

## Oligopsony Power: Evidence from the U.S. Beef Packing Industry

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# Oligopsony Power: Evidence from the U.S. Beef Packing Industry

Xiaowei Cai, Kyle Stiegert, and Stephen Koontz \*

## Abstract

Based on Green and Porter's (GP) noncooperative game theoretic model, oligopsonists are hypothesized to follow a discontinuous pricing strategy in equilibrium. The model allows for low procurement prices during cooperative phases and high procurement prices (i.e., aggressive purchasing) during noncooperative phases. In this paper, the GP model is applied to the U.S. beef-packing industry. Anecdotal evidence of beef-packer margins and relevant processing costs suggest part of the margin variability could be attributed breakdowns and returns to cooperative phases. To operationalize the GP framework, we apply Hamilton's Regime-Switching model assuming a first-order Markov process to test for the cooperative/competitive behavior of beef packers in three main fed-cattle markets in the central United States and the whole U.S. market. We find that the evidence of cooperative/competitive conduct among the beef packers is present in all the markets examined, but the conduct varies across markets.

**Keywords:** Margin, Beef Packing, Fed Cattle Prices, Markov Regime Switching

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# 1 Introduction

The U.S. fed cattle industry has seen shifts of production to larger farms since the 1980s, but the beef-packing industry has become much more concentrated than cattle feeding (MacDonald and McBride 2009). In the 1990s, beef-packing plants increased in size and decreased in number. The average number of slaughter per plant increased by 5 times from 32,383 in 1972, to 163,071 heads in 1998 (Ward and Schoeder 2002). The number of slaughter plants for cattle declined from over 600 in 1980 to about 170 in 1999 (Barkema, Drabentstott and Novack 2001). As of 1999, the four largest beef packers account for 80% of the national beef slaughter, as opposed to 36% in 1980 (GIPSA 2002). The Herfindahl-Hirschmann Index (HHI) for steer and heifer slaughter increased from 999 in 1985 to 1,982 in 1995, which was above the threshold level of 1,800, and considered as moderately concentrated (ERS 1998). Profits in beef packing in the mid-1990s were several times higher than the early 1990s (Ward and Schoeder 1996). Although some argued that higher profits were a result of lower processing costs due to economies of scale (Brester and Marsh 2001; MacDonald and Ollinger 2005), this type of argument does not consider the possibility of lower prices paid to the cattle feeders due to imperfect competition.

For many years, the increased concentration contributed by the series of mergers and acquisitions among beef-packing firms in the 1980s and 1990s has raised a major public policy concern about whether increased concentration has provided beef packers with the market power to lower the fed-cattle prices. There are a lot of studies in the literature on the market power in the beef-packing industry. Some studies find that higher levels of concentration generally lead to lower prices paid for fed cattle by examining the relationship between regional fed-cattle prices and beef-packing concentration (e.g., Azzam and Schroeter 1991; Marion and Geithman 1995; Azzam 1997). Some find monopsony price distortions in the beef channel by estimating aggregate effects from structural changes (e.g., Schroeter 1988; Schroeter and Azzam 1990; Azzam and Pagoulatos 1990). Beef packer conjectures suggest a distortion of 1% to 3% of fed-cattle prices due to the concentration (Schroeter 1988). Others find no evidence of market power exercised by the beef packers during the study years (e.g., Morrison-Paul 2001).

Most of these studies have used either the structure-conduct-performance paradigm or the conjectural-variation approach. Although both approaches have proven very informative, they have been criticized when applied to the beef-packing industry. The estimated relationships reflected correlations rather than cause and effect in the structure-conduct-performance paradigm. And, despite the fact that regional markets are most relevant in fed-cattle procurement, the conjectural-variation approach did not examine the regional markets (Koontz, Garcia and Hudson 1993).

There are three studies that have evaluated the beef-packing industry in the context of regime switching. Koontz, Garcia and Hudson (KGH 1993) used a noncooperative game model to study meat-packer behavior. They assessed the degree of oligopsony power exercised by beef packers through examination of daily movements in the regional beef margins and the evidence of the exercise of market power was indicated during the early-to-mid 1980s in the markets examined. Koontz and Garcia (KG 1997) later extended the single-market model in KGH (1993) to multiple markets and found that low prices were paid in all relevant markets in the cooperative phase, while high prices were paid in the noncooperative phase in the early-to-mid 1980s. Azzam and Park (1993) adopted 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 competitive and cooperative conduct.

In the present paper, we extend the KGH (1993) model in two important ways. First, we use data from the 1990s, when concentration levels rose substantially. Indeed, many past studies have found some degree of monopsony power in beef packing using data from the 1960s to the 1980s, even though concentration levels, at least on a national scale, were not viewed as overly problematic. From 1990 to 1999, the four-firm concentration rose another 10% to 80% (Schoeder and Azzam 1999). One purpose of this study is to assess whether or not advances in concentration have provided for more extensive or different forms of oligopsony power. Second, instead of using a Bernoulli process to describe the dynamics of regime switching in KGH (1993) and KG (1997), we employ the algorithm in Hamilton's (1989) regime-switching model assuming a first-order Markov process to test for the cooperative/competitive behavior of beef packers in three major U.S. fed-cattle markets

and the national market. We use a Markov process because it is suggested by the trigger strategy from the economic model, and it is computationally feasible for the first-order Markov process by using Hamilton's (1989) econometric approach. Given the nature of fed-cattle purchasing patterns, using weekly data (as opposed to KGH's use of daily data) may provide a better platform for understanding the potential breakdowns in cooperative behavior that would constitute switches between regimes.

The remainder of the paper is structured as follows. Section 2 examines a model of a noncooperative repeated pricing game among the beef packers with complete but imperfect information. Section 3 discusses the econometric model we use. The margin model using a Multivariate Markov-Switching framework is explained by some variables that are regime dependent and the others that are regime independent. The beef packers' cooperative/competitive conduct is not directly observable but is subsumed into the margin model. We use the margin variability due to the switching regimes to test for cooperative/competitive behavior of beef packers. Section 4 provides a description of the data and the estimation results. Evidence of cooperative/competitive conduct among the beef packers is present in all the markets examined, but the conduct is different across markets. The conclusion and the suggestions for future research are in Section 5.

## 2 Economic Model

The economic model in this paper is very similar to the one from KGH (1993). Based on Green and Porter's (1984) noncooperative game theoretic model, our economic model is a noncooperative repeated pricing game among  $n$  beef packers with complete but imperfect information. The assumptions of the model are:

1. The  $n$  beef packers buy an undifferentiated product — fed cattle from the regional cash market;
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 the pricing actions by others;
5. Beef packers are risk neutral and only maximize their expected profit.

Beef packers' profits each period are determined by price competition for fed cattle and the profit of the  $i$ th beef packer is given by:

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

where  $p_{it}$  is the cattle price paid by the  $i$ th 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 (cutability ratio),  $W_t$  is a vector of exogenous variables,  $y_{it}$  is the beef quantity the  $i$ th packer produces from fed cattle and other inputs,  $\xi_t$  is a random term,  $c_i$  is the variable processing cost of the  $i$ th beef packer and is a function of  $z_t$ , a vector of non-cattle variable input prices, and  $y_{it}$ . The set up of the variable processing cost in equation (1) is fundamentally different from the one in KGH (1993) in which beef packers' variable processing costs do not depend on the meat quantity or  $y_{it}$ . The reason for this difference is that KGH used daily data and in such a short run, all the costs except the costs of fed cattle were considered as fixed and did not vary with the output. While in the current paper, we are using the weekly data, so the production process is in the longer-run, and variable costs include both the costs of cattle slaughtered and other non-cattle inputs such as energy and labor. We assume Leontief beef production because of the limited substitution between fed cattle and other inputs.

In this repeated game, given the packer's own pricing strategy  $s_{it}$ , other packers' strategies  $s_{jt}$  and the discount rate  $\delta$ , beef packer  $i$  is trying to maximize the sum of the current and the discounted expected future profits:

$$V_i(s_t) = E \left[ \sum_{t=0}^{\infty} \left( \frac{1}{1+\delta} \right)^t \pi_i(s_{it}, s_{jt}) \right] \quad (2)$$

$i \neq j, i, j = 1, \dots, n$  and  $0 < \delta < 1$

If the prices under one-shot Nash are denoted as  $p''$  and prices under collusion as  $p'$ , then the few beef packers in the market will cooperate as long as:

$$V_i(p') > V_i(p'') \text{ for all } i \quad (3)$$

Different from the single-period game where packers can increase the price paid for the fed cattle without the fear of any punishment, in the repeated game, punishment can be used to deter the behavior of increasing the fed-cattle price unilaterally by any packer. If some packer secretly increases the cattle price offer to  $p^*$  and  $p^* > p'$ , all the packers will offer the single-period Nash price  $p''$  and  $p'' > p'$ . Therefore, if collusive pricing is beef packers' pricing strategy in equilibrium, the expected returns from cooperation should be greater than the expected returns from cheating followed by the Nash behavior:

$$V_i(p') > \pi_i(p^*) + \frac{1}{1+\delta}V_i(p'') \text{ for all firms} \quad (4)$$

According to Green and Porter (1984), each firm cannot directly observe other firms' actions. However, they can observe their own margin level which is the difference between the boxed-beef price and the fed-cattle price. Their pricing strategies each period would be dependent on their own observed margin in the previous periods. Therefore, when the beef packers cannot observe each other's pricing behavior, they try to maximize their value function  $V_i(s_t)$  subject to a trigger strategy:

$$S_{it} = \begin{cases} p' & \text{if } \mu < m_{t-1} \\ p'' & \text{if } \mu \geq m_{t-1} \text{ in the last } T - 1 \text{ period} \end{cases} \quad (5)$$

where  $\mu$  is the trigger margin level, and  $m_{t-1}$  is the margin level in the previous period. If the beef packer's own observed margin in the previous period is greater than the trigger level  $\mu$ , this packer offers a cooperative price  $p'$ . However, if the observed margin in the previous T-1 periods is less than  $\mu$ , this packer offers a competitive price  $p''$ . In this way, the trigger strategy allows cooperation among the beef packers on the equilibrium path because any cheater would be punished by getting low profits for T-1 periods after it unilaterally raises the fed-cattle price.

With the trigger strategy, the value function for a packer starting in the cooperative phase is given by the sum of the current period collusive profit and the discounted expected

future profits weighted by the occurrence probability of cooperation and competition:

$$\begin{aligned}
V_i(p') &= \pi_i(p') + Pr(\mu < m_i)\delta V_i(p') \\
&+ Pr(\mu \geq m_i) \left[ \sum_{t=0}^{T-1} \left(\frac{1}{1+\delta}\right)^t \pi_i(p'') + \left(\frac{1}{1+\delta}\right)^T V_i(p') \right]
\end{aligned} \tag{6}$$

Let  $Pr(\mu \geq m_i) = F$  and  $F$  is a distribution function, then equation (6) can be rewritten as:

$$V_i(p') = \frac{(1+\delta)\pi_i(p'')}{\delta} + \frac{(1+\delta)^T(\pi_i(p') - \pi_i(p''))}{(1-\delta)^T - (1+\delta)^{T-1} + ((1+\delta)^{T-1} - 1)F} \tag{7}$$

Beef packers choose the price to maximize the expected returns, so the interior solution to the first order condition of equation (7) is:

$$\begin{aligned}
\frac{\partial V_i}{\partial s_i} &= \frac{\partial \pi_i(p')}{\partial s_i} (1+\delta)^T [(1+\delta)^T - (1+\delta)^{T-1} + ((1+\delta)^{T-1} - 1)F] \\
&+ [\pi_i(p') - \pi_i(p'')] ((1+\delta)^{T-1} - 1) \frac{\partial F}{\partial s_i} f = 0
\end{aligned} \tag{8}$$

where  $f$  is the density function of  $F$ . The actions of beef packers are discontinuous: they aggressively purchase fed cattle in the competitive state and offer a lower price for fed cattle in the cooperative state.

Suppose the detection of cheating behavior and the subsequent punishment can take place in a timely manner. For a collusive equilibrium to exist in the multiple-period game,  $p'$ ,  $p''$  and  $\delta$  must satisfy the following condition:

$$V_i(p') > \pi_i(p') + \sum_{t=1}^{T-1} \left(\frac{1}{1+\delta}\right)^t \pi_i(p'') + \left(\frac{1}{1+\delta}\right)^T V_i(p') \tag{9}$$

Equation (9) means that the expected returns from tacit collusion are greater than the profits from cheating for one period followed by T-1 periods of punishment profits. If we can find  $T$ ,  $\mu$ ,  $p'$ , and  $p''$  to satisfy both equations (8) and (9), a collusive equilibrium will exist.

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 could not tell if it is a



consequence of a deviation from the collusive pricing by one of their rivals or if it is due to a low realization of the fed-cattle supply shock. Following Green and Porter (1984), some degree of collusion can be sustained in our game by trigger strategies that involve aggressive fed-cattle procurement whenever the margin level drops below some endogenously determined threshold value.

### 3 Econometric Model

As we discussed in the previous section, we expect to see a discontinuous pattern in beef packers' margins when a trigger strategy is the equilibrium strategy. We will look for the collusive conduct by calculating the length of the cooperative regime. Beef packers' oligopsony power exists if we can find the duration of cooperation sufficiently long.

The beef packers maximize their profits in equation (1) through price choice. The first order condition is given by:

$$\frac{\partial \pi_i}{\partial p_i} = (r - p_i k) \left[ \frac{\partial y_i}{\partial p_i} + \sum_{j \neq i} \frac{\partial y_i}{\partial p_j} \frac{\partial p_j}{\partial p_i} \right] - k y_i - \frac{\partial c_i}{\partial y_i} \left[ \frac{\partial y_i}{\partial p_i} + \sum_{j \neq i} \frac{\partial y_i}{\partial p_j} \frac{\partial p_j}{\partial p_i} \right] = 0 \quad (10)$$

Assume that the effect of the  $j$ th firm's price on the  $i$ th firm's fed-cattle purchase is smaller than the effect of its own price, and firms are symmetric. Let  $\frac{\partial y_i}{\partial p_i} = \gamma$  ( $\gamma > 0$ ) and  $\frac{\partial y_i}{\partial p_j} = -\frac{\gamma}{q}$ , where  $q > 1$  is a constant, then equation (10) then becomes:

$$(r - p_i k - m c_i) \left[ 1 - \frac{\sum_{j \neq i} \frac{\partial p_j}{\partial p_i}}{q} \right] \gamma = k y_i \quad (11)$$

where  $m c_i$  is the marginal processing cost. Let  $\frac{\sum_{j \neq i} \frac{\partial p_j}{\partial p_i}}{q} = \beta$  and  $\beta$  be the sum of packers' conjectures about each other's price offer for fed cattle, then  $\beta = 0$ , when firms are in the competitive regime because the packers only offer the one-shot Nash price and  $\beta > 0$ , if they are in the cooperative regime because the packers all offer lower prices. Because only aggregate regional data is available, we sum up equation (11) over  $n$  firms and obtain:

$$(r_t - p_t k - m c_t) (1 - \beta) \gamma = k y_t \quad (12)$$

Rewriting it, we have the regional margin equation:

$$m_t = r_t - p_t k = mc_t + \frac{ky_t}{(1 - \beta)\gamma} \quad (13)$$

For econometric estimation, we assume a generalized Leontief cost function for the beef-processing industry:

$$C_t(y, w) = y_t(\delta_{11}w_{1t} + \delta_{22}w_{2t} + 2\delta_{12}\sqrt{w_{1t}w_{2t}}) + y_t^2(\delta_1w_{1t} + \delta_2w_{2t}) \quad (14)$$

where  $w_1$  is the labor price and  $w_2$  is the energy price. Then the marginal processing cost of the beef packers is given by:

$$mc_t = \delta_{11}w_{1t} + \delta_{22}w_{2t} + 2\delta_{12}\sqrt{w_{1t}w_{2t}} + 2y_t(\delta_1w_{1t} + \delta_2w_{2t}) \quad (15)$$

The regional margin in equation (13) can now be written as:

$$m_t = r_t - p_t k = \delta_{11}w_{1t} + \delta_{22}w_{2t} + 2\delta_{12}\sqrt{w_{1t}w_{2t}} + 2y_t(\delta_1w_{1t} + \delta_2w_{2t}) + \frac{ky_t}{(1 - \beta)\gamma} \quad (16)$$

In equation (16),  $y_t$  is the weekly regional cattle supply. However, weekly regional cattle supply data is not available, so we need to estimate the supply. In the regional fed-cattle cash market, market-ready inventories are the available supply over which beef packers and cattle feeders negotiate. Although they are not measured in any government report, they are discussed and measured informally by the industry participants. Because the market-ready inventory data is also not available, we use the following weekly marketing model to estimate the weekly market-ready inventories:

$$\begin{aligned} rw_t = & \alpha + \alpha_1rw_{t-1} + \alpha_2D_2 + \alpha_3D_3 + \alpha_4D_4 + \alpha_5D_5 + \alpha_6D_6 + \alpha_7D_7 + \alpha_8D_8 \\ & + \alpha_9D_9 + \alpha_{10}D_{10} + \alpha_{11}D_{11} + \alpha_{12}D_{12} + \alpha_{13}plc_{lag4m} + \alpha_{14}plc_{lag5m} \\ & + \alpha_{15}plc_{lag6m} + \alpha_{16}cof_{lag1m} + \alpha_{17}corn + e_t \end{aligned} \quad (17)$$

where  $rw_t$  is the weekly slaughter value,  $rw_{t-1}$  is the slaughter number in the previ-

ous week,  $D_2, D_3, D_4, D_5, D_6, D_7, D_8, D_9, D_{10}, D_{11}, D_{12}$  are the monthly dummy variables,  $plc_{lag4m}$ ,  $plc_{lag5m}$ , and  $plc_{lag6m}$  are the regional cattle placements 4, 5 and 6 months prior respectively,  $cofl_{lag1m}$  is the last month's regional cattle on feed, and  $corn$  is the price of corn. According to KGH (1993), weekly marketing is not affected by the fed-cattle price, rather it is affected by cattle feeders' marginal decision of either sending the cattle to slaughter or keeping the cattle on feed. So their marginal decision is dependent on the seasonal availability of feeder cattle, cattle inventory and the feeding cost. The marketing model is estimated using GLS. The residual from this model shows the variation of market-ready inventories. For example, the market-ready inventories expand this week if the estimated marketings exceed the actual slaughter value and market-ready inventories decrease if the actual slaughter is more than the estimated number.

From the fact that a periodic shift from a margin increase to a margin drop is a recurrent feature of the cattle markets, our empirical model will relate the margin between boxed-beef and fed-cattle prices with the factors such as processing costs, market-ready inventory variation and the unobserved state of cooperation among beef packers. The unobserved state of cooperation among beef packers is included in the last term of equation (16) because the parameter varies in different regimes, i.e., firms are in the competitive regime if  $\beta = 0$  and they are in the cooperative regime if  $\beta > 0$ . Instead of using the estimated market-ready inventories as  $y_t$  in the regional margin equation (16), we use the residuals from the weekly marketing model because the inclusion of the estimated market ready inventories can be interpreted as market power by the switching model, but they are really supply and demand dynamics. The final margin estimation model follows a Multivariate Markov-Switching framework:

$$\begin{aligned}
m_t &= \nu_{st} + \beta^s \hat{y}_t + \gamma_1 w_{1t} + \gamma_2 w_{2t} + \gamma_3 (2\sqrt{w_{1t}w_{2t}}) + \gamma_4 (2\hat{y}_t w_{1t}) + \gamma_5 (2\hat{y}_t w_{2t}) + \varepsilon_t \quad (18) \\
\nu_{st} &= \kappa_1 \xi_t^1 + \kappa_2 \xi_t^2 \\
\varepsilon_t | S_t &\sim N(0, \sigma_{st}^2) \text{ where } \sigma_{st}^2 = \rho_1 \xi_t^1 + \rho_2 \xi_t^2
\end{aligned}$$

where  $\hat{y}_t$  is the market-ready inventory variation obtained from equation (17).

Let  $S_t = \{1, 2\}$  denote the 2-state unobserved regime with  $S_t = 1$ , representing the

competitive regime and  $S_t = 2$ , representing the cooperative regime. The transition between these two states is governed by a first-order Markov process:

$$\begin{aligned} Prob[S_t = 1|S_{t-1} = 1] &= p & Prob[S_t = 2|S_{t-1} = 1] &= 1 - p \\ Prob[S_t = 2|S_{t-1} = 2] &= q & Prob[S_t = 1|S_{t-1} = 2] &= 1 - q \end{aligned} \quad (19)$$

$\xi_t^1$  and  $\xi_t^2$  in equation (17) are the “shadow random variables” and they are given by  $\xi_t^1 = I_{S_t=1}$  and  $\xi_t^2 = I_{S_t=2}$ , where  $I_t$  is the information set available at  $t$  (Bellone 2005). Therefore, the conditional probabilities related to the two states are:

$$\begin{aligned} P(S_t = 1|I_t) &= E(\xi_t^1|I_t) \\ P(S_t = 2|I_t) &= E(\xi_t^2|I_t) \end{aligned}$$

In the Markov-Switching model in equation (17),  $\hat{y}_t$  is the only exogenous variable that is subject to switching regimes and  $(w_{1t}, w_{2t}, 2\sqrt{w_{1t}w_{2t}}, 2\hat{y}_tw_{1t}, 2\hat{y}_tw_{2t})$  are the exogenous variables that are not subject to the switching regimes. Therefore  $(\beta^s, \kappa_1, \kappa_2, \rho_1, \rho_2)$  is the vector of regression coefficients which are regime-dependent and  $\gamma = (\gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5)$  is the vector of regression coefficients which are regime-independent.

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

$$f(m_t|S_t = j, I_{t-1}, \Theta) = \frac{|\Sigma_j^{-1/2}|}{(2\pi)^3} \exp\left(-\frac{\varepsilon_t' \Sigma_j^{-1} \varepsilon_t}{2}\right) \quad (20)$$

where  $\Theta = (p, q, \beta^s, \gamma, \kappa, \rho)$  and  $\Sigma_j = \rho_1 \xi_t^1 + \rho_2 \xi_t^2$ . Then the unconditional density of  $m_t$  is calculated by summing conditional densities over the two values of  $S_t$ :

$$f(m_t|I_{t-1}, \Theta) = \sum_{j=1}^2 P(S_t = j|I_{t-1}, \Theta) f(m_t|S_t = j, I_{t-1}, \Theta) \quad (21)$$

The maximum likelihood estimate of  $\Theta$  is obtained by maximizing the following log

likelihood function:

$$L(\Theta) = \sum_{t=1}^T \ln(f(m_t|I_{t-1}, \Theta)) \quad (22)$$

## 4 Data and Estimation Results

The data set used in this paper is from Livestock Marketing Information Center (LMIC), National Agricultural Statistics Service (NASS) and the Department of Labor. There are three fed-cattle markets — Kansas, Colorado and Texas, and one national market in the study. These three states are chosen because they are the most important markets in the U.S. fed-cattle producing regions. The beef prices are the weekly boxed-beef cutout values. These price series are then converted to regional margins by subtracting the regional fed-cattle price converted to a carcass equivalent (price/0.615) from the boxed-beef cutout values. To remove the impact of inflation, the margin values are deflated and the base year is 1995. The energy price index is from the producer price index for the meat-packing industry and the labor price is the average hourly production worker earnings for the meat-packing industry. The weekly slaughter, cattle placement and cattle on feed numbers used for Kansas, Texas and Colorado are from region 7, 6 and 8 respectively. And those for the national market are the sum of the corresponding values in regions 5, 6, 7 and 8. The corn price for Kansas is the Nebraska corn price, and the corn price for Texas and Colorado is the Texas corn price. Because our economic model requires a relatively stable market structure, our study period is from January, 1993 to January, 2001, when concentration level was high and meanwhile the four-firm concentration ratio in terms of steer and heifer slaughter was relatively stable. Before 1993, and since 2001, a lot of mergers and acquisitions occurred in the beef-packing industry, which violated the assumption of stable market structure in the economic model.

We estimate the weekly marketing model in equation (18) using GLS and the results are reported in Table I. The amount of slaughter in the week before has a significantly positive effect on this week's slaughter in all four markets. The cattle on feed last month in the corresponding region has a significantly positive effect on the slaughter amount each week in Texas, Colorado and the national markets. Cattle placements and corn price have no impact on the weekly numbers of slaughtering. We then estimate the Markov-Switching

model of equation (17) using MSVARlib developed by Bellone (2005). We let state 1 be the competitive state and state 2 be the cooperative state. A possible outcome that might have been expected as a prior would associate the states  $s_t = 1$  and 2 with margin drop and margin growth due to the unknown factors in the regional fed-cattle markets. Applying Hamilton's (1989) algorithms of filtering and smoothing to margin changes in three regional fed cattle markets and the national market, numerical maximization of the conditional log likelihood function led to the maximum likelihood estimates reported in Tables II and III. Specifically, the MLE of the regime-independent parameters are shown in Table II and the MLE of the regime-dependent parameters are shown in Table III. Using the Jarque and Bera test, the normality hypothesis of the residuals cannot be rejected for all three regional models and the national model.

In Kansas,  $\text{prob}(S_t=1|S_{t-1}=1) = 0.958$  and  $\text{prob}(S_t=2|S_{t-1}=2) = 0.944$ . This shows that the beef packers will cooperate in the current period with a possibility of 94.4%, if they cooperate in the previous period and with a 95.8% chance they will not cooperate now if they compete in the previous period.

In Texas, the beef packers will cooperate in the current period with a possibility of 96.6%, if they cooperate in the previous period and with a 92.6% chance they will not cooperate in the current period if they compete in the previous period.

In Colorado, the beef packers will cooperate in the current period with a possibility of 93.3%, if they cooperate in the previous period and with a 97.5% chance they do not cooperate now if they compete in the previous period.

In the national market, the beef packers will cooperate in the current period with a probability of 94.1%, if they cooperate in the previous period and with a 96.3% chance they will not cooperate now if they compete in the previous period.

The estimation results show that the beef packers in these four markets are consistent in their cooperative/competitive behavior. In Kansas, Colorado and the national market, with a probability of 96 - 97%, beef packers will compete based on the fact that they compete one period before, and with a probability of 93-94%, beef packers will cooperate conditional on their cooperation in the previous period. Texas is a little different, the conditional probability of competition is lower, while the conditional probability of cooperation is higher comparing

with the other regions.

From the MLE results in Table III, we find that  $\beta^s$  parameters in all markets are positive in both competitive and cooperative regimes. In addition,  $\beta^s$  in the cooperate regime is larger than that in the competitive regime. This infers that the average conjecture across the firms indicated by parameter  $\beta$  in equation (16) is between 0 and 1. These empirical results are consistent with the theoretical expectations. The expansion of market-ready inventories results in the increase of the beef packers' margin, and vice versa. In the cooperative regime, because of the conjectures by the packers, i.e.,  $0 < \beta < 1$ , the impact of market-ready inventory variation on the packers' margin is even bigger in size.

From the maximum likelihood parameters, we also calculate the expected durations of cooperation and competition. Conditional on being either in cooperative state or competitive state, the expected durations <sup>1</sup> are given by:

$$\sum_{\lambda=1}^{\infty} \lambda p^{\lambda-1} (1-p) = (1-p)^{-1} \quad (23)$$

$$\sum_{\lambda=1}^{\infty} \lambda q^{\lambda-1} (1-q) = (1-q)^{-1} \quad (24)$$

The results are shown in Table IV. The expected durations of cooperation are 17.86 weeks, 29.41 weeks, 14.93 weeks and 16.95 weeks for Kansas, Texas, Colorado and the national market respectively. The expected durations of competition are 23.81 weeks, 13.51 weeks, 40 weeks and 27.03 weeks for Kansas, Texas, Colorado and the national market respectively. In Kansas and the national market, the expected duration of cooperation is approximately 2/3 of the expected duration of competition. In Colorado, the cooperation time is about 1/3 of the competition time. While in Texas, the cooperation duration is about one-half more than the competition time.

Using Hamilton's (1989) filter techniques, the inferred probabilities that the beef packers in the three regional markets and the national market are in the competitive state ( $S_t = 1$ ) and the cooperative state ( $S_t = 2$ ) at time  $t$  based on the available information at that

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<sup>1</sup>Detailed calculation is in Hamilton's 1989 paper.

time  $P[S_t=1|\varepsilon_t, \varepsilon_{t-1}, \dots]$  are calculated. The results are reported in Figures 1 to 4. Following Hamilton, our decision rule is that beef packers are in the cooperative regime when  $P[S_t = 2] > 0.5$ , and they are in the competitive regime when  $P[S_t = 1] > 0.5$ , because the algorithm we use can reach a fairly strong conclusion about which regime beef packers are in.

The beginning and ending time of the inferred cooperative regime in the four markets are identified in Table V. In Kansas, beef packers tacitly cooperate for 7 months in 1993, 4 months in 1994, 5 months in 1995, 2 months in 1996, 9 months in 1997, 6 months in 1999 and 7 months in 2000. The total time of cooperation accounts for 42.9% of the 8 years. In Texas, beef packers tacitly cooperate approximately 68.5% of the 8 years in study. They cooperate for the whole year of 1993, 9 months in 1994, 7 months in 1995, 3 months in 1996, 1 month in 1997, 4 months in 1998, 11 months in 1999, and 10 months in 2000. In Colorado, beef packers tacitly cooperate 27.2% of the 8 years examined. They cooperate for 4 months in 1994, 7 months in 1996, 11 months in 1998, and 1 month in 1999. In the national market, beef packers tacitly cooperate about 38.5% of the 8 years and compete in the rest of the time. They cooperate for 6 months in 1993, 3 months in 1994, 3 months in 1995, 3 months in 1996, 11 months in 1997, 6 months in 1999 and 6 months in 2000.

## 5 Conclusion

In this paper, we apply the GP model using Hamilton's Markov-Regime-Switching technique to the U.S. beef-packing industry. The weekly margin between boxed-beef and fed-cattle prices is modeled and the unobserved cooperative/competitive conduct among beef packers in the four fed-cattle markets is analyzed. The results at the regional markets suggest varied levels of cooperative and competitive regimes exist in the years examined. Based on the regime type in the previous period, in Texas, beef packers have a higher conditional probability of cooperation than competition. While in Kansas, Colorado and the national market, the conditional probability of cooperation is lower than that of competition. The inference of probability of beef packers being in the two regimes is calculated. We find that the fed-cattle market in Texas is in cooperation for more than one-half of the time during the eight years in study, while the fed cattle markets in Kansas, Colorado and the



national market are in a competitive state for about one-third of the study years and in a noncooperative state for the remainder. Market power appears to have been exercised in the fed-cattle procurement from the early 1990s to the early 2000s, but the conduct varies across regions. Future research will focus on modifying the main factors that explain the margin variability of beef packers, and on including higher-order Markov processes in the multivariate regime switching.

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**Table I: GLS Estimates of Weekly Marketing Model**

	Kansas	Texas	Colorado	U.S.
Cons.	9.043 (1.119)	5.377 (0.529)	1.054 (0.239)	14.697 (2.031)
$rw_{t-1}$	0.766 (0.023)	0.595 (0.029)	0.813 (0.022)	0.797 (0.022)
$D_2$	-0.830 (0.318)	-0.538 (0.165)	-0.149 (0.102)	-1.765 (0.551)
$D_3$	-0.758 (0.323)	-0.026 (0.207)	-0.101 (0.128)	-1.107 (0.717)
$D_4$	0.436 (0.349)	0.199 (0.236)	0.069 (0.128)	0.830 (0.822)
$D_5$	1.749 (0.352)	1.149 (0.198)	0.319 (0.096)	3.105 (0.654)
$D_6$	1.142 (0.376)	0.481 (0.183)	0.297 (0.108)	1.994 (0.689)
$D_7$	0.349 (0.353)	0.691 (0.179)	-0.004 (0.102)	0.350 (0.648)
$D_8$	1.191 (0.342)	0.166 (0.199)	0.222 (0.113)	1.883 (0.638)
$D_9$	0.250 (0.364)	-0.125 (0.199)	0.102 (0.110)	0.268 (0.656)
$D_{10}$	0.011 (0.335)	-0.352 (0.212)	0.014 (0.113)	-0.176 (0.656)
$D_{11}$	-0.107 (0.356)	-0.629 (0.1249)	-0.002 (0.105)	0.008 (0.665)
$D_{12}$	-1.407 (0.343)	-0.731 (0.168)	-0.351 (0.096)	-2.327 (0.544)
$plc_{lag4m}$	0.002 (0.001)	0.0008 (0.0005)	0.0009 (0.0006)	0.0007 (0.0007)
$plc_{lag5m}$	0.001 (0.001)	0.0002 (0.0006)	-0.0005 (0.0006)	0.0003 (0.0008)
$plc_{lag6m}$	0.0003 (0.001)	0.0007 (0.0005)	-0.0003 (0.0005)	0.0001 (0.0006)
$cof_{lag1m}$	0.0003 (0.0004)	0.0003 (0.0001)	0.0007 (0.0002)	0.0002 (0.0001)
corn	-0.072 (0.106)	-0.008 (0.056)	-0.015 (0.030)	0.033 (0.190)

Asymptotic standard errors are in parentheses.

**Table II: Maximum Likelihood Estimates of Regime Independent Parameters**

	Kansas	Texas	Colorado	U.S.
p	0.958 (0.022)	0.926 (0.045)	0.975 (0.031)	0.963 (0.019)
q	0.944 (0.027)	0.966 (0.018)	0.933 (0.043)	0.941 (0.028)
$\gamma_1$	-0.410 (1.235)	-0.534 (0.492)	-0.257 (0.441)	-0.368 (0.503)
$\gamma_2$	-0.465 (2.191)	-0.693 (0.888)	-0.242 (0.816)	-0.392 (0.885)
$\gamma_3$	0.515 (2.277)	0.743 (0.926)	0.285 (0.830)	0.434 (0.936)
$\gamma_4$	0.145 (1.475)	-0.167 (0.742)	0.612 (2.574)	0.890 (0.459)
$\gamma_5$	0.669 (2.034)	-0.031 (0.340)	-0.320 (6.152)	-0.591 (0.764)
Log Likelihood	-575.84	-571.21	-574.81	-582.57

Asymptotic standard errors are in parentheses.

**Table III: Maximum Likelihood Estimates of Regime Dependent Parameters**

	Competitive Regime ( $S_t = 1$ )			Cooperative Regime ( $S_t = 2$ )		
	$\beta^s$	$\kappa_1$	$\rho_1$	$\beta^s$	$\kappa_2$	$\rho_2$
Kansas	0.018 (0.615)	-0.714 (3.381)	1.367 (0.172)	0.024 (0.197)	-0.741 (3.403)	0.453 (0.087)
Texas	0.003 (0.063)	0.396 (0.502)	1.781 (0.335)	0.009 (0.083)	0.101 (0.441)	0.603 (0.071)
Colorado	0.012 (0.425)	-0.288 (8.744)	0.652 (0.142)	0.033 (0.897)	-0.421 (8.375)	1.863 (0.837)
U.S.	0.007 (0.117)	-0.298 (0.746)	1.324 (0.153)	0.010 (0.059)	-0.189 (0.728)	0.431 (0.081)

Asymptotic standard errors are in parentheses.

**Table IV: Expected Duration of Cooperation and Non-Cooperation in weeks**

Region	Expected duration of cooperation	Expected duration of non-cooperation
Kansas	17.86	23.81
Texas	29.41	13.51
Colorado	14.93	40.00
U.S.	16.95	27.03

**Table V: Inferred Cooperative Regime**

Kansas		Texas		Colorado		U.S.	
<u>Begin</u>	<u>End</u>	<u>Begin</u>	<u>End</u>	<u>Begin</u>	<u>End</u>	<u>Begin</u>	<u>End</u>
1993: Jan.	1993: Apr.	1993: Jan.	1994: Apr.	1994: May	1994: Aug.	1993: Jan.	1993: Mar.
1993: Oct.	1994: Mar.	1994: Aug.	1995: Jan.	1996: Mar.	1996: June	1993: Oct.	1994: Feb.
1994: Dec.	1995: Feb.	1995: July	1996: Mar.	1996: Oct.	1996: Dec.	1994: Dec.	1995: Jan.
1995: Oct.	1996: Feb.	1997: Jan.	1998: Jan.	1998: Feb.	1999: Jan.	1995: Nov.	1996: Mar.
1997: Mar.	1997: Nov.	1998: Apr.	1998: June			1997: Feb.	1997: Dec.
1999: Mar.	1999: Aug.	1999: Feb.	2000: Oct.			1999: Mar.	1999: Aug.
2000: Mar.	2000: Sept.					2000: Mar.	2000: Aug.

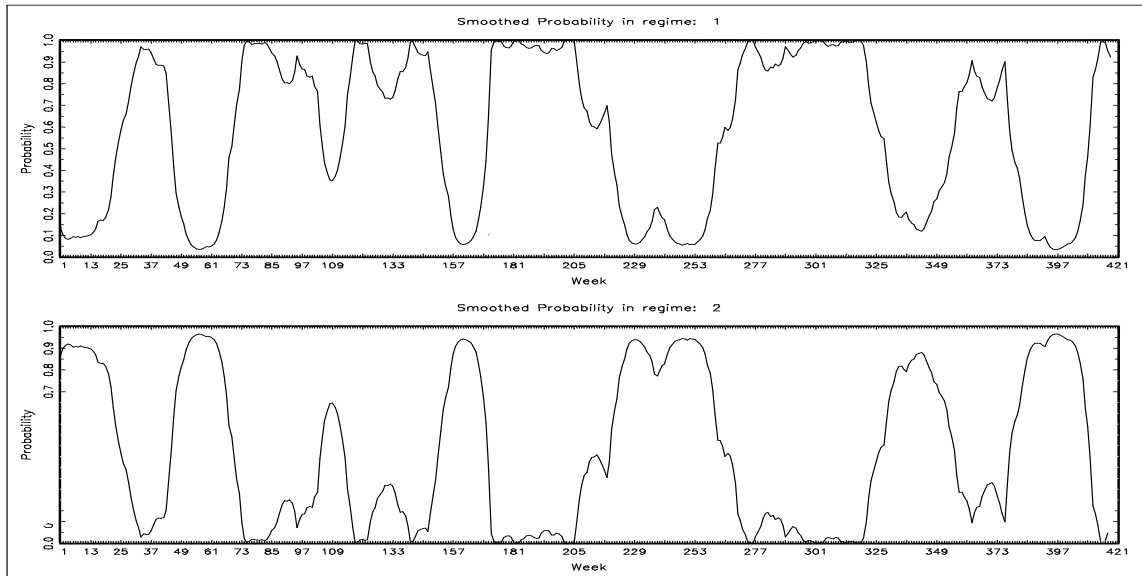


Figure 1: Kansas: Inferred probability that beef packers are in competitive and cooperative regimes

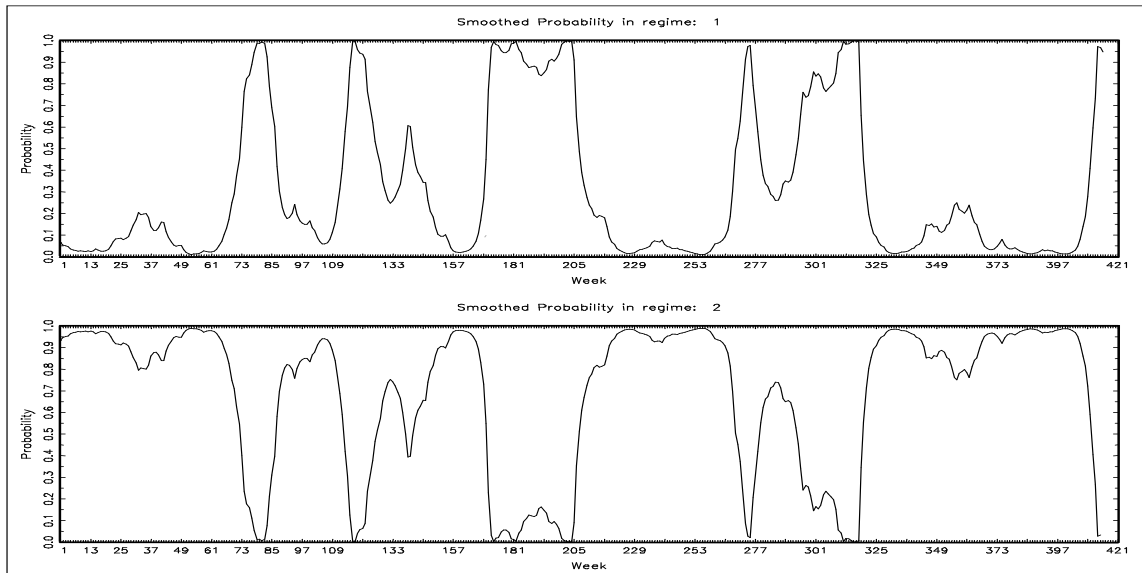


Figure 2: Texas: Inferred probability that beef packers are in competitive and cooperative regimes



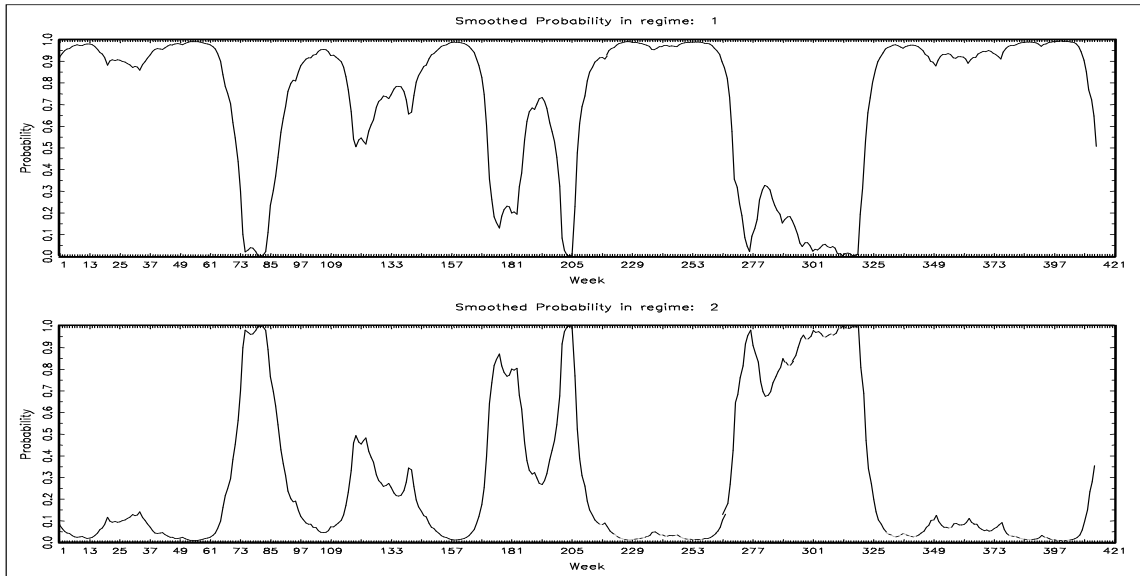


Figure 3: Colorado: Inferred probability that beef packers are in competitive and cooperative regimes

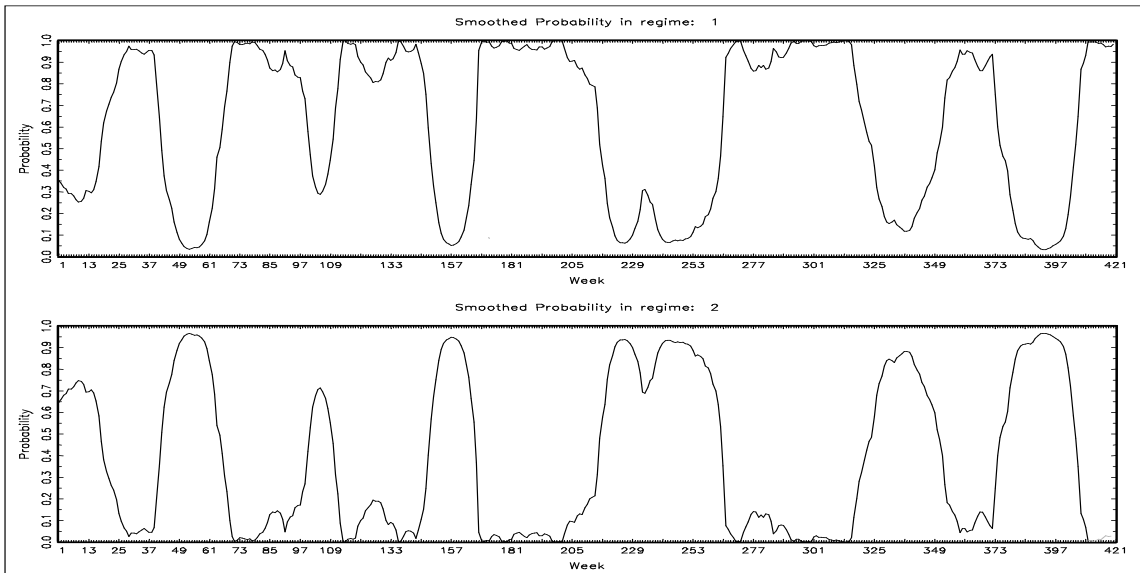


Figure 4: National Market: Inferred probability that beef packers are in competitive and cooperative regimes