, and that firms are symmetric. Let $\frac{\partial y_i}{\partial p_i} = \delta$ $(\delta > 0)$ and $\frac{\partial y_i}{\partial p_j} = -\frac{\delta}{q}$, where $q > 1$ is a constant. Eq. (12) can be rewritten as

$$(r - p_i k - mpc_i)\left[1 - \frac{\sum_{j \neq i} \frac{\partial p_j}{\partial p_i}}{q}\right]\delta = k y_i, \tag{13}$$

where mpc_i is the firm i's marginal processing cost. Let $\frac{\sum_{j \neq i} \frac{\partial p_j}{\partial p_i}}{q} = \beta$ where β is the sum of reactions to firm i's purchase price p_i. When $\beta = 0$, firms offer the noncooperative price, which is consistent with noncooperative conduct. The cooperative conduct occurs with $0 < \beta < 1$. Summing Eq. (13) over n symmetric firms gives

$$(r_t - p_t k - mpc_t)(1 - \beta)\delta = k y_t. \tag{14}$$

Rewriting Eq. (14) yields, the beef packer marketing margin:

$$m_t = r_t - p_t k = mpc_t + \frac{k y_t}{(1 - \beta)\delta}. \tag{15}$$

Note that fluctuations in marginal processing costs are linked directly to movement in the marketing margin. Thus, it is important to control for such variations to limit its impact on the conduct term that assigns variation to specific regime. For econometric estimation, we assume a Generalized Leontief processing cost function given by

$$C_t(y, w) = y_t(\phi_{11} w_{1t} + \phi_{22} w_{2t} + 2\phi_{12}\sqrt{w_{1t} w_{2t}}) + y_t^2(\phi_1 w_{1t} + \phi_2 w_{2t}), \tag{16}$$

where w_1 is the labor price and w_2 is the energy price. Marginal processing cost for beef packers is specified as

$$mpc_t = \phi_{11} w_{1t} + \phi_{22} w_{2t} + 2\phi_{12}\sqrt{w_{1t} w_{2t}} + 2 y_t(\phi_1 w_{1t} + \phi_2 w_{2t}). \tag{17}$$

Some discussion of the last term in Eq. (15) is necessary before proceeding. Unlike many industrial organization studies, our focus is not on evaluating certain benchmark conditions such as Bertrand or Stackleberg leader pricing. Our focus is on evaluating the market for regime switching between high levels and low levels of cooperative behavior. In Eq. (15), we let $k/(1 - \beta) = \beta_s$, where β_s is the regime-dependent conduct parameter. Our model provides a unique estimate for β_s when the market is in a cooperative regime and when it is in a noncooperative regime. When $\beta > 0$ in either regime, it infers that market power is present. The model also suggests that if there are regime-switching patterns related to market power, the β_s in the cooperative phase will be larger than the β_s in the noncooperative regime.

Given that β_s captures regime switching (if present), the fundamental question thus becomes what might trigger the market into different regimes? We are interested in understanding the role of supply shocks in this regard. Crepsi et al. (2010) found that cattle supply has a negative effect on live cattle prices and the effect can be increased by market concentration. While their model conditions the degree of market power on market-ready supply, it does not confront the possibility of switching between regimes. Stiegert et al. (1993) found that the unanticipated supply shocks were responsible in breaking down average cost pricing in beef packing using quarterly data from 1972 to 1986. However, the use of quarterly data does not allow a determination for whether or not such shocks led directly to changes in market regimes or whether or not any such regime changes were sustainable through time.[7] In this article, we focus on the potential for disruptions between the derived demands for processed beef and supply of live cattle as a driving force in regime-switching activity. In particular, when slaughter is higher (lower) than what is anticipated, our hypothesis is that this may provide the impetus to switch from a cooperative (noncooperative) to a noncooperative (cooperative) regime. It is important to note that not all supply disruptions may lead to a switch in behavior. While we do not observe why actual slaughter differs from anticipated, our hypothesis is suggestive of derived demand driven results. Thus, our expectation is that when the downstream market demands more beef than can be easily delivered, packers will become aggressive in attracting additional supply to their plants. In doing so, they would signal to other beef packers a breakdown in the cooperative regime. To integrate a design of this nature into our model, let δ reference the ratio of actual slaughter to predicted slaughter, that is, $\delta = y_t/\hat{y}_t$. Using the marginal processing cost specification and the specification for regime switching, the marketing margin in Eq. (15) is now written as

$$m_t = r_t - p_t k = \phi_{11} w_{1t} + \phi_{22} w_{2t} + 2\phi_{12}\sqrt{w_{1t} w_{2t}} + 2 y_t(\phi_1 w_{1t} + \phi_2 w_{2t}) + \beta_s \hat{y}_t. \tag{18}$$

We obtain anticipated supply in a manner similar to that used by Stiegert et al. (1993) but modified for weekly data. Specifically, we estimate the following auxiliary regression model:

$$y_t = \alpha + \alpha_1 y_{t-1} + \alpha_2 \mathrm{cof}_1 + \alpha_3 p_c + \sum_{i=4}^{6} \alpha_i \mathrm{plc}_i + \sum_{i=7}^{17} \alpha_i D_i + e_t, \tag{19}$$

[7] See also Mathews et al. (1999). They show that there was no cyclical pattern in the price spreads during the 1990s, and that intrayear seasonality impacts price spreads to a much larger degree than the cyclical components.

where y_{t-1} is slaughter in the previous week; cof_1 is the previous month's cattle on feed; p_c is the price of corn; plc_i are cattle placements lagged 4, 5, and 6 months; and D_i contains 11 monthly dummy variables. cof_1 and plc_i are used to estimate the cattle inventory, and D_i is used to capture the effect of seasonal changes. We assume that predicted slaughter is estimated by $\hat{y}_t$ for each week: $y_t - e_t = \hat{y}_t$. In the conceptual model, we assumed that the live cattle shock follows a continuous uniform distribution; as a result, only deviations toward higher prices are optimal. According to the central limit theorem for the continuous uniform distribution, as the sample size increases, the sampling distribution will eventually look like normal distribution although the population itself is uniformly distributed. So, the auxiliary regression is estimated using GLS.

Weekly changes in the marketing margin is a recurrent feature of cattle markets. Our empirical model will look to evaluate that part of the marketing margin that is not related to marginal processing costs for potential regime-switching behavior. While the conduct associated with either cooperation or noncooperation is unobserved, the potential for switching between the two regimes is modeled using a Multivariate Markov-Switching framework given by

$$m_t = \nu_{st} + \beta_s \hat{y}_t + \gamma_1 w_{1t} + \gamma_2 w_{2t} + \gamma_3 (2\sqrt{w_{1t} w_{2t}}) + \gamma_4 (2 y_t w_{1t}) + \gamma_5 (2 y_t w_{2t}) + \varepsilon_t, \tag{20a}$$

$$\nu_{st} = \kappa_1 \eta_{1t} + \kappa_2 \eta_{2t}, \tag{20b}$$

$$\varepsilon_t \mid S_t \sim N(0, \sigma_{st}^2) \text{ where } \sigma_{st}^2 = \rho_1 \eta_{1t} + \rho_2 \eta_{2t}. \tag{20c}$$

Let $S_t = \{1, 2\}$ denote the two-state unobserved regimes with $S_t = 1$, representing the noncooperative regime and $S_t = 2$, representing the cooperative regime. The transition between these two states is governed by a first-order Markov process:

$$\mathrm{Prob}[S_t = 1 \mid S_{t-1} = 1] = p \quad \mathrm{Prob}[S_t = 2 \mid S_{t-1} = 1] = 1 - p, \tag{21a}$$

$$\mathrm{Prob}[S_t = 2 \mid S_{t-1} = 2] = q \quad \mathrm{Prob}[S_t = 1 \mid S_{t-1} = 2] = 1 - q. \tag{21b}$$

The punishment strategies in Abreu et al. (1986) and Mailath and Samuelson (2006) follow a Markov process thus our empirical model and the economic model are internally consistent whereas KGH, and even Porter (1983b), approximate the T-Markov economic model with a Bernoulli empirical model.

Following Bellone (2005), define the time dependent information sets I_t available in each regime, which are equal to the shadow random variables in Eqs. (20a) and (20b): $\eta_{1t} = I_{S_t=1}$ and $\eta_{2t} = I_{S_t=2}$. As a result, we can define the conditional probabilities related to each state as

$$P(S_t = 1 \mid I_t) = E(\eta_{1t} \mid I_t), \tag{22a}$$

$$P(S_t = 2 \mid I_t) = E(\eta_{2t} \mid I_t). \tag{22b}$$

In the Markov-Switching model defined in (20a), besides the intercept ν_{st}, $\hat{y}_t$ is the only exogenous variable that is subject to switching regimes. All other terms are related to marginal processing costs determined after the noncattle input prices and subsequent supply levels are obtained in the market. The error terms are assumed to have different variances in the two regimes. Also, β_s varies in the two regimes: β_1 is the parameter in the noncooperative regime and β_2 is the parameter in the cooperative regime. Therefore, $(\beta_1, \beta_2, \kappa_1, \kappa_2, \rho_1, \rho_2)$ is the vector of regression coefficients which are regime-dependent, and $\gamma = (\gamma_1, \cdots, \gamma_5)$ is the vector of regression coefficients that are regime-independent.

Following the estimation of the Multivariate Markov-Switching models developed by Bellone (2004, 2005), with the normality assumption of ε_t, the conditional probability density function of m_t is given by

$$f(m_t \mid S_t = j, I_{t-1}, \Theta) = \frac{|\Sigma_j^{-1/2}|}{(2\pi)^3} \exp\left(- \frac{\varepsilon_t' \Sigma_j^{-1} \varepsilon_t}{2} \right), \tag{23}$$

where $\Theta = (p, q, \beta_1, \beta_2, \gamma, \kappa, \rho)$ and $\Sigma_j = \rho_1 \eta_{1t} + \rho_2 \eta_{2t}$. Then the unconditional density of m_t is obtained by summing Eq. (23) over the two values of S_t:

$$f(m_t \mid I_{t-1}, \Theta) = \Sigma_{j=1}^2 P(S_t = j \mid I_{t-1}, \Theta) \times f(m_t \mid S_t = j, I_{t-1}, \Theta). \tag{24}$$

Θ is estimated by maximizing the following log likelihood function:

$$L(\Theta) = \Sigma_{t=1}^T ln(f(m_t \mid I_{t-1}, \Theta)). \tag{25}$$

4. Estimation procedures and data

The data sets used in this article were collected from Livestock Marketing Information Center (LMIC), National Agricultural Statistics Service (NASS), and the Department of Labor. One analysis was conducted for the national beef market and one for the state of Kansas. Kansas represents a prominent beef production region where cattle feeding and slaughter industries are both present. The weekly slaughter, cattle placement,[8] cattle on feed, and corn price data were used in the auxiliary regression described in Eq. (19). The Markov-Switching regression used processing margins and beef processing cost data. The processing margins were obtained by subtracting from the boxed beef price the regional or national fed cattle price converted to a carcass equivalent (price/0.615). To remove the impact of inflation, the margin values are deflated to a 1992 base year. The energy price index is from the producer price index for the

[8] The cattle placement data are monthly; we convert the monthly data to weekly numbers based on how many weeks there are in the month and how many business days there are in each week of the month.

Table 1
GLS estimates of weekly marketing model

	Kansas		United States	
	Estimate	S.D.	Estimate	S.D.
Cons.	9.479***	(1.206)	17.803***	(2.282)
y_{t-1}	0.748***	(0.027)	0.726***	(0.028)
cof_{-1}	0.073*	(0.039)	0.066***	(0.017)
p_c	−0.120	(0.111)	0.173	(0.212)
plc_{-4}	0.133	(0.134)	0.040	(0.072)
plc_{-5}	0.113	(0.150)	−0.012	(0.089)
plc_{-6}	0.073	(0.120)	0.045	(0.065)
D_2	−1.026***	(0.345)	−2.205***	(0.611)
D_3	−1.185***	(0.347)	−2.214***	(0.797)
D_4	0.032	(0.380)	−0.318	(0.914)
D_5	1.480***	(0.380)	2.762***	(0.733)
D_6	0.984**	(0.404)	2.287***	(0.762)
D_7	0.153	(0.377)	0.469	(0.712)
D_8	1.037***	(0.367)	2.022***	(0.714)
D_9	0.126	(0.390)	0.676	(0.750)
D_{10}	−0.172	(0.364)	−0.183	(0.740)
D_{11}	−0.366	(0.388)	−0.730	(0.739)
D_{12}	−1.922***	(0.374)	−3.495***	(0.608)
Adjusted R^2	0.823		0.833	

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 2
Maximum likelihood estimates

	Parameters	Kansas		United States	
		Estimate	S.D.	Estimate	S.D.
Regime-independent MLE	γ_1	−4.244***	(0.952)	−3.505***	(1.005)
	γ_2	−1.800***	(0.435)	−0.887*	(0.465)
	γ_3	3.594***	(0.793)	2.609***	(0.839)
	γ_4	1.006*	(0.549)	1.581***	(0.550)
	γ_5	−0.270	(0.312)	−0.774***	(0.318)
Regime-dependent MLE	p	0.969***	(0.012)	0.970***	(0.014)
	q	0.936***	(0.024)	0.953***	(0.018)
	β_1	0.131**	(0.056)	0.082*	(0.056)
	β_2	0.239***	(0.078)	0.268***	(0.074)
	κ_1	−0.417***	(0.034)	−0.561***	(0.037)
	κ_2	0.941***	(0.069)	0.820***	(0.060)
	ρ_1	0.203***	(0.020)	0.204***	(0.019)
	ρ_2	0.317***	(0.046)	0.329***	(0.041)
Expected duration	Noncooperation	32.26		33.33	
	Cooperation	15.63		21.28	

$^{*}p < 0.15$, $^{**}p < 0.05$, $^{***}p < 0.01$.

meat packing industry and the labor price is the average hourly production worker earnings for the meat packing industry.

The study period for this analysis was selected for several reasons. First, stability in industry structure is generally preferred in the estimation of the regime-switching models. This allows for a more confident interpretation of regime-switching behavior because it limits the possibility of assigning switching patterns to relatively more permanent structural changes. The period from 1992 to 1999 represents a good time frame for analysis. In the years previous to 1992, the market had undergone significant restructuring through mergers and plant closures. The HHI passed the DOJ threshold of 1,800 in 1992 but then leveled off in future years. After 2000, the beef market may have been significantly impacted by additional restructuring via mergers, increased regulations related to food safety concerns, and bioterrorism concerns after terrorists attacks on 9/11/2001.

The results from the estimation of Eq. (19) are reported in Table 1. Not surprising, the coefficient on slaughter lagged one week was significant for both Kansas and the national market. It appears to capture trends in slaughter that relate to weather or other factors in the normal animal production process. Cattle placements were not statistically significant in either regression. It is plausible that lagged slaughter, lagged cattle on feed, and seasonal variables explain much of the variation in slaughter that placement data might otherwise capture. Additionally, multicollinearity within the placement variables and the corn price could be present. A joint test of the three lagged placements and corn price was highly statistically significant: F-stat for Kansas = 3.77 and F-stat for the national market = 3.20. Both are larger than the 1% critical value of 3.17. This indicates that there is important information in this group of variables useful for predicting slaughter on a weekly basis. The adjusted R^2 numbers for Kansas and the United States indicate that the regressions do a good job of predicting slaughter.

We next estimated the Markov-Switching model described by Eq. (20) using MSVARlib developed by Bellone (2005). Applying Hamilton's (1989) algorithms of filtering and smoothing to margin changes in one regional market and the national market, numerical maximization of the conditional log likelihood function led to the maximum likelihood estimates of the transition probabilities, and the regime-dependent and -independent parameters.

The regression estimates are presented in Table 2. The first section of Table 2 contains the estimated regime-independent parameter values associated with marginal processing costs. Almost all the γ terms are statistically significant in both regressions, which means the marginal processing cost components are important in explaining weekly movements in the margin.

The next section of Table 2 contains the estimates for each regime-dependent parameter. The conditional probabilities of remaining in the noncooperative regime (p) and the cooperative regime (q) are estimated through the EM algorithm and reported first. Low (high) conditional probabilities suggest that switching between regimes is both easy (difficult) and frequent (infrequent). Importantly, all of these estimates are highly statistically significant and in a range between 0.936 and 0.970. This indicates that the markets analyzed have a high probability of remaining in the previous period regime. Using the Kansas results as an example, the term prob($S_t = 2|S_{t-1} = 2$) = q = 0.936 means that there is a 93.6% chance that packers will cooperate when they cooperate in the previous week. Similarly, there is a 96.9% chance that Kansas packers will remain in a noncooperative state when they are in a noncooperative state in the previous week. These findings suggest that regimes are stable once entered.

Both β_1 and β_2 parameters for each regression are positive and are all statistically significant. Additionally, each of the β_1 parameters in the cooperative regime are quite a bit larger in magnitude than the comparative β_2 in the noncooperative regime. This infers that the firms observe the different regimes and switch their behavior to comply with either a more cooperative or a more competitive environment. The intercept is a regime-dependent parameter controlled by κ_1 and κ_2. All are significant in both regressions. Finally, the variances of each regression are allowed to vary depending on the regime and controlled through ρ_1 and ρ_2. The estimates of ρ_1 and ρ_2 provide clear evidence that the variances differ strongly in each regime in both regressions. The estimates and the significance of the $\rho's$ and the $\kappa's$ offer additional support for the presence of a switching pattern.

The focus of the remaining analysis was on defining and analyzing the conditional outcomes associated with switching. Five analyses were conducted. First, as shown at the bottom of Table 2, we calculated the expected duration of cooperation and noncooperation respectively.[9] The expected duration of cooperation is about 16 weeks for Kansas and 21 weeks for the national market. The expected duration of noncooperation is about 33 weeks for Kansas and the national market. Note that Kansas appears representative of the national market during the noncooperative regime. The duration of the cooperative phase in Kansas is about 27% lower compared to the national market. This is likely the regional nature of the Kansas regression. Although Kansas is central to the largest feeding and slaughtering region in the United States, supply injections and leakages to and from neighboring states could disrupt the status quo and thus cause localized breakdowns in cooperative regimes. Clearly, spatial arbitrage opportunities would require that a region eventually align its pricing with other regions. We develop this subject further in the second and third analyses of switching patterns.

Second, using Hamilton's (1989) filter techniques, we calculate the probability of being in a state of cooperation ($S_t = 2$) or noncooperation ($S_t = 1$) at time t. We present the week-to-week probabilities of cooperation for each market from February 1, 1992 to February 20, 1999 in Fig. 1. Note that the unshaded regions represent the weeks in noncooperative states and the shaded regions represent weeks in cooperative states.[10] As we see in the figure, there are eight cooperative periods for Kansas and six for the national market during the study years. Note also that the cooperative regime for the United States centered on week 223 is broken into two very short cooperative regimes in Kansas. It appears the Hamilton algorithm could not keep Kansas in a single regime during these weeks. This helps to explain why the average cooperative duration for Kansas is 27% shorter than for the national market.

Third, we investigated the conditions that led to each of the 16 switches in Kansas and 12 switches for the U.S. market during February 1992 and February 1999. Our model setup suggests that shocks in the actual versus anticipated slaughter levels are a potential source of the switching behavior. In Table 3, we report the percentage of unanticipated slaughter during the week that a switch takes place. Note that for the U.S. market, there are six weeks with a switch to a noncooperative state (unshaded rows) and six weeks with a switch related to a cooperative state (shaded rows). The results in Table 3 reveal an interesting pattern of unanticipated slaughter-related switching behavior. Specifically, we note that a breakdown of cooperative behavior is related with slaughter levels above the anticipated level. For Kansas, in six of eight of the weeks that the market switched to a noncooperative state, unanticipated slaughter is 0.54—8.59% above the anticipated level. For the national market, unanticipated supply is 0.94–15.76% above the level of anticipated slaughter in three of six of the weeks that cooperation breaks down. The results suggest that when packers need larger levels of supply than are, perhaps, readily available, cooperation breaks down. The reverse pattern is similar when the market switches to a cooperative regime. The actual slaughter is below anticipated slaughter in five of eight of the switches in the Kansas market (−0.43% to −8.08%) and in four of six of the switches for the national market (−0.26% to −5.56%). These results suggest that when slaughter is below the anticipated level, beef packers recognize that supplies have

Table 3
Percentage of unanticipated slaughter in the switching weeks from February 1992 to February 1999

Kansas		United States	
Week	%	Week	%
2/1/1992	−2.58		
3/7/1992	−3.54		
5/23/1992	−0.43	4/25/1992	−0.80
7/4/1992	8.59	6/6/1992	−1.66
8/13/1994	0.86	4/16/1994	−1.54
9/10/1994	3.51	10/1/1994	1.28
5/27/1995	0.48	4/8/1995	−5.56
1/6/1996	3.84	12/30/1995	15.76
4/20/1996	−2.36	3/23/1996	1.72
5/4/1996	−1.61		
6/22/1996	−8.08		
7/6/1996	2.44	6/8/1996	−1.52
11/9/1996	1.82	10/12/1996	−0.26
1/11/1997	0.54	12/28/1996	−5.15
7/18/1998	−2.62	6/20/1998	0.44
1/9/1999	1.23	1/9/1999	0.94

Rows highlighted in gray represent switches into the cooperative regime. Rows not highlighted represent switches into noncooperative regimes. Percentage change results are from $(y - \hat{y})/\hat{y}$.

[9] Conditional on being either in cooperative state or noncooperative state, the expected durations are calculated by $\sum_{\lambda=1}^{\infty} \lambda p^{\lambda-1}(1-p) = (1-p)^{-1}$ and $\sum_{\lambda=1}^{\infty} \lambda q^{\lambda-1}(1-q) = (1-q)^{-1}$.

[10] Following Hamilton (1989), our decision rule is that beef packers are in the cooperative regime when $P[S_t = 2] > 0.5$, and they are in the noncooperative regime when $P[S_t = 1] > 0.5$.

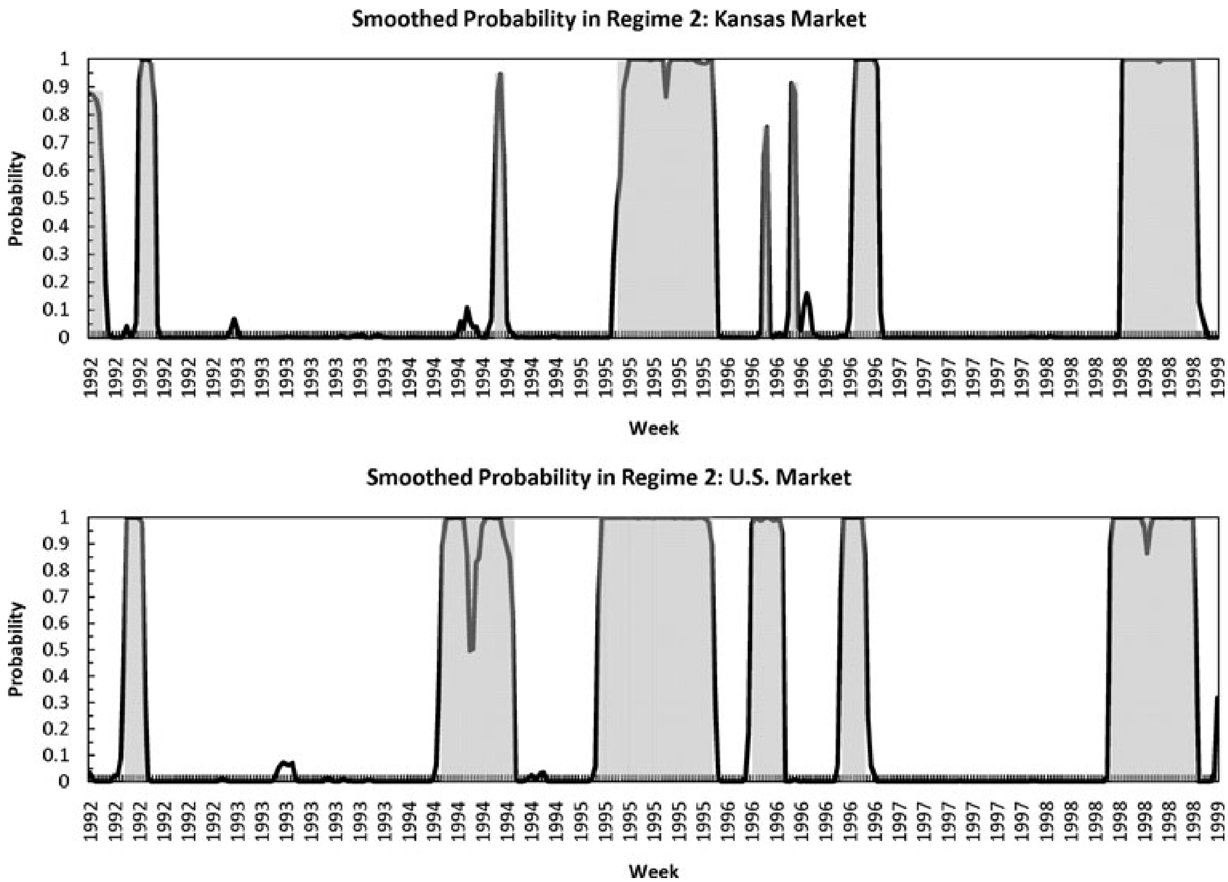

Fig. 1. Probability of cooperative regime for Kansas (above graph), and U.S. (lower graph). Shaded regions define periods of cooperative regime, February 1992 to February 1999.

Table 4
Margins in cooperative and noncooperative regimes from February 1992 to February 1999

Region	Cooperative margin	Noncooperative margin	% Decrease in the noncooperative regime
Kansas	7.70	2.75	64.29
United States	7.24	2.34	67.68

Unit: $/hundredweight of boxed beef.

become plentiful and switch to less aggressive bidding stance. This softer bidding has the potential to last many weeks past the event.

Fourth, using the shaded and unshaded regions presented in Fig. 1, we calculated the average regime-dependent marketing margins. These results are in Table 4. Our results for the national market indicate that the noncooperative regime produces a marketing margin that is 67.68% below the marketing margin for the cooperative regime. Kansas is slightly lower at 64.16%. Based on the inferred regimes from February 1992 to February 1999 in Table 3, on average, the national market is in a noncooperative state 68% of the time. This means that the expected decrease in the national marketing margin due to switching patterns is 46% or $4.90 per hundredweight of boxed beef. For Kansas, the result is a 50% decrease in the margin or $4.95 per hundredweight of boxed beef. Based on the annual production of beef in the national market over the study years, there is an average expected increase in economic profit to the packing industry of nearly 28 million 1992 dollars each year.[11]

Fifth, we also calculated the average prices in different regimes using the inferred cooperative and noncooperative regimes. In the Kansas market, the fed cattle prices are 8.9% lower in the cooperative regime than in the noncooperative regime. In the national market, the fed cattle prices are 9.52% lower in the cooperative regime than in the noncooperative regime. Therefore, our results suggest a higher oligopsonistic loss than in most previous studies.

CHW examined transactions data from an economic experiment-based market. While their market is simulated, the structure of that artificial market is based on real-world biology, production, cost, demand, and market institution parameters and therefore the results should generalize to the real-world

[11] Using the market power parameters, β_1 and β_2 we find that 3.4% (1.76%) of the cooperative (noncooperative) regime margin is due to market power. From 1992–1999, annual beef production in the U.S. was in a range primarily from 25–27 billion lbs. For 26 billion pounds of production, economic profit is calculated as: (26,000,000,000/100)* (7.24* .034* .32 + 2.34* .0176* .68) = 27.76 mil.

fed cattle markets. Further, many parameters are known and do not need to be estimated as in studies using real-world data. In CHW, the extent of cooperation differs for the different replications. For their first replication, the market was in the cooperative regime 78.6% of the time. In the second replication where a marketing agreement experiment was conducted, the market was in the cooperative regime 40.5% of the time but the switching process was not significant—there was not clear evidence of collusive price behavior but fed cattle prices paid in the replication were higher. In the third replication where a lack of common market information experiment was conducted, the market was in the cooperative regime 40.7% of the time. While the marketing agreement and lack of common market information appears to mitigate collusive behavior, it remains a persistent problem. Also, we see similarity between our real-world results modeled under imperfect monitoring and those from the latter two CHW experiments. We believe such similarities strengthen the case for analyzing these markets using flexible dynamic models. It also provides support for the Markov model, as opposed to the simpler and more common Bernoulli model, because the Markov model allows for extended periods of cooperation and extended periods of competition.

5. Conclusion

In 1992, concentration in the U.S. beef packing industry for the first time passed over the HHI = 1,800 level, which is recognized by the Department of Justice as the threshold for a heavily concentrated industry. Most previous studies of market power in this industry analyzed data in periods prior to 1992. In this article, we construct an oligopsony with imperfect monitoring model using Hamilton's Markov regime-switching technique to analyze weekly marketing margin data for the U.S. beef packing industry from 1992 to 1999. We focus on changes in the normal throughput of supply as a potential catalyst for regime-switching behavior. The model was estimated for one region (Kansas) and for the national market. Both models produced results with sufficient statistical support for switching behavior. Each estimation identified similar cooperative periods and noncooperative periods that mostly began and ended within one to four weeks of each other.

A major finding from the study was that slaughter levels higher than anticipated were a catalyst leading to breakdowns in cooperative regimes while lower than anticipated slaughter provided a way for packers to switch to a cooperative regime. This seems to suggest that cooperation, once established as a norm, can last until insufficient short-term supply may spark a return to more competitive behavior. Our analysis indicates that cooperative regimes are expected to last about 21 weeks while noncooperative regimes last about 33 weeks. For the United States (Kansas) model, our results show that live cattle prices were suppressed by about 9.5% (8.9%) as a result of price reductions during the cooperative phases.

During the study years, national concentration levels remained fairly stable, so regime-switching patterns were likely not unduly influenced by major structural changes to the industry. Since 2000, however, the concentration levels in beef packing have continued to rise. If a condition for sustained cooperative phases is high levels of concentration leading to only a few buyers for live cattle in any given location, then allowing concentration to rise has the potential to lengthen cooperative phases and extract greater rents than what is observed in our study. Additional research is necessary to determine ways in which markets such as live cattle are able to maintain long phases of cooperative behavior.

Our results suggest that market power by beef processors cannot be understood through simple static models of industrial organization. Indeed, we find that it is manifested in ways that would not be easily detected in more aggregated data or with a model that does not provide sufficient flexibility in allowing for major breakdowns and returns to cooperation. The results of this study and the results of several past studies that also allow for dynamics to shape the nature of market power consistently suggest that oligopsony losses to cattle producers are nontrivial and represent an important public policy issue.

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