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Impact of Captive Supply on Cash Price in the U.S. Cattle Procurement Market: A Dynamic Modeling Approach

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Keywords

Cash market, Captive supply, Kalman filter, Market conduct, Dynamic approach

Abstract

This paper examines the impact of captive market supply on cash market price in the U.S. cattle procurement market with consideration of dynamic interactions between captive and cash markets. Both conceptual and empirical analyses explore advantages of dynamic models over static models by focusing on the temporal change in the ratio of captive purchase to packers' total procurement and discount factor. Empirical models were estimated using the Kalman filter procedure with three alternative cost functions: generalized Leontief, translog, and quadratic functions. Dynamic estimation results found a statistically significant and negative relationship between captive market quantity and cash market prices from all functional forms of cost function. However, results of static models showed that the captive market quantity – cash market price relationship was sensitive to functional forms of cost function. Findings from our empirical analysis suggest that dynamic models could be more appropriate than static models in examining the impact of captive supply on cash price in the cattle procurement market.

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미국 육우시장의 선물거래 물량이 현물 가격 변동성에 미치는 영향 분석: 동적 모델링 접근

이정민*, 정찬진**

Keywords

현물시장(Cash Market), 선물거래 물량(Captive Supply), 칼만 필터(Kalman Filter), 동적 분석(Dynamic Approach)

Abstract

본 연구에서는 선물시장과 현물시장의 상호작용을 반영할 수 있는 동적분석 방법을 이용하여 미국내 육우시장에서 선물시장 거래물량이 현물시장 가격에 미치는 영향을 분석하였다. 개념 및 실증 분석 결과 시간에 따른 선물시장 구입비율과 할인율을 고려할 수 있는 동적분석 방법이 정적분석 방법보다 효과적인 것으로 파악되었으며, 추가로 민감성 검증을 위해 일반화된 레온티에프 소비함수, 트랜스로그 소비함수, 이차(Quadratic) 소비함수에 대해 칼만필터를 이용하여 실증분석을 시행하였다. 동적분석 결과 모든 소비함수 형태에서 선물시장 거래물량은 현금시장 가격에 유의한 부(−)의 영향을 미치는 결과가 도출되었다. 이에 반해 정적분석에서 선물시장 거래물량과 현금시장 가격 관계는 소비함수 형태에 따라 다양한 결과가 도출되었다. 종합적인 분석 결과 선물시장 거래물량이 현금시장 가격에 미치는 영향을 파악하기 위해서는 본 연구에서 제시한 동적분석 방법이 정적분석보다 적합한 것으로 나타났다.

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1. Introduction

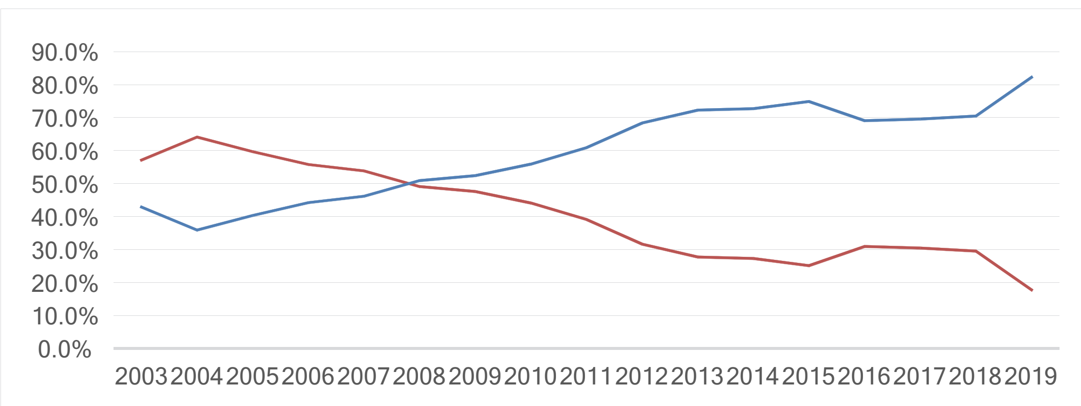
There are two major cattle purchase methods for beef processors to acquire cattle in the U.S. cattle market. One is cash market purchase, and the other is captive supply. The cash market supply is a traditional type of cattle purchase and represented a major part of the fed cattle market over past decades. The cattle buyer inspects cattle at feed-yard and suggests price bids with negotiation based on a live weight basis. Procured cattle are usually delivered to processor plant within one week of purchase contracts. Captive supply includes forward contracts, marketing agreements, and packer-feeding (Schoreter and Azzam 2003). Cash market purchases include auction sales, sales through dealers and brokers, and direct trade through negotiation between a producer and a packer. Forward contract agreement is a way for producers and packers to price cattle ahead of an expected sale date to reduce price risk. Many producers use a basis forward contracting, where packers provide basis bid at producers' requests. The producers decide when to price the cattle prior to delivery of cattle to the packer. Delivery timing is determined by the agreement between packer and producer. Cattle quality is specified in the contract, and premiums and discounts are determined based on the specification after delivery. For the marketing agreements, a feeder and a packer agree on a specified number of cattle for some specified time period, and price is typically determined as a base price plus premiums and discounts calculated based on cattle quality. Packer-feeding cattle typically transferred to the packing plant directly from a packer-owned feedlot when cattle need to be harvested.

Recently as the proportion of captive cattle supplies greatly increased from 42.9% in 2003 to 82.2% in 2019 in the U.S. cattle procurement market (USDA-GIPSA), many researchers and cattle producers have been concerned about the impact of captive supplies on fed cattle prices, particularly, cash prices. For many years, cattle producers have argued that packers' captive cattle supply harms the fed cattle industry by reducing cash prices. They claim that as beef packers procure increased proportion of cattle from the captive supply market, their cattle demand from the cash market decreases and as a result, the cash price decreases. In other words, beef packers use captive supply as a tool to lower cash price and as a result, cattle producer's profit is decreased. This problem has intensified as the captive supply ratio increases (Zhang and Sexton 2000; Crespi, Saitone and Sexton 2012). As the cash price is used as the basis for captive supply market prices under the current price discovery system, the lower cash price would lead to lower overall cattle price, and the cash market will be further shrunk and thinned. The cash market is already thin, and in some regions, the cash trade is less than 10 percent, which is not significant enough to provide an accurate base price for fed cattle.

The Cattle Price Discovery and Transparency Act recently proposed by the U.S. Congress also recognizes the importance of studying the impact of captive supply on cash prices. The proposed Act requires packers to establish minimum levels of fed cattle purchases through approved pricing mechanisms such as cash market and would penalize any large packer (i.e. any packer that has slaughtered five percent or more of cattle nationally in the past five years) that did not abide (Henderson 2022). The purpose of the Act is, in general, to limit large packers' potential market power exertion through the captive market, which can lower overall fed cattle prices.

The interaction between captive and cash markets can be represented by the ratio of captive market purchase to total procurement. Figure 1 shows change in ratios of captive supply and cash market purchase from 2003 to 2019. The ratio of captive market purchase increased year by year, while the ratio of cash market purchase continuously decreased. Specifically, the ratio of captive supply increased from 42.9% in 2003 to 82.2%, while the corresponding cash market supply decreased from 58.1% to 17.8% in 2019.

Figure 1. Ratio of Captive and Cash Market Purchases



Source: National Direct Slaughter Cattle Reports. USDA.

Prior studies suggest that when the extent of reduced demand in cash market is greater than supply decrease, the cash price decreases (Azzam 1998; Love and Burton 1999; Schroeter and Azzam 1999; Zhang and Sexton 2000). Other studies claim that the relationship between captive supply and cash prices should be neutral, as curtailed packer demand in cash market keeps in balance with its diminished supply (U.S. General Accounting Office 1987; USDA-AMS 1996). For example, a USDA report states that "If 20% of the demand of fed cattle is removed, so is 20% of the supply, then, the net effect on the market is zero" (USDA-AMS 1996, p.30). Overall, the relationship between captive supply and cash market prices has not been clearly determined in the literature.[1]

Many previous studies in the literature might have reached the inconclusive ambiguous results because the results are mostly based on static models that do not consider dynamic interactions between captive and cash supplies. However, in reality, beef packers are likely to determine their cattle procurement quantity from captive market first and then fill their need from cash market. Therefore, the cattle procurement from cash market is likely to be affected by the choice of captive market quantity. This dynamic process should be repeated consecutively, which is very similar to 'repeated game' in dynamic analysis. Therefore, so-called "new empirical industrial organization (NEIO)" static framework used in earlier studies is not appropriate to simulate dynamic interactions between beef processors and rival firm's reaction to each other's quantity or price strategies (Dockner 1992).

Corts (1999) points out that if firm's optimization process has dynamics, estimates of market power parameters are sensitive to discount factor and persistency of demand. Therefore, a static model is useful only if firms can modify their strategies instantaneously. However, firms cannot change input quantities that they process rapidly without cost and therefore need large modification costs for their inventory, capital input, and production (Karp and Perloff 1993a, 1993b; Slade 1995). Demand and supply shifts caused by captive supply are not explicit in static models as interactions between captive and cash markets continue through multi-periods. Therefore, the static model is difficult to capture shifts of demand and supply in cash market induced by captive supply change (Azzam 1998; Katchova, Sheldon and Miranda 2005; Kutu and Sickles 2012).

Among three ways of captive supply, i.e., marketing agreement, forward contract, and

[1] Findings from previous studies are summarized in Appendix A.

packer-owned cattle, in 2019 (Livestock Monitor of LMIC), marketing agreement and forward contract have reached 74.9% and 7.3% of packers' total captive supply procurement. The cattle price from marketing agreements is calculated by base price plus premium or discount from yield grade, quality grade and carcass weight range. The base price is decided by cash market price paid the week before delivery of the cattle procured from marketing agreement. Cattle delivery takes usually one week. However, it can take more days than one week in some cases.[2] Therefore, the cattle price from marketing agreement can be tied up to one- or two-week prior cash market price. In case of forward contract supply, delivery of exact cattle heads in the designated month is determined with a specified price ahead of an expected sale date. The forward contract allows packers (buyers) to reduce price risk by locking in a price ahead of the expected sale date (Ward, Koontz and Schroeder 1996).

Our study estimates the impact of captive supply on cash price in the U.S. cattle procurement market using a dynamic modelling approach. First, a conceptual illustration is provided to show that captive supply could either negatively or positively affect cash prices depending upon the discount factor and the proportion of packers' beef procurement through captive supply market. Then, an empirical dynamic model is developed to incorporate multi-period interactions between captive and cash market supplies and is estimated using the Kalman filter estimation procedure.

In the next section, we provide a brief literature review on the relationship between captive supply and cash prices in the U.S. beef industry. The following section provides conceptual discussions on the importance of using dynamic models for the analysis of the impact of captive supply and cash prices. Then, development of empirical models and estimation results are discussed. The final section presents a brief summary of findings and conclusions of this study.

2. Literature Review and Data

There are a limited number of studies in the literature that discuss the impact of captive supply on cash prices in the U.S. cattle procurement market. A few studies find a negative

[2] The average delivery date is 6.98 and the standard deviation is 3.28 (Schroeter and Azzam 2004).

relationship between captive supply and cash prices, but no causal link is examined in these studies (Hayenga and O'Brien 1990, 1991; Elam 1992; Schroeder et al. 1993). Azzam (1998) uses an equilibrium displacement model and finds that captive supply causes a negative effect on cash market price. Love and Burton (1999) argue that a superior downstream firm has an incentive to integrate upstream firms to increase the efficiency of its procurement market, which could affect the open market price. Burton's study points out that the open market price can increase or decrease depending on the effect of integration on the supply elasticity of cattle. Zhang and Sexton (2000) consider high transportation cost as an important key factor in the cattle procurement market and conduct a spatial analysis using a non-cooperative game approach. The study suggests that the captive supply provides geographic buffers that reduce competition among packers but is less effective in reducing packers' competition in markets where the spatial dimension is less important.

Some studies suggest a neutral relationship between captive supply and cash prices, but causal link is not analyzed in these studies (e.g., U.S. General Accounting Office 1987; USDA-AMS 1996). The other studies show incoherent relationship depending on type of captive procurement (Ward, Koontz and Schroeder 1998; Schroeter and Azzam 2004) or model form (Wohlgenant 2013). Ward, Koontz and Schroeder (1998) examine the interdependent nature between pre-committed captive supplies and fed cattle prices from the cash market and find a negative relationship with marketing agreement and packer-fed, on the other side, a positive relation with forward contract. Schroeter and Azzam (2004) claim that the delivery timing incentive is a crucial point in explaining the captive supply-cash price relationship, and also find a negative relationship between quantities of captive deliveries and cash market prices using marketing agreement. However, their model shows an insignificant relationship if the forward market contract is considered.

Most previous studies on captive supplies in the beef packing industry have employed either the structure-conduct-performance paradigm or various econometric structural models associated with the NEIO. Both approaches have faced challenges representing dynamic interactions between captive supplies and cash prices. The empirical findings about impacts of captive supplies on cash prices are not consistent in the literature.

Weekly cattle procurement price and quantity from captive and cash markets and wholesale beef price are obtained from the Livestock Marketing Information Center from the 1st week of 2003 to 52nd week of 2019 (Livestock Monitor of LMIC). Descriptive statistics of key variables are reported in Table 1. The average cattle procurement from captive supply market per week is 170 million lbs. and has 59.4% of total cattle procurement. The average cash market procurement is 117 million pounds, which is 40.6% of total cattle procurement for the study. Average cattle prices of captive and cash markets are $173.2/cwt and $172.2/cwt, respectively. Average wholesale beef price is $180.8/cwt.

Table 1. Descriptive Statistics of Key Variables

	Unit	Mean	St.Dev	Maximum	Minimum
Captive Supply Procurement	1,000lbs	170,431	45,207	293,100	21,417
Cash Market Procurement	1,000lbs	116,664	47,727	265,239	26,682
Captive Supply Price	$/cwt	173.2	36.2	266.9	114.7
Cash Market Price	$/cwt	172.2	36.6	270.8	117.3
Wholesale Beef Price	$/cwt	180.8	36.5	263.2	121.7

3. Conceptual Discussion

An analytical illustration is provided in this section to demonstrate the importance of considering dynamic interactions between captive and cash markets. The illustration focuses on the role of dynamic factors such as expectations of discount factor and the ratio of captive market purchase to total cattle purchase. The captive supply ratio has increased over time, while cattle procurement from cash market has been increasingly affected by the expanded captive market. The interaction between captive and cash markets, represented by the ratio of captive purchase, is an important component of repeated games over time in the dynamic model. In addition, the firm's decision-making process for the multi-period is represented by a packer's maximization problem of the current and discounted expected future profit for each period.

Our conceptual framework draws on Allaz and Vila (1993) and Adilov (2010). For the purpose of illustration, only two period models are constructed in this study to analyze the interactions between captive and cash markets.[3] It is assumed that all processors can

[3] Our conceptual illustration here is limited to periods of t and $t+1$. However, the empirical model is constructed

participate in captive market, but processors buy only a proportion of their cattle procurement from the captive supply market. In this framework, change in a beef processor's captive supply affects a rival processor's strategy in cash market depending upon the ratio of captive market purchase (r) out of total cattle procurement and discount factor (δ).

Suppose that a closed form of demand function at time t is $Q_t = a - P_t$ ($a > 0$) and a is intercept of demand function. Here, for simplification, a linear demand function is assumed following Allaz and Villa (1993) and Adilov (2010).

A processor purchases only proportion (r) of its cattle procurement from the captive market. Then the captive market demand is given by:

$$Q_{cap,\,t} = r(a - P_{cap,\,t}) \quad (1)$$

where $Q_{cap,t}$ and $P_{cap,t}$ are quantity-demanded and price in captive supply market at week t, respectively.

Then, the inverse residual demand function in cash market is:

$$P_{cash,t} = a - Q_{cash,t} - r(a - P_{cap,t}) \quad (2)$$

where $Q_{cash,t}$ and $P_{cash,t}$ are quantity-demanded and price in cash market at week t.

The marketing agreement price is used as captive market price because the cattle purchase quantity through marketing agreement is almost 90% of captive market. The base price of marketing management is decided by cash market prices paid the week before the delivery of the cattle procured in marketing agreement. In most cases, the delivery takes usually one week for marketing agreement.[4)]

Therefore, the captive market price ($P_{cap,t}$) usually ties with the previous week's cash market price and we assume $P_{cap,t+1} = P_{cash,t}$ for simplicity (Schroeter and Azzam 2004). It is also assumed that the processor incurs only fixed cost (c_t) with zero marginal cost following Adilov (2010). Then, the processor decides captive and cash supplies in current period t maximize its discounted stream of profit in the optimization problem. In this case, the profit function of processor i at week t is:

$$\pi_t^i = Max\left(P_t^{beef} - P_{cap,t}\right)\cdot q_{cap,t}^i + \left(P_t^{beef} - P_{cash,t}\right)\cdot q_{cash,t}^i - c_t + \delta\pi_{t+1}^i, \quad (3)$$

as a recursive model.

4) The average delivery date is 6.98 and the standard deviation is 3.28 (Schroeter and Azzam 2004).

$$s.t.\, P_{cash,t} = a - Q_{cash,t} - r(a - P_{cap,t}) \text{ and } P_{cap,t} + 1 = P_{cash,t},$$

where P_t^{beef} is beef price received by the processor, δ is discount factor, $0 \leq \delta \leq 1$, $q_{cap,t}^i$ is processor i's cattle procurement quantity from captive market at time t, $q_{cash,t}^i$ is cattle procurement quantity from cash market, and c_t is fixed cost of processor i at time t.

A two-step process is involved in solution formation. In step 1, beef processor i chooses captive market quantity ($q_{cap,t}^i$), and captive market price ($P_{cap,t}$) is determined. In step 2, the beef processor chooses its cash market quantity ($q_{cash,t}^i$), and cash market price ($P_{cash,t}$), and as a result, the processor's profit is also determined.

Profit maximizing prices of captive and cash markets can be derived from the first order condition of equation (3). Then, assuming the steady state price solution, i.e., $P_{cash,t}$ = $P_{cap,t}$ for all t, we obtain[5)]

$$P_{cash,t}^* = P_{cap,t}^* = \frac{a(r^2\beta - 2r\delta + r - 1) - 2P_t^{beef}}{r^2\delta - 2r\delta + r - 3}. \quad (4)$$

The corresponding demand quantities from captive and cash markets are:

$$Q_{cap} = \frac{2(P_t^{beef} - a)r}{r^2\delta - 2r\delta + r - 3}, \quad (5)$$

$$Q_{cash} = \frac{2(P_t^{beef} - a)(1-r)}{r^2\delta - 2r\delta + r - 3}. \quad (6)$$

When γ =0, equations (4) – (6) become the Cournot-Nash equilibrium solution without considering captive supply.

The cash price without considering captive market is equal to price under Cournot equilibrium (Adilov 2010) and can be labeled as $P_{cournot}$. Then, $P_{cournot}$ is derived from equation (4) by setting r=0 as follows:

$$P_{cournot} = \frac{1}{3}(a + 2P_t^{beef}). \quad (7)$$

To see the effect of packers' captive supply on the steady state cash price in the cattle procurement market, we calculate the price difference between the cash price, $P_{cash,t}$, of equation (4) and the price without considering captive supply, $P_{cournot}$ of equation (7), as

5) Detailed derivation is presented in Appendix B.

follows:

$$P_{cash,t} - P_{cournot} = \frac{2r\left(a - P_t^{beef}\right)\{1 + (r-2)\delta\}}{3\left(r^2\delta - 2r\delta + r - 3\right)}. \quad (8)$$

If the equation (8) is negative, we can conclude that there exists the price-reducing effect of captive supply on cash price, while the positive equation (8) would imply that captive supply increases cash price. Equation (8) shows that the sign of the equation is dictated by captive supply purchase ratio (r), discount factor (δ) and sign of $\alpha - P_t^{beef}$. Figures 2 and 3 show the sign of equation (8) as δ and r change under assumptions of $\alpha - P_t^{beef} > 0$ and $\alpha - P_t^{beef} < 0$.

Figure 2. Comparison of P_{cash} and $P_{cournot}$ as δ and r Change under $a - P_t^{beef} > 0$

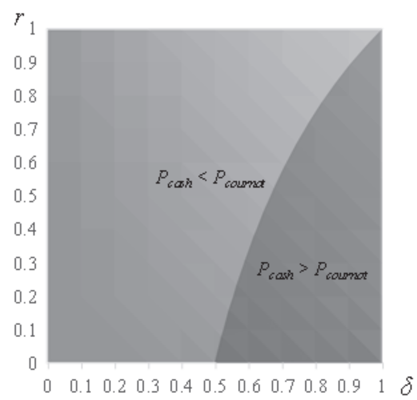
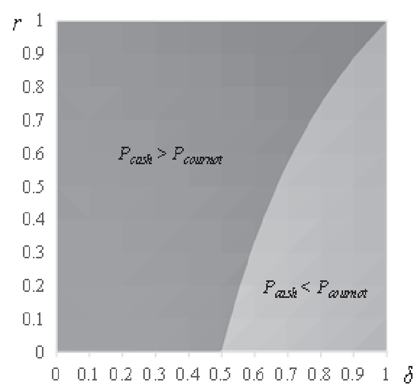


Figure 3. Comparison of P_{cash} and $P_{cournot}$ as δ and r Change under $a - P_t^{beef} < 0$



In Figure 2 under the assumption of $\alpha - P_t^{beef} > 0$, equation (8) is always negative when $0 \leq \delta \leq 0.5$ with the full range of r. However, when $0.5 < \delta \leq 1$, equation (8) becomes less likely to be negative as r increases. Figure 3 shows an opposite result due to the change in sign of $\alpha - P_t^{beef}$. Equation (8) and figures 2 and 3 clearly illustrate the possibility of the mixed results on the relationship between captive supply and cash price from previous studies. The illustration also indicates that static models may not be well suited to analyze the dynamic relationship between captive supply and cash price in the cattle procurement market.

Our study estimates a dynamic model consecutively to incorporate packers' changing behavior of optimization over time using the Kalman filter procedure (Kalman 1960). The Kalman filtering is an efficient recursive estimation procedure that combines a series of measurements using a joint probability distribution of the variables over time; adjusting and updating are done by comparing measurement values with predicted values (Rhudy, Salguero and Holappa 2017).

4. Derivation of Empirical Dynamic Model

A generalized Leontief cost function[6] of beef packing firm i for week t is written as:

$$c_i = q_t^i \sum_j \sum_k \beta_{j,k} (P_{j,t} P_{k,t})^{0.5}, \tag{9}$$

where $\beta_{j,k}$ represent parameters of cost function j, k=cap, $cash$ indicates captive and cash markets, q^i is processor i's total cattle procurement from captive and cash markets, i.e., $Q_t^i = q_{c,t}^i + q_{s,t}^i$. Then, a profit function of processor i at time t is given by:

$$\pi_t^i = P_t^{beef}\left(q_{cap,t}^i + q_{cash,t}^i\right) - P_{cap,t} q_{cap,t}^i - P_{cash,t} q_{cash,t}^i - q_t^i \sum_j \sum_k \beta_{j,k} (P_{j,t} P_{k,t})^{0.5}. \tag{10}$$

From the first order condition of maximizing equation (10) with respect to $q_{cap,t}^i$, we have:[7]

$$margin_{cap,t} = \theta_i \left(\eta_t \frac{P_{cap,t} q_{cap,t}^i}{Q_{cap,t}} + \lambda q_{cash,t}^i \right) - \left\{ \beta_{cap,cap} P_{cap,t} + 2\beta_{cap,cash} (P_{cap,t} P_{cash,t})^{0.5} + \beta_{cash,cash} P_{cash,t} \right\}, \tag{11}$$

where $margin_{c,t} = P_t^{beef} - P_{cap,,t}$ is packer i's margin from the captive supply market, $\frac{\partial Q_{cap,t}}{\partial q_{cap,t}^i} = \theta_i$ is packer i's market conduct parameter in the captive supply market,

6) The cost function used in this study is a simplified form of the generalized Leontief function.

7) The detailed derivation of equation (11) is presented in Appendix C.

$\frac{\partial P_{cap,t}}{\partial Q_{cap,t}} \frac{Q_{cap,t}}{P_{cap,t}} = \eta_t$ is the inverse price elasticity for captive supply, $\frac{\partial P_{cash,t}}{\partial Q_{cap,t}} = \frac{\partial P_{cash,t}}{\partial P_{cap,t}} \frac{\partial P_{cap,t}}{\partial Q_{cap,t}} = \lambda$ represents the relationship between captive supply and cash market price.

For an industry level analysis, equation (11) is summed over N firms and divided by N after imposing a symmetry assumption, $\theta^i = \theta$ (for all i), which gives us:

$$margin_{cap,t} = \frac{\theta}{N}(\eta P_{cap,t} + \lambda Q_{cash,t}) - \{\beta_{cap,cap} P_{cap,t} + 2\beta_{cap,cash}(P_{cap,t} P_{cash,t})^{0.5} + \beta_{cash,cash} P_{cash,t}\}. \tag{12}$$

Following Kutlu and Sickles (2012), we incorporate a dynamic parameter, μ_t^* in our empirical model. Assuming that the dynamic factor is linearly correlated with captive market shock ($ds_{cap,t}$) and cash market shock ($ds_{cash,t}$) leads to:

$$\mu_t^* = \mu_1 + \mu_2 ds_{cap,t} + \mu_3 ds_{cash,t}, \tag{13}$$

where captive and cash market shocks are defined as:

$$ds_{cap,t} = \frac{Q_{cap,t}}{Q_{cap,t+1}} - mean\left(\frac{Q_{cap,t}}{Q_{cap,t+1}}\right);\ ds_{cash,t} = \frac{Q_{cash,t}}{Q_{cash,t+1}} - mean\left(\frac{Q_{cash,t}}{Q_{cash,t+1}}\right).$$

Combining equations (12) and (13) gives:

$$margin_{cap,t} = \frac{\theta}{N}(\eta P_{cap,t} + \lambda Q_{cash,t}) - \{\beta_{cap,cap} P_{cap,t} + 2\beta_{cap,cash}(P_{cap,t} P_{cash,t})^{0.5} + \beta_{cash,cash} P_{cash,t}\} + \mu_t^*. \tag{14}$$

Equation (14) is similar to traditional NEIO models equation (12) except the dynamic parameter, μ_t^*. The processor plays a static game if μ_t^* is zero for each time period in the equation. However, in the dynamic setting with non-zero μ_t^*, processors can play repeated games consecutively, and λ is expected to be statistically significant as long as dynamic interactions exist between captive supply and cash price. Our study allows the varying nature of the relationship between captive supply and cash price, represented by λ over time. We construct the time-varying state, λ whose evolution is generated by AR(1) process following Kutlu and Sickles (2012). Then, observation equation (14) becomes as equation (15) and state equation is as (16):

$$\begin{aligned} margin_{cap,t} = {} & \tau P_{cap,t} - \alpha_t \frac{\theta_t}{N} Q_{cash,t} + \lambda_t \frac{\theta}{N} Q_{cash,t} - 2\beta_{cap,cash}(P_{cap,t} P_{cash,t})^{0.5} \\ & - \beta_{cash,cash} P_{cash,t} + \mu_1 + \mu_2 ds_{c,t} + \mu_3 ds_{s,t} + \epsilon_t \end{aligned} \tag{15}$$

$$\alpha_{t+1} = \rho \alpha_t + \nu_t \tag{16}$$

where $\tau = \eta \frac{\theta_t}{N} - \beta_{cap,cap}$, λ= E[λt], and α_t = λt-λ, ρ is a transition parameter, ε_t and ν_t are standard error terms with ε_tt ~N(0,1), ν_t ~N(0, 1).

In equation (15), $\lambda = \frac{\partial P_{cash,t}}{\partial Q_{cap,t}}$ reflects the relationship between captive supply and cash market price. If the captive market quantity increases and the cash price decreases, λ will have a negative sign. The negative and significant λ indicates that cash market price decreases as beef packers increase captive supply, which is consistent with our discussion in figures 2 and 3. If λ is positive and significant or λ is insignificant, the empirical result should be inconsistent with findings from figures 2 and 3. Equations (15) and (16) reflect a dynamic interaction between captive and cash markets.

Equations (15) and (16) are a measurement equation and a transition equation, respectively, and are estimated using a Kalman filter procedure. The Kalman filter procedure used in this study has a two-step calculation process of prediction and updating. In the prediction stage, estimates of parameters from (15) are calculated using given information from a based period. After $margin_{cap,t}$ is predicted from the prediction stage, the prediction error can be calculated by comparing the predicted value and observed values in the updating process. Then using the calculated prediction error, stated parameters in (15) are recursively modified. The Kalman filter procedure allows one to estimate the dynamic linear model specified in (15) and (16), which reflect the dynamic interaction between captive market volume at time t and cash market price at time $t+1$.

The static form of equation (15) without dynamic consideration is:

$$margin_{cap,t} = \tau P_{cap,t} + \lambda \frac{\theta}{N} Q_{cash,t} - 2\beta_{cap,cash}(P_{cap,t} P_{cash,t})^{0.5} - \beta_{cash,cash} P_{cash,t}. \quad (17)$$

Both dynamic and static equations, (15) and (16), are estimated for the purpose of comparison in this study. For a sensitivity analysis, we also estimate the models with two other functional forms of cost function: trans-log and quadratic cost functions.[8)]

8) Derivation of empirical models with trans-log and quadratic cost functions is presented in Appendix D and E.

5. Estimation Results

Equations (15) and (16) are estimated using the Kalman filter procedure. The Kalman filter model typically includes two component equations: 1) observation equation and 2) state transition equation. The relationship between Y_t and α_t is modeled in the observation equation, and the relationship between α_t and α_{t+1} is represented in the state transition model as:

$$Y_t = \alpha_t + \epsilon_t, \epsilon_t \sim (0, H), \tag{18}$$

$$\alpha_{t+1} = \alpha_t + u_t, u_t \sim N(0, Q);\ \alpha_1 \sim N(\alpha_1, P_1) \tag{19}$$

where ε_t and u_t are noise terms of observation equation and state equation and independent mutually, α_1 is initial state value and its mean and variance are a_1 and P_1.

Consider a_{t+1}=$E[\alpha_{t+1} | Y_t]$, which means that a_{t+1} is the prediction of α_{t+1} conditional on Y_t at time t and P_{t+1}=$var[\alpha_{t+1} \mid Y_t]$ is the conditional variance of α_{t+1}. The one step ahead forecast error, v_t is calculated as $v_t = y_t - a_t$ and its variance, var(v_t)=F_t is one of components to calculate the Kalman gain. Given a_t and P_t, a_{t+1} and P_{t+1} can be calculated as follows:

$$\alpha_{t+1} = \alpha_t + K_t v_t, \tag{20}$$

$$P_{t+1} = P_t(1 - K_t) + Q,. \tag{21}$$

where $K_t = P_t / F_t$ and defined as Kalman gain, Q is process noise covariance matrix. Then, α_t can be predicted by Y_{t-1}, and a_t (prediction value of α_t) can be updated by using additional information, Y_t with equations (18) and (19). The a_{t+1} (prediction value of α_{t+1}) has the same value with a_t at time $t(a_{t|t}$ = $E[\alpha_t \mid Y_t]$). Therefore, K_t term in the equation (19) is optimal weight between a_t and v_t. The new observation is more weighted if P_t (conditional variance of α_t) has larger value. In the same way, new observation is not reliable and has smaller weight if F_t (variance of forecasting error) has larger value. The P_t value can be updated by using equation (21) and identical logic can be applied in equation (21). The system parameters and initial values can be estimated by the maximum likelihood estimation method (Kutlu and Sickles 2012).

Three alternative cost functions, generalized Leontief, trans-log and quadratic cost functions are considered for sensitivity of model. Table 2 presents estimation results from static and dynamic models with three types of cost functions. The estimate of λ is negative and statistically significant at the 1% level from the dynamic model with all three types of cost functions. The statistically significant and negative value of λ indicates that the cash market price decreases as captive supply increases, which is consistent with findings from some of previous studies (Schroeder et al. 1993; Azzam 1998; Love and Burton 1999; Schroeter and Azzam 1999; Zhang and Sexton 2000; Schroeter and Azzam 2003; Schroeter and Azzam 2004; Wohlgenant 2013). The estimate of λ[9] ranges from -0.0007 to -0.0009, which implies that as captive market quantity increases by one thousand pounds, cash price decreases by $0.0007/cwt to $0.0009/cwt.

Table 2. Estimates from Dynamic and Static Models with Alternative Cost Functions

	Generalized Leontief Cost Function		Trans-log Cost Function		Quadratic Cost Function	
	Dynamic Model	Static Model	Dynamic Model	Static Model	Dynamic Model	Static Model
τ	0.6670***	3.5092***	-4.0700***	2.9211***	0.5260***	0.3883***
λ	-0.0007***	0.0002***	-0.0008***	-0.0003***	-0.0009***	-0.0007***
$\beta_{cap,cash}$	-0.4830	-2.2255***				
$\beta_{cash,cash}$	0.2810	2.6405***				
β_q			-4.4400*	6.7263***		
$\beta_{cap,q}$			1.5700**	0.4468***		
$\beta_{cash,q}$			-2.0900***	0.4913***	-0.1700	0.4318***
$\beta_{q,q}$			0.9710***	-0.8543***	0.0007***	0.0009***
μ_1	321.00***		240.00***		176.000***	
μ_2	-12.500*		-22.900***		-24.800***	
μ_3	35.000***		15.000***		16.000***	

Note: It is assumed that θ=0.1, N=20 for simplicity following Azzam (1997).
*, **, *** indicate significant at the 10%, 5% and 1% level.

Estimates of μ_2 and μ_3, from the dynamic parameter specification are all statistically significant at least at the 10% level, regardless of types of cost function. The statistically significant estimates of dynamic factors show the importance of using dynamic models over static models. Overall, estimates of λ from static models are also statistically significant at the 1% level. However, the static model with the generalized Leontief cost function estimates a positive coefficient for λ. Positive relations were also estimated by Hayenga and O'Brien (1990), Schroeder et al. (1993), and Ward, Koontz and Schroeder (1998).

[9] λ_t is a time varying parameter and λ is the mean of λ_t as indicated in equation (15) (λ = E[λ_t]).

The dynamic model found a negative relationship between captive market quantity and cash market prices regardless of different types of cost functions. However, results from static models show that the sign of λ estimate is sensitive to assumptions on the functional form of cost function. Findings from our empirical analysis indicate that dynamic models could be more appropriate than static models in examining the impact of captive supply on cash price in the cattle procurement market.

6. Conclusions

In this study, the impact of captive supply on cash price in the U.S. cattle procurement market is estimated using a dynamic modelling approach. First, the conceptual illustration showed how packers' price-reducing behavior through captive supply depended upon assumptions on dynamic factors such as expectations of discount factor and ratio of captive market purchase to cash market procurement. In this illustration, captive supply could either negatively or positively affect cash prices, depending upon the discount factor and the proportion of packers' beef procurement through captive supply market. Then, our study developed a dynamic model by incorporating multi-period interactions between captive and cash market supplies, while three different types of cost functions (generalized Leontief, trans-log, and quadratic cost function forms) were considered for a sensitivity analysis. Finally, both dynamic and static models were estimated for the purpose of comparison. The dynamic model was estimated using the Kalman filter procedure iteratively to address the dynamic interactions between captive and cash supplies.

Dynamic estimation results found a statistically significant and negative relationship between captive market quantity and cash market prices regardless of cost function types. However, results of static models showed that the captive market quantity - cash market price relationship was sensitive to assumptions on functional forms of cost function. Findings from our empirical analysis suggest that dynamic models could be more appropriate than static models in examining the impact of captive supply on cash price in the cattle procurement market.

Our findings provide important implications to the U.S. cattle market. First, cash price could be formed at a lower price than it is supposed to be as a majority of cattle procurement is obtained through AMA. In particular, this problem could harm small-scale farms more than large farms as it is difficult for small farms to meet the proper amount of supply for AMA. Second, overall cattle price received by farmers should decrease continuously as the cash price is used as the base price for AMA. This is because when the cash price decreases, the cattle price from AMA should also decrease. Lastly, if the current cash price continues to decline, cattle quantity traded in cash market is highly likely to decline as well. In 2019, the ratio of cash market purchases was only 17.8%. If this ratio continues to fall, the cash price can no longer be able to be used as the base price.

The Korean Ministry of Agriculture, Food and Rural Affairs has continuously supported large pork processors to increase efficiency of distribution of pork products. As a result, large pork processors had about 17% of market share in the Korean pork retail market in 2021. Establishing large processors has some advantages such as product standardization, reduction of price fluctuations, and securing distribution channels. However, if these large processors further extend their market share to the higher level, e.g., 80 to 90 percent, in the future, the high concentration of market share could affect the market negatively, which would hurt both consumers and producers as we can see in the U.S. beef market. As shown in this paper, large processors and packers could use their market power to lower producer prices of pigs and beef cattle, leading to lower producer profits. Market power exertion of large processors and packers could also increase pork and beef retail prices. Findings from our study could help one to better understand current problems caused by large packers in the U.S. and could also help establish a better Korean packer system.

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Appendix

A. Previous Studies on Relationship between Captive Supply and Spot Market Price

	Study	Data	Data Period	Industry	Relationship between captive supply and spot market price
1	Hayenga and O'Brien (1990)			Beef processing	P (Colorado) N (Texas)
2	Hayenga and O'Brien (1991)	Daily, State	1973-89	Beef processing	N (Kansas) I (Colorado, Texas, Nebraska)
3	Elam (1992)	Monthly, State	1988-91	Beef processing	N (national data, Kansas, Colorado) I (Nebraska, Texas)
4	Ward (1992)			Beef processing	I
5	Schroeder et al. (1993)	Transaction, Local	1990	Beef processing	N P (some packers and time periods)
6	Azzam (1998)			Beef processing	N
7	Ward, Koontz and Schroeder (1998)	Transaction, U.S.	1992-93	Beef processing	P (forward contract) N (marketing agreement and packer-fed)
8	Love and Burton (1999)			Beef processing	N
9	Schroeter and Azzam (1999)	Transaction, Regional	1995-96	Beef processing	N
10	Zhang and Sexton (2000)			Beef processing	N
11	Schroeter and Azzam (2003)	Transaction, Regional	1995-96	Beef processing	N (small magnitude)
12	Schroeter and Azzam (2004)	Transaction, Regional	1995-96	Beef processing	N (marketing agreement) I (forward contract)
13	Wohlgenant (2013)	Transaction, Weekly	2001-05	Pork processing	N I (reduced form model)

Note: P and N indicate positive and negative relationship, respectively, and I refers to statistically insignificant relationship.

B: Derivation of Equation (4)

$$\pi_t^i = \left(P_t^{beef} - P_{cap,t}\right) \cdot q_{cap,t}^i + \left(P_t^{beef} - P_{cash,t}\right) \cdot q_{cash,t}^i + \delta \pi_{t+1}^i \quad \text{(B- 1)}$$

The first order condition of equation (B-1) can be written as

$$\frac{\partial \pi_t^i}{\partial q_{cash,t}^i} = P_t^{beef} - a + 2q_{cash,t}^i + q_{cash,t}^{-i} + r\left(a - P_{cap,t}\right) + \delta \frac{\partial \pi_{t+1}^i}{\partial q_{cash,t}^i} = 0 \quad \text{(B- 2)}$$

The equation (B-2) is simplified as[10)]

$$P_t^{beef} - a + 2q_{cash,t}^i + q_{cash,t}^{-i} + r\left(a - P_{cap,t}\right) + \delta\left(q_{cap,t+1}^i + r \cdot q_{cash,t+1}^i\right) = 0 \quad \text{(B- 3)}$$

The other processor $-i$'s first order condition can be calculated in the same way

$$P_t^{beef} - a + q_{cash,t}^h + 2q_{cash,t}^{-h} + r\left(a - P_{cap,t}\right) + \delta\left(q_{cap,t+1}^{-i} + r \cdot q_{cash,t+1}^{-i}\right) = 0 \quad \text{(B- 4)}$$

The equation (B-3) with (B-4) is as follows:

$$\begin{aligned} &2\left(P_t^{beef} - a\right) + 3\left(q_{cash,t}^i + q_{cash,t}^{-i}\right) + 2r\left(a - P_{cap,t}\right) + \delta\left(q_{cap,t+1}^i + q_{cap,t+1}^{-i}\right) \\ &+ \delta r\left(q_{cash,t+1}^i + q_{cash,t+1}^{-i}\right) = 0 \end{aligned} \quad \text{(B- 5)}$$

The simple equation (B-5) is as follows[11)] under assumption that analysis is restricted to steady state price solution, i.e., $P_{cash,}t = P_{cap,t} = P$ for all t.

Then, assuming the steady state price solution, i.e., $P_{cash,t} = P_{cap,t}$ for all t, we obtain (6) as follows:

$$P_{cash,t}^* = P_{cap,t}^* = \frac{a\left(r^2\beta - 2r\delta + r - 1\right) - 2P_t^{beef}}{r^2\delta - 2\gamma\delta + r - 3}. \quad \text{(B- 6)}$$

C: Derivation Process of Equation (11)

The equation (11) is as follows:

$$\pi_t^i = P_t^{beef}\left(q_{cap,t}^i + q_{cash,t}^i\right) - P_{cap,t} q_{cap,t}^i - P_{cash,t} q_{cash,t}^i - q_t^i \sum_j \sum_k \beta_{j,k}\left(P_{j,t} P_{k,t}\right)^{0.5}. \quad \text{(C-1)}$$

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10) $\pi_{t+1}^i = \left(P_{t+1}^{beef} - P_{cap,t+1}\right) \cdot q_{cap,t+1}^i + \left(P_{t+1}^{beef} - P_{cash,t+1}\right) \cdot q_{cash,t+1}^i + \delta \pi_{t+2}^i$ and $P_{cash,t} = P_{cap,t}$ Then
$\frac{\partial \pi_{t+1}^i}{\partial q_{cash,t}^i} = \frac{\partial \pi_{t+1}^i}{\partial P_{cash,t}} \cdot \frac{\partial P_{cash,t}}{\partial q_{cash,t}^i} = q_{cap,t+1}^i + \delta \cdot q_{cash,t+1}^i$

11) $q_{cash,t}^i + q_{cash,t}^{-i} = Q_{cash,t} = a - P_{cash,t} - r\left(a - P_{cash,t}\right) = a - P - r(a - P)$,
$q_{cap,t+1}^i + q_{cap,t+1}^{-i} = Q_{cap,t+1} = r\left(a - P_{cap,t+1}\right) = r\left(a - P_{cash,t}\right) = r(a - P)$.

From the first order condition of maximizing equation (C-1) with respect to $q^i_{cap,t}$, we have:

$$\frac{\partial \pi^i_t}{\partial q^i_{cap,t}} = P^{beef}_t - \left(\frac{\partial P_{cap,t}}{\partial q^i_{cap,t}} q^i_{cap,t} + P_{cap,t}\right) - \left(\frac{\partial P_{cash,t}}{\partial q^i_{cap,t}} q^i_{cash,t}\right) + \left\{\beta_{cap,\,cap} P_{cap,t} + 2\beta_{cap,cash}\left(P_{cap,t}P_{cash,t}\right)^{0.5} + \beta_{cash,cash}P_{cash,t}\right\} = 0. \quad \text{(C-2)}$$

The equation (C-2) can be rewritten as (C-3):

$$P^{beef}_t - P_{cap,t} = \frac{\partial Q_{cap,t}}{\partial q^i_{cap,t}}\left(\frac{\partial P_{cap,t}}{\partial Q_{cap,t}} \frac{Q_{cap,t}}{P_{cap,t}} \frac{P_{cap,t}}{Q_{cap,t}} q^i_{cap,t} + \frac{\partial P_{cash,t}}{\partial P_{cap,t}} \frac{\partial P_{cap,t}}{\partial Q_{cap,t}} q^i_{cash,t}\right) - \left\{\beta_{cap,cap}P_{cap,t} + 2\beta_{cap,cash}\left(P_{cap,t}P_{cash,t}\right)^{0.5} + \beta_{cash,cash}P_{cash,t}\right\} \quad \text{(C-3)}$$

The equation (C-3) can be written as simple form as the equation below:

$$margin^i_{cap,t} = \theta\left(\eta \frac{P_{cap,t}}{Q_{cap,t}} q^i_{cap,t} + \lambda q^i_{cash,t}\right) - \left\{\beta_{cap,\,cap}P_{cap,t} + 2\beta_{cap,cash}\left(P_{cap,t}P_{cash,t}\right)^{0.5} + \beta_{cash,cash}P_{cash,t}\right\}, \quad \text{(C-4)}$$

where $margin^i_{cap,t} = P^{beef}_t - P_{cap,t}$, $\theta^i = \frac{\partial Q_{cap,t}}{\partial q^i_{cap,t}}$, $\eta = \frac{\partial P_{cap,t}}{\partial Q_{cap,t}} \frac{Q_{cap,t}}{P_{cap,t}}$, $\lambda = \frac{\partial P_{cash,t}}{\partial P_{cap,t}} \frac{\partial P_{cap,t}}{\partial Q_{cap,t}}$.

D: Trans-log Cost Function Approach

Trans-log cost function form is given as:

$$\log c_i = \beta_0 + \sum_{j=cap,cash} \beta_j \log P_{j,t} + \frac{1}{2} \sum_{j=cap,cash} \sum_{k=cap,cash} \beta_{jk} \log P_{j,t} \log P_{k,t} + \sum_{j=cap,cash}^{2} \beta_j \log q_i \log P_{j,t} + \beta_q \log q_i + \beta_{q,q}(\log q_i)^2, \quad \text{(D-1)}$$

where q^i is firm i's total cattle procurement.

The price equation with marginal cost function of (D-1) can be written as:

$$margin_{cap,t} = \frac{\theta}{N}\left(\beta_{cash}P_{cap,t} + \lambda Q_{cash,t}\right) - \frac{c}{Q_t}\left(\beta_q + \beta_{cap,q}\log P_{cap,t} + \beta_{cash,q}\log P_{cash,t} + 2\beta_{q,q}\log Q_t\right). \quad \text{(D-2)}$$

Then, the model is as follows:

$$margin_{cap,t} = \alpha_t \frac{\theta}{N} Q_{cash,t} + \tau P_{cap,t} + \frac{\theta}{N} \lambda_t Q_{cash,t}$$
$$+ \frac{c}{Q_t} (\beta_q + \beta_{cap,q} \log P_{cap,t} + \beta_{cash,q} \log P_{cash,t} + 2\beta_{q,q} \log Q) + \mu_t^*, \quad \text{(D-3)}$$

where $\tau = \frac{\theta}{N} \beta_{cash}$.

E: The Quadratic Cost Function Form

$$c_i = \sum_{\substack{j = cap, \\ cash}} \beta_j P_{j,t} + \beta_q q_i + \frac{1}{2} \left(\sum_{\substack{j = cap, \\ cash}} \sum_{\substack{k = cap, \\ cash}} \beta_{jk} P_{j,t} P_{k,t} + \beta_{qq} q_i^2 \right) + \sum_{\substack{j = cap, \\ cash}} \beta_{q,j} P_{j,t} q_i, \quad \text{(E-1)}$$

where q is firm i's total cattle procured in both captive and cash market, j, k is captive or cash market.

The price equation with marginal cost function of (E-1) can be written as:

$$margin_{cap,t} = \frac{\theta}{N} (\beta_{cash} P_{cap,t} + \lambda q_{cash,t}) + (\beta_{q,q} Q + \beta_{cap,q} P_{cap,t} + \beta_{cash,q} P_{cash,t}). \quad \text{(E-2)}$$

The dynamic model is as follows:

$$margin_{cap,t} = \alpha_t \frac{\theta}{N} q_{cash,t} + \tau P_{cap,t} + \frac{\theta}{N} \lambda_t q_{cash,t}$$
$$+ (\beta_{qq} q_r + \beta_{cap,q} P_{cap,t} + \beta_{cash,q} P_{cash,t}) + \mu_t^*, \quad \text{(E-3)}$$

where $\tau = \frac{\theta}{N} \beta_{cash}$.