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CAPTIVE SUPPLY IMPACT ON THE U.S. FED CATTLE PRICE: AN APPLICATION OF NONPARAMETRIC ANALYSIS*

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Abstract
Conventional regression technique is restrictive because it assumes a specific functional form for the model and the constancy of parameters. Nonparametric method, however, is flexible and supplementary to parametric analysis. In this study, impact of captive supply on the U.S. fed cattle cash market price is investigated via nonparametric analysis. Results indicate that the price effect of captive supply does not appear until its share reaches about 20% of the total cattle procurement. Beyond this point, the U.S. fed cattle price decreases approximately $0.20/cwt ~ $0.40/cwt for each percent increase in the captive supply share.

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I. Introduction

The U.S. fed cattle market is part of the beef supply chain where packers purchase fed cattle from cattle feeders, slaughter and process the cattle in their packing plants to produce the boxed (or wholesale) beef as the final product. Fed cattle represent a major input to the packer's production process, accounting for the bulk of the production costs. Packers in the U.S. procure fed cattle in two ways: through cash market transactions and the contract arrangement, the so-called captive supply. The Grain Inspection, Packers and Stockyards Administration (GIPSA) of the U.S. Department of Agriculture (2002, p. vi) defines the captive supply as the cattle owned or fed by a packer, procured through forward contracts and marketing agreements, and cattle that are otherwise committed to a packer more than 14 days prior to slaughter. Proponents argue that use of captive supply decreases transaction costs, reduce market risk, and enhance beef quality (Feuz et al., 2002). Opponents contend that it has adverse impact on fed cattle cash market prices, reduces market access by small cattle producers, and increases market power of packers (Conner *et al*., 2004). In particular, the potential impact of use of captive supply on fed cattle cash market price is a controversial issue for market participants and policymakers. In this study, the price impact of captive supply use is investigated via a nonparametric method.

Most econometric literature on the relationship between the use of captive supply and fed cattle cash price (e.g., Elam, 1992; Hayenga and O'Brien, 1992; Parcell, Schroeder, and Dhuyvetter, 1997; Ward, Koontz, and Schroeder, 1998 Schroeter and Azzam, 2003) utilize the parametric approach, which assumes a specific functional form between fed cattle cash price, captive supply, and other variables. However, the true functional form for the relationship among the variables is not known and assumption of a particular functional form may lead to biased estimation.

Nonparametric methods have attracted attentions from applied economists in the past few decades (see examples in Racine, 2008). Nonparametric methods are statistical techniques that do not require specification of a functional form for the relationship being estimated. Instead, the data itself informs the resulting model in a particular manner. In a regression framework, this approach is known as nonparametric regression or nonparametric smoothing

(Racine, 2008). Nonparametric regression relaxes the common assumption of linearity in the parametric approach and enables one to explore the data more flexibly, uncovering the structure in the data that might otherwise be missed by parametric approach[1]. As we expected, the results indicate that the price impact of captive supply is nonlinear and depends on the level of captive supply use.

This paper is organized as follows. The next section introduces the conceptual model for investigating the impact of captive supply on the fed cattle cash market price. Section III briefly describes the nonparametric estimation procedure. The data are described in section IV, and section V discusses results and concludes.

II. Conceptual Model

In this section, a stylized model of beef packer behavior based on Azzam (1998) and Schroeder *et al*. (1993) is developed to derive an empirical model to be estimated. Consider a beef packer who purchases v_{sp} units of fed cattle from spot (or cash) market at the price, p_{sp} and v_{cs} units through captive supply at the contract price, p_{cs}. Assuming perfect substitution between captive and cash market cattle, the share λ of captive supply in the total procurement is obtained by $\lambda = v_{cs}/(v_{cs} + v_{sp})$.

Based on the predetermined level of captive supply, the packer decides on the quantity of fed cattle to be procured from the spot market to maximize its profit as follows:

$$(1) \qquad \underset{v}{\text{Max}} \quad p_{box} \cdot f(v) - p_{sp}v_{sp} - p_{cs}v_{cs} - FC \, ,$$

where p_{box} is the boxed beef price or wholesale value of processed beef, which is the output price of the packer, f is the packer's production function, v is the number of the fed cattle and FC is the fixed cost. The fed cattle is the function of cattle from spot market and from the captive supply as

1 To authors' best knowledge, there is no study examining the price impact of captive supply using a nonparametric method.

(2) $v = g(v_{sp}, v_{cs})$,

where v_{sp} is the units of fed cattle from spot market and v_{cs} is the units fed cattle from captive supply. Note that v_{sp} and v_{cs} may or may not be perfect substitute. If v_{sp} and v_{cs} are perfect substitute $v = v_{sp} + v_{cs}$. Note that here v_{cs} is *fixed* when the packer decides the amount of v_{sp} to maximize the profit as in equation (1).

The first order condition to maximize equation (1) is:

(3) $$p_{box} \cdot \frac{\partial f(v_{sp} \mid v_{cs})}{\partial v_{sp}} - p_{sp} = 0 \ .$$

Equation (3) is solved for the derived input demand function for spot market fed cattle, conditional on the predetermined quantity of captive supply, $v_{sp}^{dmd} = v_{sp}^{dmd}(p_{sp}, p_{box} \mid v_{cs})$.

Assuming each packer *i* faces the same fed cattle spot market price and boxed beef price, the individual packers' spot market fed cattle demands can be aggregated to obtain the market demand, $V_{sp}^{dmd} = \sum_i v_{sp,i}^{dmd} = V_{sp}^{dmd}(p_{sp}, p_{box} \mid V_{cs})$, where i is the index of firms (packers) and $V_{cs} = \sum_i v_{cs,i}$.

Let the market supply of fed cattle be $V_{sp}^{spl} = V_{sp}^{spl}(p_{sp}, M)$, where M is the exogenous supply shifter. Then, the market equilibrium price and quantity of fed cattle can be found by setting the market demand equal to the market supply. Substituting the equilibrium price and quantity thus found into the market demand equation yields $V_{sp}^{*} = V_{sp}^{*}(p_{sp}^{*}, p_{box} \mid V_{cs})$ or the inverse market demand function:

(4) $$p_{sp}^{*} = h(V_{sp}^{*}, p_{box} \mid V_{cs}) \ .$$

Equation (4) provides a basis for an empirical model to be estimated, expressing fed cattle cash market price, p_{sp}^{*}, as a function of captive supply, cash market procurement, and boxed beef price. Fed cattle cash market price may also be affected by the U.S. government policy, for example, the mandatory price reporting (MPR) which requires the reporting of cattle transaction prices. Cattle price reporting was on voluntary basis until the MPR was implemented in early 2001 in the U.S. This policy variable is included in the model as a dummy variable to investigate the effect of MPR on fed cattle cash market price.

III. Nonparametric Regression

Equation (4) can be estimated using the nonparametric regression which traces the relationship between a dependent variable and explanatory variables without specifying a functional form of the relationship. To briefly explain the procedure, define J explanatory variables $\mathbf{x}_i = [x_{1i}, x_{2i}, \cdots, x_{Ji}]$ and dependent variable y_i, where i = 1, . . ., N are observations. Assume all explanatory variables are continuous. The nonparametric model is given by

(5) $$y_i = m(\mathbf{x}_i) + \varepsilon_i, \qquad i = 1, \ldots, N, \text{ and } \varepsilon_i \sim iid(0, \sigma_\varepsilon^2)$$

where $m(\mathbf{x}_i)$ is a function of $\mathbf{x}_i$. As mentioned above, the functional form of m is not specified and m is estimated using the local weighted average estimator which finds the average of y_i around an observation $\mathbf{x}_0$. The kernel regression is the method most frequently utilized in applied analyses. In this method, the estimator is given by,

(6) $$\hat{m}(\mathbf{x}_0) = \frac{\dfrac{1}{N\gamma_1\gamma_2\cdots\gamma_J}\sum_{i=1}^{N} K\left(\dfrac{\mathbf{x}_i - \mathbf{x}_0}{\gamma}\right) y_i}{\dfrac{1}{N\gamma_1\gamma_2\cdots\gamma_J}\sum_{i=1}^{N} K\left(\dfrac{\mathbf{x}_i - \mathbf{x}_0}{\gamma}\right)} \quad \text{and}$$

$$K\left(\frac{\mathbf{x}_i - \mathbf{x}_0}{\gamma}\right) = k\left(\frac{\mathbf{x}_{1i} - \mathbf{x}_{10}}{\gamma_1}\right) \cdots k\left(\frac{\mathbf{x}_{Ji} - \mathbf{x}_{J0}}{\gamma_J}\right),$$

where $K(\cdot)$ is the multivariate kernel function which is the product of the univariate kernel functions, $k(\cdot)$, and γ_j are bandwidths. The univariate kernel function and the bandwidths should be determined properly. Usually, the Gaussian or Epanechnikov function is used for the univariate kernel function and in this study, the Gaussian function is used. The results are sensitive to the choice of γ_j and there are various ways to select γ_j . We utilize the cross validation (CV) method (Li and Racine, 2007; Pagan and Ullah, 1999) which is a popular, data-driven method for choosing the bandwidth in the standard kernel regression (Leung, 2005). The CV method involves finding γ_j to minimize the following:

(7) $$CV(\gamma) = \sum_{i=1}^{N} (y_i - \hat{m}_{-i}(\mathbf{x}_i))^2 \pi(\mathbf{x}_i),$$

where $\hat{m}_{-i}(\mathbf{x}_i)$ is the estimate that obtains when $\mathbf{x}_i$ is excluded and $\pi(\mathbf{x}_i)$ is a weighted function. For more information on the cross validation method, see Li and Racine (2007) or Pagan and Ullah (1999).

It is possible to extend the kernel regression to include discrete variables in the analysis, for example, mandatory price reporting (MPR)[2] dummy variable. Li and Racine (2003 and 2007) present a different type of kernel function to be used with discrete variables. Let a vector of continuous explanatory variables be $\mathbf{x}_i^c = [x_{1i}^c, \cdots x_{pi}^c]$ and a vector of discrete explanatory variables be $\mathbf{x}_i^d = [x_{1i}^d, \cdots x_{qi}^d]$. Thus, the vector of explanatory variables is now $\mathbf{x}_i = [\mathbf{x}_i^c, \mathbf{x}_i^d]$. Li and Racine (2007) suggested the following function as the kernel function for discrete variables:

(8) $$L(\mathbf{x}_0^d, \mathbf{x}_i^d, \eta) = \prod_{s=1}^{q} \eta_s^{N_{is}(\mathbf{x}_0)} \text{ and } 0 \le \eta_s \le 1$$

where $N_{is}(\mathrm{x}_0) = 1$ when $x_{si}^d = x_{0i}^d$ and 0 otherwise. The parameter η in equation (8) is the smoothing parameter like γ for continuous variables. The value of

2 In April 2001, the U.S. Department of Agriculture implemented the Livestock Mandatory Price Reporting (LMPR) law which requires large packers to report negotiated sales, forward contract, and formula arrangement transactions to increase the availability of market information.

η can be determined using the CV method described above. The nonparametric estimator with continuous and discrete variables is now modified as follows (Li and Racine, 2007, pp 136-138):

$$(9) \qquad \hat{m}(\mathbf{x}_0) = \frac{\frac{1}{N}\sum_{i=1}^{N} W(\mathbf{x}_0, \mathbf{x}_i \mid \gamma, \eta) y_i}{\frac{1}{N}\sum_{i=1}^{N} W(\mathbf{x}_0, \mathbf{x}_i \mid \gamma, \eta)} \quad ,$$

where $W(\mathbf{x}_0, \mathbf{x}_i \mid \gamma, \eta) = \prod_{s=1}^{p} \frac{1}{\gamma_s} k\left(\frac{x_{si}^c - x_{s0}^c}{\gamma_s}\right) \times L(\mathbf{x}_0^d, \mathbf{x}_i^d, \eta)$.

IV. Data and Estimation

Data are collected from various sources. The monthly data from January 1988 to December 2006 were used. Table 1 contains the basic statistics of variables.

Both the fed cattle cash price (p_{sp}) and the boxed beef price (p_{box}) are collected from the U.S. Livestock Marketing Information Center (LMIC). The LMIC provides the collection of price data over various time spans. Since Nebraska tended to be the center for price discovery for the major cattle feeding regions including Texas/Oklahoma, Kansas, Nebraska, Colorado, and Iowa/Minnesota (Ward, 2004), the Nebraska steer prices (Slaughter Steer Price, Choice 2-4, Nebraska Direct, 1100-1300 lb) were used as the national fed cattle spot market prices. The U.S. boxed beef prices are the Wholesale Boxed Beef Cut-Out Value, Choice, 600-900 lb. from the LMIC, too. Both prices are deflated using the producer price index (PPI).

USDA-GIPSA (2008) compiles monthly data on the share (λ) of captive supply cattle in the total number of fed cattle procured by the four largest packing firms. These percentages are converted to the number of captive supply cattle as $V_{cs} = \lambda V_{total}$, and the quantity procured from the spot market, $V_{sp} = V_{total} - V_{cs}$, where V_{total} is the total number of fed cattle slaughtered. The data on the total number of fed cattle slaughtered is obtained from USDA- NASS

Archive, various issues of *Livestock Slaughter* published by National Agricultural Statistics Service (NASS). Unfortunately, monthly captive supply data are available up to year 2006 (See P&SP Statistical Reports: Available at http://www.gipsa.usda.gov/Publications/pub_psp.html). Nonparametric estimation is performed using the nonparametric package (np package) developed by Hayfield and Racine (2008) which is featured in R-package (www.r-project.org).

TABLE 1. Basic Statistics

Variable	Psp	λ	Vcs	Vsp	Pbox
Description	Fed cattle price	Captive supply	Captive cattle	Spot market cattle	Boxed beef price
Unit	$/cwt	%	1000 head	1000 head	$/cwt
Average	55.70	28.18	675.95	1694.58	90.27
Std Dev	6.78	9.83	267.76	230.80	9.43
Max	72.51	52.90	1408.91	2246.37	121.00
Min	44.62	10.30	197.25	1183.52	73.28

Note: Monthly data from January 1988 to December 2006.
All price data are deflated using producer price index.

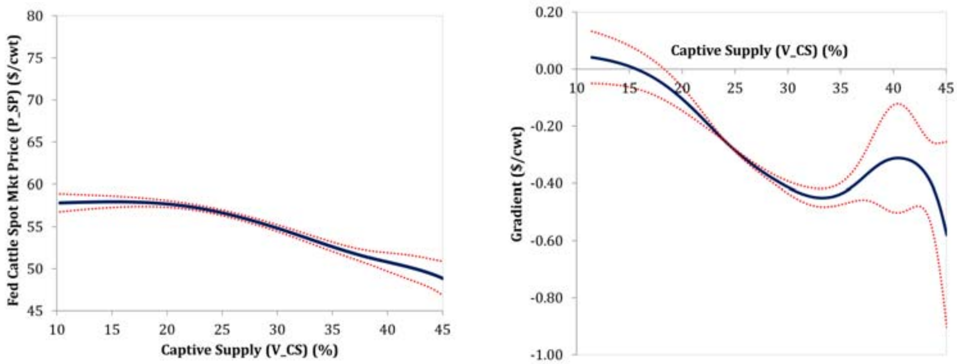
V. Results and Discussion

Using a simple specification of the U.S. fed cattle market in equation (4), the impact of use of captive supply on fed cattle cash market price was investigated via the nonparametric regression analysis. Figures 1 to 4 summarize the non-parametric regression results. The R^2 value[3] for the model is 0.97 indicating a good fit between the data and the model. Nonparametric regression results may be presented using plots, that is, plots of fed cattle cash market price (p_{sp}) versus one covariate holding all other covariates constant at their respective me-

3 A unit-free measure of goodness-of-fit for nonparametric regression models, which is comparable to that used for parametric regression models, is defined as $R^2 = \frac{\left[\sum (y_i - \bar{y})(\hat{y}_i - \bar{y})\right]^2}{\sum (y_i - \bar{y})^2 \sum (\hat{y}_i - \bar{y})^2}$

dians (Figures 1 to 4). Note that dot lines indicate 95% lower and upper confidence bands. Each plot is discussed.

Panel A in Figure 1 shows the relationship between fed cattle cash market price and captive supply over a range of the level of captive supply use. In the region where the use of captive supply is low(approximately up to 20% of the total fed cattle procurement), the price impacts appear to be negligible, that is, the fitted line is almost horizontal(see Panel A in Figure 1 and also Table 2).



Panel A. Effect of Captive Supply Panel B. Gradient of Captive Supply

FIGURE 1. Kernel Regression Result for Captive Supply

TABLE 2. Captive Supply and Price Impact

Shares of captive supply	Price impact
10%~15%	Close to zero
15%~20%	$0.06/cwt
20%~25%	$0.20/cwt
25%~30%	$0.37/cwt
30%~35%	$0.44/cwt
35%~40%	$0.35/cwt
40%~45%	$0.40/cwt

However, beyond this point, it is clear that the increased use of captive supply has a negative impact on fed cattle cash market price (see Panel A in Figure 1 and also Table 2). Panel B in Figure 1 represents the gradients of the price impact in Panel A in Figure 1 which is the slope of the plot in Panel

A in Figure 1. In short, the price impact of the captive supply depends on the extent of use of the captive supply. Table 2 contains the approximation of these price impacts[4].

The result that the price impact depends on the level of captive supply use is consistent with the findings by Schroeder *et al*. (1993). Schroeder et al. (1993) found a nonlinear relationship between fed cattle cash price and the use of captive supply in the southwestern Kansas market. They observed that the cash transaction prices were lower when the contract shipments were large, and the cash prices were statistically unaffected when the contract shipments were low. One difference here is that Schroeder et al. (1993) used the individual transaction data from thousands of pens of cattle in southeast Kansas area while this study utilizes the aggregate price and captive supply data at the market level (national level).

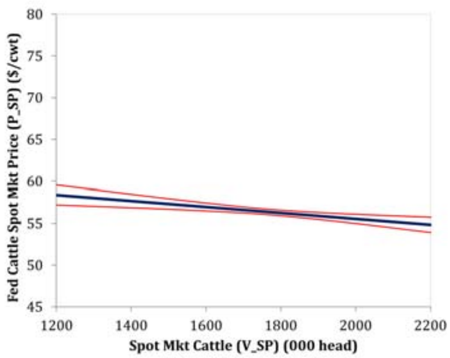


FIGURE 2. Kernel Regression Result for Spot Market Cattle

The relationship between cash market price and cash market cattle is depicted in Figure 2. It may be interpreted as the market demand curve for spot market cattle for a given level of captive supply. Fed cattle price decreases as the supply of fed cattle to the spot market increases. Being the packer's output price, boxed beef prices strongly affect the fed cattle cash price as shown in Figure 3. The increasing boxed beef prices will lead to increased production by

4 To verify the price impacts, an ordinary least squares (OLS) approach was also utilized, i.e., estimate equation (4) using the OLS. The price impact is computed as \$0.29/ cwt using the OLS results. Estimation results are available upon request.

packers, driving up the price of fed cattle, which is the most important input for the packers. The impact of the mandatory price reporting (MPR) on fed cattle cash price is not very significant as shown in Figure 4. The fed cattle price with the dummy variable equal to "1" represents the price with MPR and that with "0" indicates the fed cattle price without MPR, which is slightly higher than the price with MPR, but it is not clear.

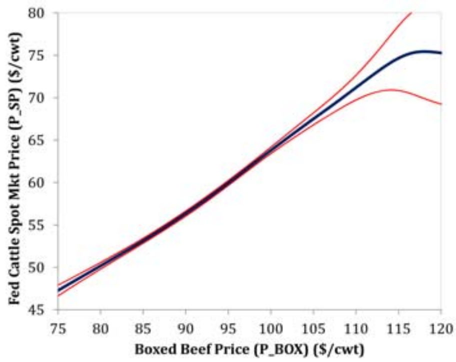


FIGURE 3. Kernel Regression Result for Boxed Beef Price

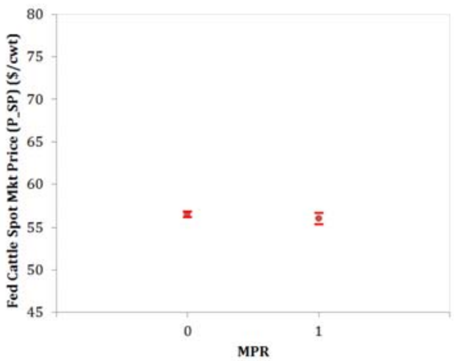


FIGURE 4. Kernel Regression Result for MPR

The U.S. fed cattle market is a complex institution involving biological commodities and various transaction mechanisms – auctions, forward contracting, and other marketing arrangements. Although the model used in this study includes some of the key variables of the fed cattle market, it is still a very simplified representation of the market. Further, this study used monthly captive supply data when in reality captive supply contracting is carried out more frequently (e.g. bi-weekly). Weekly captive supply data are not publicly available. These limitations should be noted when interpreting the results of this study.

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