The Demand for Livestock by the U.S. Meat Processing Industry

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Abstract

This paper studies the demand of domestic and imported livestock by the U.S. meat processing industry. Two types of meats are analyzed: slaughter cattle and hogs. Static and dynamic inverse input demand models are estimated. The static inversed input demand model performed better than the dynamic inversed input demand models. Calculated own price elasticities (flexibilities) and cross price elasticities (flexibilities) indicate that the demand for imported livestock by the meat processing industry is very sensitive to the change in the domestic price for livestock. The demand of domestic slaughter livestock is less sensitive to the change in imported livestock prices.

Keywords: Imported livestock, Meat processing industries, Inverse derived demand

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1. Introduction

The demand of meats by U.S. final consumers is a topic that has been studied extensively by researchers. On the other hand, the demand of livestock by the U.S. meat processing industry has received less attention. This subject is important to get a better understanding of the links between retail (consumer) demand and livestock demand. Therefore, this study focuses on the demand of slaughter cattle and hogs by the US meat processing industry.

The differentiation between domestic and imported livestock is also important given the trends of increasing liberalization of trade. On the other hand, the presence of diseases such as the mad cow disease in the United States, Canada and other countries has motivated countries to adapt import barriers that have different effects on consumers, producers and processors. For example, meat processors have claimed that the ban to import cattle from Canada was causing them financial losses. The results generated in this study might be useful to evaluate the effect of these policies.

Previous studies on the traditional model of producer behavior are based on a static theoretical framework which assumes that producers adjust instantaneously to changes in the market and technological environments in which they operate; however, some authors suggest that producers do not react instantaneously to changes in price and other exogenous factors (e.g., Reziti and Ozanne, 1999). Fox and Kivanda (1994) and Shumway (1995) had summarized the articles published in major journals of agricultural economics in the topics of testing the neoclassical theory of production. They found that many researchers rejected the neoclassical production theory such as monotonicity, curvature, symmetry and homogeneity. Clark and Grant (2000) showed that the rejection of the parametric restrictions of symmetry and homogeneity may be due to inappropriate considerations of the time-series characteristics of the data. Due to these results, the existence of long run relationships of livestock derived demand should be explored.

Therefore, the objectives of this study are first to analyze the demand of domestic and imported livestock by the US meat processing industry and second to explore the existence of long run relationships in the derived demand models which are required for the specification of dynamic demand models.

1.1 Description of the Meat Processing Industry

The beef processing industry in the United States is very important since this country is the world's largest producer of beef. The main input of the beef processing industry is the domestic cattle (around 95%). The industry also imports live cattle from Canada and Mexico. The U.S. imports of live cattle had been increasing substantially since the late 1980s due to many free trade agreements such as the Canada-United States Free Trade Agreement (CUSTA), North American Free Trade Agreement (NATFA), and the Uruguay Round trade negotiation until the discovery of BSE in Canadian Cattle in May 2003. Currently, the border trade between the US and Canada for live Canadian cattle and beef is very restricted.

The US is the world's third largest pork producer following China and the EU. Moreover, the United States is also a large net importer of hogs. Canada is the most important exporter of live hogs to the United States. The number of hogs imported annually from Canada has increased more than five-fold since 1989. However, this increase is mainly due to the increase in the number of imported feeder pigs since imported slaughter pigs have been decreasing since 1989.

Even though the demand of imported live animals is very small relative to the domestic demand for live animals, this demand plays an important role as an input for the U.S. meat packing industry plants since they usually have excess capacity. These plants with excess capacity rely on imports to reduce average slaughter costs (Brester and Marsh, 1999). Imports from Canada are also important since U.S. prices of livestock, in general, are higher than Canadian prices of livestock.

The meat processing plants in the United States are becoming larger and fewer, and scattered around the country with clusters of livestock farms (Herath et al., 2003). They are also becoming specialized in specific type of animals. The beef and hog segments of the industry are highly concentrated. In 2001, the four largest beef processing firms handled approximately 80 percent of all cattle slaughter in the U.S., compared to 36 percent in 1980. In the case of the hog segment, the four largest companies accounted for 58 percent of animals slaughtered in 2001, compared to 32 percent in 1985 (ERS/USDA).

The greater concentration in both beef and pork processing has prompted concerns about the possibility of anti-competitive behavior in the market of slaughter cattle and hogs because the big packer companies may be able to use their market power to depress cattle and hog prices below competitive levels. However, some studies suggest that there is little evidence to justify these fears because plants operate cheaper at optimal capacity. These studies argue that packers often are willing to bid significantly higher prices for cattle or hogs from longer distances, when the number of cattle or hogs purchased is below 80-90 percent of plant capacity. This is because the marginal costs of killing and processing cattle or hogs are quite low relative to expected prices for the end products.

2. Literature Review

Only few researchers have studied the demand for domestic and import livestock by the U.S. meat processing industries. Buhr and Kim (1997) estimated dynamic inputs demands for total U.S. cattle slaughter, imports of live cattle from Canada and import of carcass-weight equivalent beef products. The derived demand equations for livestock in this study are for the processing and wholesale beef sectors as a whole (i.e. both sectors are considered as one industry).

In a study about evaluating the impacts of shifts in retail beef demand on U.S. farm demand price and production, Marsh (2003) also estimated demand equations for slaughter cattle (U.S. cattle and imported cattle). However, this study does not differentiate between domestic and imported cattle.

There are other aspects of the industry that has received more attention. One of these aspects is the question on market power of the meat packing industries. However, these studies have drawn different conclusions (Muth and Wohlgenant (1999), Paul (2001), Schroeter (1988), Schroeter and Azzam (1990)). Other studies have focused on technological change in the meat packing industries. For example, Brester and Marsh (2001) estimated the long-term effects of changes in farm-level and processing-level technologies on farm-wholesale marketing margins and livestock prices in the beef and pork sectors. They found that technological change in the meat packing industry has reduced farm-wholesale marketing margins and has caused real livestock prices to increase. On the other hand, farm-level technological change has had a negative effect on real livestock prices. Overall, the negative effects from the farm level dominated the positive effects, and contributed to lower real livestock prices.

Mattson et al. (2001) studied the effect of trade liberalization on the exports of live cattle and live hogs from Canada to the U.S. during the period 1981-1999. They conclude that trade liberalization has significantly influenced the exports of live cattle; however, its effect on exported live hogs has been minor because neither the United States nor Canada levied tariffs or quotas on pork and live hogs during period of study. They also found that the appreciation of the US exchange rate relative to Canada has a positive influence on the amount of exports from Canada for pork and hogs.

In summary, few researches have studied the demand for domestic and import cattle by the U.S. beef processing industry. Moreover, previous studies have not differentiated between domestic and imported cattle. There is also a paucity of studies investigating the demand for domestic and import hogs by the pork processing industry.

3. Theoretical Model

Duality theory (Diewert, 1974) allows us to derive systems of input demand equations which are consistent with profit maximizing or cost minimizing firm behavior. In this study, static factor demand equations are derived from the Generalized Fuss Normalized Quadratic profit function. One of the advantages of this functional form over a translog or other functions is that this profit function is flexible and allows having flexible returns to scale.

3.1 Profit maximization

Let p be the firm's output price, $y = f(x)$ the production function, x the vector of factor inputs, and w the vector of factor prices. The profit function is the mathematical representation of the solution to the producer's optimization problem (profit maximization). The profit function is as follows:

$$\pi(p,w) = \max_{x \geq 0}\{pf(x) - w \cdot x\} \tag{1}$$

The profit functions satisfy the following properties Chambers (1994):

1) The profit function is nonnegative profit. $\pi(p,w) \geq 0.$

2) The profit function is nondecreasing in $p.$ If $p^1 \geq p^2$, then $\pi(p^1,w) \geq \pi(p^2,w).$

3) The profit function is nonincreasing in $w.$ If $w^1 \geq w^2$, then $\pi(p,w^1) \geq \pi(p,w^2).$

4) The profit function is convex and continuous in output price (p) and input price (w). This implies that the Hessian matrix of the profit function is positive semidefinite.

5) π is a positive homogeneous of degree one in output and input prices. $\pi(tp,tw) = t\pi(p,w),$ $t > 0$.

6) Based on Hotelling's Lemma, if the profit function is differentiable on $w,$ the unique profit-maximizing derived-demand functions are

$$x_i(p,w) = -\frac{\partial \pi(p,w)}{\partial w_i} \qquad \forall i. \tag{2}$$

The derived demands $x_i(p,w)$ depend on output price and input prices. The beef packing industries require plants with stronger carrying lines and larger equipment because beef carcasses are about five times larger than pork, and the products of beef and pork packing are also different and require different amounts of handling and processing (Melton and Huffman, 1995). Hence, the structure of slaughter, packing or processing plants is different between cattle and hog animals and the slaughter and processing plants tend to specialize in individual species. Therefore, the beef and pork processing industries were analyzed separately.

The general profit maximization problem for both industries can be written as

$$\pi(p,w) = \max_{x,l,e\geq 0}\{p_j f(x_{jd}, x_{jm}, l, e) - w_{jd}\cdot x_{jd} - w_{jm}\cdot x_{jm} - w_l \cdot l - w_e \cdot e\}, \qquad (3)$$

where p_j is the price of the output (wholesale price of meat which processors take as given), x_{jd} is the input quantity of domestic slaughter animals j, x_{jm} is the input quantity of import slaughter animal j, l is the amount of labor, e is the amount of energy, w_{jd} is the input price for domestic slaughter animal j, w_{jm} is the input price for import slaughter animal j, w_l is the average wage of meat processing industry, and w_e is the energy price. If the subscript $j=b$ it refers to the beef processing industry and if $j=p$ it refers to the pork processing industry.

Assuming that the profit function in equation (3) satisfies conditions 1) – 5) and applying Hotelling's Lemma, the input-demand or derived demand for domestic and imported slaughtered animals are

$$-\frac{\partial\pi(p,w)}{\partial w_{jd}} = x_{jd} = g_d(p_j, w_{jd}, w_{jm}, w_l, w_e) \qquad (4)$$

$$-\frac{\partial\pi(p,w)}{\partial w_{jm}} = x_{jm} = g_m(p_j, w_{jd}, w_{jm}, w_l, w_e) \qquad (5)$$

4. Empirical Model – Normalized Quadratic profit function

The Generalized Fuss Functional form was developed by Diewert and Ostensoe (1987), Diewert and Wales (1987) and Fuss (1977). This function has been used in empirical studies by

Adrangi et al. (1995) and Muth and Wohlgenant (1999). This profit function allows having both constant and non-constant returns to scale technology. The flexible constant returns to scale case is nested as a special case of the general functional form for the non-constant returns to scale case. This function can be written as

$$\pi(\tilde{p},z)/p_j z_1 = \alpha_0 + \sum_{i=1}^{N-1}\alpha_i(w_i/p_j) + \sum_{i=1}^{N-1}\sum_{h=1}^{N-1}\phi_{ih}(1/2)(w_i/p_j)(w_h/p_j)$$

$$+\sum_{i=1}^{M}\sum_{h=1}^{M}\beta_{ih}(1/2)\,(z_{i+1}/z_1)(z_{h+1}/z_1) + \sum_{i=1}^{N-1}\sum_{h=1}^{M}\theta_{ij}(1/2)(w_i/p_j)(z_{h+1}/z_i)$$

$$+\sum_{i=1}^{M}\gamma_{ih}(z_{i+1}/z_i) \tag{6}$$

where $\tilde{p} \equiv [w_1,..., w_{N-1}, p_j] >> 0_N$ denote a vector of positive prices for variable inputs and outputs, $z = (z_1, z_2,..., z_M)$ is a nonnegative capital input vector, $\alpha,\ \phi,\ \beta$ and θ are model parameters. Symmetry implies that $\phi_{ih} = \phi_{hi}$ and $\beta_{ih} = \beta_{hi}$. The ϕ matrix must be positive semidefinite in order for $\pi(p,w;z)$ to be a convex function of p_j (output price) and w (input price) for each fixed z.

From Hotelling's lemma, the Fuss normalized quadratic profit function in equation (6) can be differentiated with respect to input price ($w_1, \ldots, w_{N-1}$) to obtain input demands which are

$$-x_i(\tilde{p},z)/z_1 = -\left[\alpha_i + \sum_{h=1}^{N-1}\phi_{ih}(w_h/p_j) + \sum_{h=1}^{M}\theta_{ih}(z_{h+1}/z_1)\right], \tag{7}$$

Equation (7) is input demands which are interested in this study since our objective is to estimate derived demands for domestic and imported live animals where $i = \{jd,\ jm\}$.

4.1 Static Model

In this section we specify the empirical static derived demand equations corresponding to equation (7). Meat processing industries require live animals, labor, electricity, and capital.

Capital can be assumed to be fixed. Live animals can be differentiated between domestic and imported animals. Hence, the input demands of live animals for the processing beef and pork industries can be written as

$$-\frac{x_{js}}{z_{j1}} = -\left[\alpha_s + \phi_{s1}\frac{w_{jd}}{p_j} + \phi_{s2}\frac{w_{jm}}{p_j} + \phi_{s3}\frac{w_l}{p_j} + \phi_{s4}\frac{w_e}{p_j} + \theta_{s1}\frac{z_j}{z_{j1}}\right],\ s = d, m \qquad (8)$$

where z_{j1} is the total number of slaughter plants, z_j is the amount of fixed capital. The subscript of $s = d$ refers to slaughter domestic animals and the subscript of $s = m$ refers to slaughter imported animals.

For each industry (pork and beef industries), equation (8) defines a system of two derived demands equations which can be estimated simultaneously. Moreover, the symmetry restriction ($\phi_{d2} = \phi_{m1}$) between the domestic and imported derived demand equations can be imposed. This restriction implies that the cross-price effects in the domestic and imported derived demand functions are equal. The derived demands are also homogenous of degree zero in prices and therefore the quantities of inputs demanded remain unchanged when all prices are multiplied by the same amount.

4.2 Dynamic Model

As mentioned previously, Fox and Kivanda (1994) summarized the results of several empirical studies that have tested one or more of four characteristics (homogeneity, symmetry, curvature, and monotonicity) in the estimated static derived demand equations. They found that these characteristics are often rejected. Clark and Grant (2000) argue that rejection of the characteristics might be due to inappropriate consideration of the time series properties of the data. They show that the F statistics used to test for homogeneity and symmetry need to be modified if the variables are I(1).

A second explanation for the failure of the static model is that producers' decisions might be the result of a more dynamic optimization problem or the possibility of the presence of additional constraints in the static model. Therefore, two general approaches have been proposed to account for the dynamic aspects of production: the theory-based and the data-based approach (Reziti and Ozanne, 1999).

The theory based approach derives input demand equations utilizing the adjustment cost theory of the firm (Buhr and Kim, 1997). On the other hand, the data-based approach allows the data themselves to select the underlying data generation process and it is also captures the long-run equilibrium structure (e.g., Reziti and Ozanne, 1999).

Previous studies using the data based approach have used the Error Correction Model (ECM) which assumes that all variables must have the same order of integration. However, all variables may not have the same order of integration and therefore the results of the ECM model may not be reliable. In this study we use an unrestricted error correction model (UECM) which can be derived from an autoregressive distributed lag (ARDL) model and allows us to test the existence of long run relationship by using the bounds test procedure (Pesaran et al., 2001). Pesaran et al.'s argue that this procedure has two advantages over the common practice of cointegration analysis (Engle and Granger, 1987; Johansen, 1988; Johansen and Juselius, 1990): 1) the bounds test procedure can be applied irrespective of whether the explanatory variables are I(0) or I(1) (Pesaran et al., 2001) and 2) this procedure can be applied in a small sample size. The UECM corresponding to the static normalized quadratic derived demands stated in equation (8) is:

$$\Delta\left(\frac{x_{js}}{z_{j1}}\right)_t = \sum_{k=1}^{n}\xi_s\Delta\left(\frac{x_{js}}{z_{j1}}\right)_{t-k} + \sum_{k=1}^{n}\varphi_{s1}\Delta\left(\frac{w_{jd}}{p_j}\right)_{t-k} + \sum_{k=1}^{n}\varphi_{s2}\Delta\left(\frac{w_{jm}}{p_j}\right)_{t-k}$$

$$+ \sum_{k=1}^{n}\varphi_{s3}\Delta\left(\frac{w_l}{p_j}\right)_{t-k} + \sum_{k=1}^{n}\varphi_{s4}\Delta\left(\frac{w_e}{p_j}\right)_{t-k} + \sum_{k=1}^{n}\omega_s\Delta\left(\frac{z_j}{z_{j1}}\right)_{t-k}$$

$$+\lambda_{s0}\left(\frac{x_{js}}{z_{j1}}\right)_{t-1}+\lambda_{s1}\left(\frac{w_{jd}}{p_j}\right)_{t-1}+\lambda_{s2}\left(\frac{w_{jm}}{p_j}\right)_{t-1}+\lambda_{s3}\left(\frac{w_l}{p_j}\right)_{t-1}$$

$$+\lambda_{s4}\left(\frac{w_e}{p_j}\right)_{t-1}+\lambda_{s5}\left(\frac{z_j}{z_{j1}}\right)_{t-1}, \qquad s=d,m \tag{9}$$

where $\Delta(x_{js}/z_{j1})$ is the first difference of the domestic or imported slaughter quantities per plant, $\Delta(w_{jd}/p_j)$ is the first difference of the ratio of domestic animal price to output price, $\Delta(w_{jm}/p_j)$ is the first difference of the ratio of import animal price to output price, $\Delta(w_l/p_j)$ is the first difference of the ratio of labor price to output price, and $\Delta(w_e/p_j)$ is the first difference of the ratio of energy price to output price, respectively. As previously, the subscript j is used to differentiate the derived demands corresponding to the beef and pork industries.

The bounds tests are based on the Wald or F-statistic. The asymptotic distribution of the F-statistic is non-standard under the null hypothesis of no cointegration relationship between the examined variables. The test is conducted in the following way. The null hypothesis is tested by considering the UECM for the domestic or imported derived demand function excluding the lagged variables of the level variables. Formally, a joint significance test needs to be performed, where the null is that there exists cointegration versus the alternative hypothesis that there is no cointegration.

$$H_o: \lambda_{s0}=\lambda_{s1}=\lambda_{s2}=\lambda_{s3}=\lambda_{s4}=0$$

$$H_A: \lambda_{s0}\neq\lambda_{s1}\neq\lambda_{s2}\neq\lambda_{s3}\neq\lambda_{s4}\neq 0$$

For some significance level (say α=5% or 10%), if the calculated F-statistic is lower than the lower bound critical value, there is no cointegration. In the other hand, if the calculated F-statistic is higher than the higher bound critical value, the cointegration exists. The calculated F-statistic lying between the two critical values indicates that no clear decision can be made. The

Akaike Information Criterion (AIC) and Schwartz's Criterion (SC) are used to select the number of lags in the UECM models.

5. Data and Procedure

Livestock data used in this analysis are quarterly data from 1979:1 to 2002:4 providing a total of 96 observations. The total number of commercial slaughter livestock for cattle and hog was obtained from the USDA *Red Meat Yearbook* which is available online. The total slaughter livestock figures provided by the USDA overestimate the number of domestic slaughter animals in the U.S. since they also include imported slaughter animals from Canada. Hence, the U.S. slaughter livestock quantity can be obtained by subtracting the total number of slaughter imported livestock from the total number of commercial slaughter livestock.

Import livestock quantity and expenditure data were obtained from various issues of *Foreign Agricultural Trade of the United States* published by Foreign Agricultural Service (FAS) of the USDA. It is assumed that slaughter imported cattle and hogs are the imported cattle having weights above 700 lb and the imported hogs having weights above 50 lb, respectively. Since slaughter cattle and hogs are mainly imported from Canada to the US, only imports from Canada were considered.

The slaughter domestic cattle price (in cent per pound) was constructed as a weighted average price of the average prices for slaughter domestic steers, slaughter domestic heifers and slaughter domestic cows. The weights were the proportion of each type of cattle with respect to the total number of slaughter cattle. The average price of slaughter domestic steer is the average of the slaughter steer prices in the Nebraska and Texas markets. The average price of slaughter domestic heifers is the average price in the Nebraska market, and the average price of slaughter domestic cows is the average price of this type of cattle in Sioux Falls. The 51-52% lean hog price (live equivalent) in cents per pound was used as the price for slaughter domestic hogs.

Unit values of import slaughter animals were obtained by dividing imported slaughter values by imported slaughter quantities. However, since domestic prices are measured in cents per pound they were transformed to dollar per head to be consistent with the price units of the imported slaughter animals. All import prices include all duties and tariffs.

Prices and weights of domestically produced animals were obtained from the *Red Meat Yearbook*. Producer Price Indexes of beef and pork are used as the selling prices received by processors for their output and they were obtained from the Bureau of Labor Statistics (BLS).

The average wage of meat processing industries was obtained from various issues of various issues of *Employment and Earnings* published by the BLS. The Producer Price Index of fuels and related products and power is used as the energy price and are available in the Producer Price Index Commodity dataset also from the BLS.

The total number of plants slaughtering cattle and hog are from the *Livestock Slaughter Annual Summary* published by the National Agricultural Statistics Service from the USDA and is available online. The capacity utilization of food, the industrial production data of beef and pork are from the database *Industrial Production and Capacity Utilization* from the Federal Reserve and is available online. The U.S. population data is from the Department of Commerce, Bureau of Economic Analysis and is also available online.

The USDA provides only annual data on the number of plant slaughtering cattle and hogs. An interpolation method was utilized to produce quarterly time series of the number of plants from the available annual time series. Interpolation methods allow producing a time series at a higher frequency that is actually available, for example, a quarterly series from yearly data.

A capital index of beef or pork was calculated by dividing the industrial production of beef or pork to the capacity utilization of food. In other words, it is assumed that the capacity utilization of beef and pork is the same as the capacity utilization of food. This variable was considered to take into account the effect of capital on the demand for the inputs.

6. The Econometric Model

The supply of slaughter animals is perfectly or highly inelastic in the short run because of the characteristics of livestock production (it takes several months to raise the animals). This implies that in the short run the quantities of slaughter animals are fixed and the price is the function of the quantities. Therefore the derived or factor demand equations are estimated as inverse derived demand equations.

We estimate two systems of inverse input demands in this study: one comprising domestic and imported cattle, and another comprising domestic and imported hogs. To take into account the change in the capacity of the industries, the number of slaughter animals per plant is used as the quantity in the models. The models also include output prices, prices of domestic and imported slaughter animals, labor costs and energy costs.

The inverse derived demand of domestic and imported livestock based on the general derived demand model of the beef or pork processing industry in equation (12) can be rewritten as follow:

$$-\frac{w_{js}}{p_j} = -\left[\alpha_s^* + \phi_{s1}^* \frac{x_{jd}}{z_{j1}} + \phi_{s2}^* \frac{x_{jm}}{z_{j1}} + \phi_{s3}^* \frac{w_l}{p_j} + \phi_{s4}^* \frac{w_e}{p_j} + \theta_{s1} \frac{z_j}{z_{j1}}\right],\ s = d, m \qquad (10)$$

The additional explanatory variables for the beef processing industry in equation (10) are seasonal dummy variables, a dummy variable to capture the effect of free trade agreements (1989:1-2002:2), and a dummy variable (1999:3-2000:2) to capture the effect of a countervailing duty which was imposed on the value of live cattle imported from Canada in June 1999 (Wohlgenant and Schmitz, 2005). Free trade agreements signed by the U.S. include CUSTA signed in 1989, NAFTA and the Uruguay Round signed in 1994.

For the pork processing industry the additional explanatory variables are seasonal dummy variables and a dummy variable (1998:3-1998:4) which was included to capture a supply side shock. In 1998, producers were forced to sell their animals to the market at very low prices (Goodwin and Harper) due to the sharp increase in the price of corn.

The UECM of the inverse derived demand based on equation (14) can be rewritten as follows:

$$\Delta\left(\frac{w_{js}}{p_j}\right)_t = \sum_{k=1}^{n}\xi_s^*\Delta\left(\frac{w_{js}}{p_j}\right)_{t-k} + \sum_{k=1}^{n}\varphi_{s1}^*\Delta\left(\frac{x_{jd}}{z_{j1}}\right)_{t-k} + \sum_{k=1}^{n}\varphi_{s2}^*\Delta\left(\frac{x_{jm}}{z_{j1}}\right)_{t-k}$$

$$+\sum_{k=1}^{n}\varphi_{s3}^*\Delta\left(\frac{w_l}{p_j}\right)_{t-k} + \sum_{k=1}^{n}\varphi_{s4}^*\Delta\left(\frac{w_e}{p_j}\right)_{t-k} + \sum_{k=1}^{n}\omega_s^*\Delta\left(\frac{z_j}{z_{j1}}\right)_{t-k}$$

$$+\lambda_{s0}^*\left(\frac{w_{js}}{p_j}\right)_{t-1} + \lambda_{s1}^*\left(\frac{x_{jd}}{z_{j1}}\right)_{t-1} + \lambda_{s2}^*\left(\frac{x_{jm}}{z_{j1}}\right)_{t-1} + \lambda_{s3}^*\left(\frac{w_l}{p_j}\right)_{t-1},$$

$$+\lambda_{s4}^*\left(\frac{w_e}{p_j}\right)_{t-1} + \lambda_{s5}^*\left(\frac{z_j}{z_{j1}}\right)_{t-1}, \quad s = d, m \tag{11}$$

Where again the *j* index is used to differentiate the pork and beef industries and the *s* index is used to differentiate domestic $(s = d)$ and imported $(s = m)$ slaughter animals. The additional explanatory variables included in equation (11) are the same as those included in the equation (10). In both models the symmetry restriction corresponding to quantities cross effects between domestic and imported animals was imposed in the estimation. All of the equations were estimated using SUR procedures utilizing the proc MODEL procedure of SAS.

7. Results

7.1 Results of the static inverse derived demand model

Table 1 shows the parameter estimates of the unrestricted static system of inverse derived equations. The main parameters of interest are the parameters corresponding to the quantities of animals. The parameters corresponding to domestic and imported quantities (x_d/z_1 and x_m/z_1) in both industries have the correct signs (negative). In the beef processing equations only the own quantities effects are significant. In the pork industry equations all of these variables have significant parameters. Most of the remaining parameter estimates were significant with the expected signs. Moreover, all of the equations have high R^2's.

Equations in Table 1 were estimated taking into account the autocorrelation of the error terms. Tests of autocorrelation indicated that the errors from the inverse derived demand of domestic cattle and hogs were generated by second-order AR processes. The errors from the inverse derived demand of imported cattle and hogs were generated by first-order AR processes. The fact that the DW values in Table 1 are close to 2 in all models indicates that there is no evidence of autocorrelation problem in the final estimated models.

The signs of the free trade agreement dummy variable had the expected negative sign on domestic and import inverse demand for cattle equations since a decrease in tariffs are expected to reduce import prices. This result also causes domestic prices to go down. The dummy variable corresponding to the countervailing duty was not found to be significant.

Based on the parameter estimates in Table 1, the calculated own price elasticities (flexibilities) were -2.80 for domestic cattle, -14.84 for imported cattle, -2.70 for domestic hog, and -13.42 for imported hogs. The own price elasticities (flexibilities) for domestic slaughter animals are much lower than the own price elasticities (flexibilities) for imported slaughter animals in absolute value. The cross price elasticities (flexibilities) for domestic animals with respect to the price of imported animals are 0.16 for domestic cattle and 0.18 for domestic hog. The cross price elasticities (flexibilities) for imported animals with respect to the price of domestic animals are 7.34 for imported cattle and 13.96 for imported hogs. All elasticities (flexibilities) were calculated at the mean values.

These results show that the demand for imported livestock by the meat processing industry is very sensitive to the change in the domestic price for livestock, but the demand of domestic slaughter livestock is less sensitive to the change in imported livestock prices. This might be due to the fact than the U.S. livestock market is significantly larger than the Canadian livestock market.

The compensated cross-price elasticities for imported and domestic livestock (cattle or hogs) are positive. This suggests that imported live animals are substitutes for domestically produced animals. The hypothesis of perfectly substitubility between imported livestock and domestic livestock was formally tested in the models. In order to do this, restricted models with the quantity coefficients in the domestic and imported equations being equal were estimated. The hypothesis of perfect substitutability between domestic and imported animal was rejected at the 5% level of confidence. This implies that imported cattle are not perfect substitute for domestic cattle, and that imported hogs are not perfect substitutes for domestic hogs.

Cattle imported from Canada is generally different than the U.S. cattle since Canadian producers use different breeds and feed that cause differences in the final quality of the slaughter cattle (Wohlgenant and Schmitz, 2005). The rejection of the hypothesis of perfect substitubility between domestic and imported hogs is more difficult to explain since hogs are more homogeneous in nature.

According to theory, the marginal change in input price with respect to output price must be positive. In equation (10), this marginal effect is $(\partial w_{js} / \partial p_j) = 1/p_j (w_{js} - \phi^*_{s3} w_l - \phi^*_{s4} w_e)$ >0. This marginal effect was positive for both industries and for domestic and imported animals. Another restriction derived from theory that was tested was the symmetry restriction. The null hypothesis that the symmetry restriction is satisfied is not rejected in the static system of inverse derived equations in both industries.

7.2 Results of the dynamic inverse derived demand model

All the variables included in the demand models were tested for a unit root using the Augmented Dickey-Fuller test. We found that all the variables included in the beef processing industry demand equations were I(1). Most of the variables included in the pork processing industry demand equations were also found to be I(1) except for the ratio of domestic hog prices to output price and the ratio of import hog price to output price which were found to be stationary I(0). Given these results, the bounds test procedure was utilized in this study since not all of the regressors are of the same order of integration in the pork processing industry demand equations. Even though, all of the explanatory variables in the beef processing industry demand equations had the same order of integration, the bounds test approach also can be applied.

7.3 Cointegration and Bound Testing Approach

The null hypothesis for no cointegration among the variables in the UECM of the inverse derived demand models (equation 16) Ho: $\lambda_{io}^{*} = \lambda_{i1}^{*} = \lambda_{i2}^{*} = \lambda_{i3}^{*} = \lambda_{i4}^{*} = 0$ against the alternative Ha: $\lambda_{i0}^{*} \neq \lambda_{i1}^{*} \neq \lambda_{i2}^{*} \neq \lambda_{i3}^{*} \neq \lambda_{i4}^{*} \neq 0$. The null hypothesis corresponds to testing the 'nonexistence of a long-run relationship'. If the computed F-statistics falls outside the critical bounds, a conclusive decision can be made regarding cointegration without knowing the order of integration of the regressors. If the F-statistic is lower than the lower bound critical value, there is no cointegration. A calculated F-statistic lying between the two critical values indicates that no clear decision can be made. The F-statistic was calculated in the usual form:

$$F_{statistic} = \frac{(ESS_R - ESS_U)/q}{ESS_U/(n-k)} ,$$

where ESS_R is the error sum squares of the restricted model and ESS_u is the error sum squares of the unrestricted model.

In order to test the existence of long-run relationship among variables, the UECM inverse derived demand are estimated with lags $n = 1, 2, \ldots, 5$ in both beef and pork processing industries. The results of these tests are showed in Table 5. In most cases, the results of the tests can not reject the null hypothesis of nonexistence of a long-run relationship since the calculated F statistics are lower than the lower critical values (at 5 % level of significance). Only in two cases the calculated F statistics are between the two critical values and therefore the results are inconclusive.

The performance of the UECM version of the inverse demand models was also evaluated by analyzing the economic and statistical significance of the parameter estimates of these models. Table 2 shows the parameter estimates of the UECM models using only one lag. The dynamic inverse demand models for domestic and imported cattle model did not perform well as indicated by the low R^2's values and the insignificance and incorrect signs of the parameter estimates.

Table 3 presents the parameter estimates of the dynamic inverse derived demand models for the pork processing industry. The parameters of quantity variables were negative but most of them were insignificant. Most of the remaining parameters were also not significant and the equations had low R^2's values.

The result that the static model performs better than the data-based dynamic model contrasts with Buhr and Kim's results based on a theory-based approach. Whereas we do not find evidence of long run relationships in the variables of the derived demand livestock models of the meat processing industry in the U.S., they found evidence of the presence of dynamic adjustments in the processing and wholesale beef sectors as whole. However, the results are not directly comparable since their estimation considers the processing and wholesale beef sectors as one industry.

8. Summary and Conclusions

The static inversed input demand model performed better than the dynamic inversed input demand models for both the beef and pork processing industries. The results of this study indicate that there is no a long relationship in the variables of the inverse demand models for livestock.

The static models seem to be appropriate. The reason behind this result might be that meat processing industries cannot store the livestock or the output for a long time. The null hypothesis that imported slaughter animals and U.S. slaughter animals are perfect substitutes (homogeneous) goods was rejected. This implies that the meat processing industry considers imported meat differently than U.S. meat production. This result has implications for the analysis of meat trade policies between the U.S. and other countries which usually assume than the meats are homogenous.

The calculated own price elasticities (flexibilities) and cross price elasticities (flexibilities) indicate that the demand for imported livestock by the meat processing industry is very sensitive to the change in the price of domestic livestock. The demand of domestic slaughter livestock is less sensitive to the change in the price of imported livestock.

Table 1: Parameters of the static inverse livestock demand models

1a. Beef processing industry

Parameters	Domestic Cattle	Imported Cattle
Constant	7.9105 (0.4505)*	4.0779 (1.0068)*
x_d / z_1	-0.00031 (0.000067)*	-0.00015 (0.000139)
x_m / z_1	-0.00015 (0.000139)	-0.00258 (0.000881)*
w_l / p_j	8.424997 (4.9541)**	47.0254 (11.5268)*
w_e / p_j	-0.1309 (0.2921)	-0.1497 (0.7573)
d1	0.0448 (0.0361)	0.340446 (0.0733)*
d2	0.0411 (0.0357)	0.4960 (0.0874)*
d3	0.030714 (0.0376)	0.564449 (0.0746)*
D(Free Trade Agreements)	-0.14268 (0.1503)	-0.80719 (0.3525)*
D(Countervailing duty)	-0.02023 (0.1084)	-0.24604 (0.2593)
DW R^2 Adjusted R^2	2.0870 0.8409 0.8211	1.9264 0.6883 0.6536

1b. Pork processing industry

Parameters	Domestic Hogs	Imported Hogs
Constant	1.980437 (0.0695)*	1.487794 (0.1356)*
x_d / z_1	-0.00002 (0.000002695)*	-0.00002 (0.00000672)*
x_m / z_1	-0.00002 (0.00000672)*	-0.00029 (0.00011)*
w_l / p_j	-3.34633 (1.0297)*	4.750218 (2.0633)*
w_e / p_j	0.011957 (0.0723)	-0.22519 (0.1469)
d1	-0.00704 (0.011)	-0.04231 (0.0182)*
d2	0.017075 (0.0104)	-0.03871 (0.0209)**
d3	-0.01573 (0.0113)	-0.02674 (0.0181)
Dummy(Capture Shock)	-0.08865 (0.0322)*	-0.19116 (0.0589)*
DW R^2 Adjusted R^2	1.7624 0.9429 0.9366	1.9035 0.8855 0.8743

Significance levels of 0.05 and 0.10 are indicated by * and * *, respectively

Table 2: Parameters of the dynamic inverse livestock derive demand model for the U.S. beef processing industry

Parameters	Domestic Cattle	Imported Cattle
Constant	0.916678 (0.6941)	1.687343 (0.8461)*
$\Delta(w_s/p_j)^a_{t-1}$	-0.3121 (0.1191)*	-0.09513 (0.1212)
$\Delta(x_d/z_1)_{t-1}$	0.000086 (0.000085)	0.000398 (0.000173)*
$\Delta(x_m/z_1)_{t-1}$	-0.00038 (0.000455)	0.000966 (0.00117)
$\Delta(w_l/p_j)_{t-1}$	11.82477 (6.3735)**	6.607102 (15.5827)
$\Delta(w_e/p_j)_{t-1}$	-0.4911 (0.3937)	-0.98163 (0.898)
$(w_s/p_j)^a_{t-1}$	-0.11904 (0.0795)	-0.19555 (0.0879)*
$(x_d/z_1)_{t-1}$	-4.16E-07 (0.000022)	6.75E-06 (0.000067)
$(x_m/z_1)_{t-1}$	6.75E-06 (0.000067)	0.000954 (0.000987)
$(w_l/p_j)_{t-1}$	-0.23066 (4.2774)	-11.6725 (10.1554)
$(w_e/p_j)_{t-1}$	-0.08935 (0.1939)	0.164634 (0.456)
d1	0.112607 (0.0575)**	0.682718 (0.1495)*
d2	-0.04381 (0.0604)	0.501465 (0.1425)*
d3	-0.08774 (0.0555)	0.445544 (0.127)*
D(Free Trade Agreements)	0.016862 (0.0873)	-0.2107 (0.1943)
D(Countervailing Duty)	0.011929 (0.0899)	0.081026 (0.2402)
R^2 Adjusted R^2	0.3812 0.2669	0.4564 0.3560

Significance levels of 0.05 and 0.10 are indicated by * and * *, respectively
[a] If $s=d$ refers to domestic hog and $s=m$ refers to imported hog.

Table 3: The estimated parameters of the dynamic inverse livestock derive demand model for the U.S. pork processing industries

Parameter	Domestic Hogs	Imported Hogs
Constant	0.2739 (0.2137)	0.1531 (0.1083)
$\Delta(w_s/p_j)^a_{t-1}$	-0.2104 (0.1407)	0.0319 (0.1145)
$\Delta(x_d/z_1)_{t-1}$	0.0000049 (0.000011)	-0.00000022 (0.000015)
$\Delta(x_m/z_1)_{t-1}$	0.000091 (0.0001)	0.000173 (0.00014)
$\Delta(w_l/p_j)_{t-1}$	-1.3496 (1.8737)	0.0212 (2.5766)
$\Delta(w_e/p_j)_{t-1}$	-0.0721 (0.1204)	-0.1772 (0.1663)
$(w_s/p_j)^a_{t-1}$	-0.3277 (0.1189)*	-0.23929 (0.0739)*
$(x_d/z_1)_{t-1}$	-0.0000066 (0.00000232)*	-0.000002 (0.0000025)
$(x_m/z_1)_{t-1}$	-0.000002 (0.00000253)	-0.00007 (0.000058)
$(w_l/p_j)_{t-1}$	1.5431 (0.9936)	1.2339 (1.2103)
$(w_e/p_j)_{t-1}$	0.0780 (0.0649)	0.0664 (0.0867)
d1	0.065541 (0.0237)*	0.00523 (0.0310)
d2	0.10579 (0.0268)*	0.02065 (0.0375)
d3	0.050464 (0.0203)*	0.011234 (0.0262)
Dummy(Capture Shock)	-0.12685 (0.0486)*	-0.10281 (0.0675)
R^2 Adjusted R^2	0.4831 0.3953	0.2309 0.1003

Significance levels of 0.05 and 0.10 are indicated by * and * *, respectively
[a] If s=d refers to domestic hogs and s=m refers to imported hogs.

Table 4: Critical values for the bounds of the F statistic (Unrestricted intercept and no trend)

	90% level		95% level		99% level	
obs = 80*						
# of lags	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
1	4.135	4.895	5.060	5.930	7.095	8.260
2	3.260	4.247	3.940	5.043	5.407	6.783
3	2.823	2.885	3.363	4.515	4.568	5.960
4	2.548	3.644	3.010	4.216	4.096	5.512
5	2.355	3.500	2.787	4.015	3.725	5.163
obs = 1,000**						
# of lags	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
1	4.04	4.78	4.94	5.73	6.84	7.84
2	3.17	4.14	3.79	4.85	5.15	6.36
3	2.72	3.77	3.23	4.35	4.29	5.61
4	2.45	3.52	2.86	4.01	3.74	5.06
5	2.26	3.35	2.62	3.79	3.41	4.68

*Critical value bounds of the F-statistic derived by Narayan (2005)
**Critical value bounds of the F-statistic derived by Pesaran et al. (2001)

Table 5: Calculated F statistic for the tests of cointegration

5a. Beef processing industry

# of lags	Domestic input	Imported input
1	0.841	2.246
2	1.220	1.705
3	0.902	1.731
4	0.846	1.845
5	1.297	2.890

5b. Pork processing industry

# of lags	Domestic input	Imported input
1	5.766	2.935
2	3.425	3.363
3	4.740	2.252
4	2.356	0.677
5	2.033	0.809

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