Reexamining the Question: Are Imported Beef and Domestic Beef Complements or Substitutes?

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Abstract: The relation between beef imports and domestic beef at the wholesale level has been examined from various viewpoints. Thus far, results seem mixed in the literature. The purpose of this paper is to reexamine the question of whether beef imports and domestic beef are complements or substitutes. This analysis and data collection follow closely with that of previous work with expanded consideration given a longer period and more robust assessment. Results reveal significant seasonality and technical change within the industry. Elasticity estimates show little substitutability between carcass beef and imported beef, but show a greater degree of substitutability between cull cow beef and imported beef. Implications are provided of how results importantly differ from past research.

Keywords: beef imports, cost function, cost shares, ground beef

Introduction

The U.S. beef industry is segmented by two primary product categories. The first is high-valued beef cuts, where carcasses are fabricated into primal and subprimals, from which individual fabricated cuts are derived and sold to consumers. The other is ground beef, typically produced by blending 50 percent lean/50 percent fat with 90 percent lean trimmings (Elam, 2003). The primary source of 50 percent lean/50 percent fat is grain-fed beef steers and heifers, while the main source of 90 percent lean trimmings is from cull beef cows, dairy cows, grass-fed beef, and beef imports. Together, these various fat and lean sources are blended to reach the target lean point. Specifically, the lean point refers to the lean-to-fat ratio (e.g. 73/27 refers to 73 percent lean beef and 27 percent fat).

Beef imports are an important component of total U.S. beef production. In 2015, the U.S. imported 2.5 billion pounds of beef and veal with Australia, Canada, Mexico and New Zealand accounting for 80.7 percent of total import volume (USDA, FAS). In total, 2015 beef imports amounted to 14 percent of total domestic beef supplies (USDA, FAS 2016). Not surprisingly, one primary driver of U.S. beef imports has been the limited domestic supply of 90 percent lean trimmings, referred to as 90s, used in ground beef production. Alone, the U.S. does not produce enough 90s to meet the growing domestic demand for ground beef. This, in turn, has left processors with the task of sourcing an adequate supply from various outlets. The most recent estimates from the Livestock Marketing Information Center (LMIC) show the U.S. importing 2.3 billion pounds of beef trimmings in 2015, which equates to 93 percent of total U.S. beef and veal imports and 29 percent of total available trimmings (domestic and imported).

While it is clear that beef imports play a major role in U.S. beef production, what is less clear is the economics of imports on domestic prices. Someresearch suggests imports are a detriment to domestic beef and livestock prices (Dhoubhadel, Azzam, and Stockton, 2015). Conversely, some claim that imported beef serves as a complement to domestic beef (Elam, 2003). Concerns regarding U.S. beef imports date back as far as the 1950's and in response, the U.S. introduced the 1964 Meat Import bill restricting meat import volume to 7 percent of total domestic production (Freebairn and Rausser, 1975; Nelson et al., 1982; Dhoubhadel and Stockton, 2010). Following the bill's enactment, partially in response to consumer pressure, incremental changes were made to quota levels (Freebairn and Rausser, 1975; Dhoubhadel and Stockton, 2010) and later amended by the U.S. Meat Import Act of 1979 (Bester and Wohlgenant, 1997). More recently, the U.S. implemented Tariff Rate Quotas (TRQ's) as a result of the World Trade Organization (WTO) Uruguay Round Agreement.

Mandatory country-of-origin labeling (MCOOL), the trans-pacific partnership (TPP), and the reopening of the Brazil market continue to be points of interest in broader U.S. beef trade discussions. Many argued that the implementation of COOL would present significant trade barriers for many key beef exporting countries, mainly Canada and Mexico. COOL was later repealed in 2015, a result of the World Trade Organizations ruling in favor of Mexico and Canada, which authorized increased tariffs. In August 2016 it was announced that the U.S. would be reopening fresh beef trade with Brazil. Prior to this announcement, U.S. beef imports from Brazil were limited to cooked products only. However, due to TRQ's Brazils access to the U.S. market will be limited for some time. Specifically, Brazil falls in the "Other Countries" category limiting total exports of all "Other Countries" to 64,805 metrics tons.

Numerous previous studies have examined the effect of varying levels of beef imports on the domestic beef market (e.g., Jackson, 1972; Houck, 1974; Rausser and Freebairn, 1974; Freebairn and Rausser, 1975; Chambers et al., 1981; Nelson et al., 1982; Brester and

Wohlgenant, 1997) and more recently (Dhoubhadel and Stockton, 2010; Dhoubhadel, Azzam, and Stockton, 2015). Houck (1974) finds that increased beef imports result in meat prices that are 35 to 50 percent below their respective short-run levels. Freebairn and Rausser (1975) find reductions in feeder cattle, fed cattle and cull cow prices resulting from increased beef imports. Brester and Wohlgenant (1997) report results from a disaggregate model of the U.S. beef industry that allows for relative changes in beef imports. Overall, results show fed cattle and cow-calf producers benefiting from increased beef imports, but also reveal significant reductions in nonfed cattle prices (Brester and Wohlgenant, 1997).

Research has also determined the relative use and substitution of domestic beef for beef imports at the wholesale level; thus far, results have been mostly mixed. Dhoubhadel and Stockton (2010) estimate a derived inverse demand system for wholesale choice and select beef primals and lean trimmings, finding that beef import volumes do not have a statistically significant effect on domestic beef prices. In contrast, Dhoubhadel, Azzam, and Stockton (2015) report results from a translog processing cost function that suggests that imported beef is a substitute for domestic beef.

While the results of Dhoubhadel, Azzam, and Stockton (2015) may intuitively seem valid, it may be important to assess if their findings would hold if consideration were given towards seasonality and time trend, as one would expect such considerations to significantly impact a firm's costs as well as resulting changes in input use decisions. Moreover, it appears the researchers examined a time period, January 2009 to December 2013, that may drive their results. Between 2009 and 2013, the U.S. experienced a serve drought, impacting many of the major cattle and beef producing states. The resulting effect of the 2012 drought was a shortage of domestic cattle and higher livestock prices, which might help explain the findings reported in

Dhoubhadel, Azzam, and Stockton (2015). Moreover, during this time period a strong U.S. dollar was observed which may drive increased beef imports. Finally, Dhoubhadel, and Stockton (2015) report cross-price elasticities of input demand that are evaluated at the mean of the sample period. A more thorough assessment would evaluate elasticities for each year within the sample period, which might provide better insight towards changes in input relationships over time.

The purpose of the research is to reexamine the question of whether imported beef and domestic beef are compliments or substitutes. For comparison, our analysis follows closely with that of previous work (Dhoubhadel, Azzam, and Stockton, 2015), but considers a larger sample period and further incorporates seasonality and time trend impacts. Subsequent sections describe a processing translog cost function and data collection procedures. We then present empirical results and discuss implications with emphasis on price elasticities of input demand and elasticities of substitution.

Translog Cost Function

Following the approach of past work a translog cost function was selected, because it places no priori restrictions of the processing technology (Christensen and Greene, 1976). The translog processing cost function is one that incorporates two outputs and four variable inputs formulated as:[1]

(1)
$$ln\, VC = \alpha_0 + \sum_{i=1}^{2} \alpha_1 lnY_i + \sum_{j=1}^{4} \beta_j lnW_j + \frac{1}{2}\sum_{i=1}^{2}\sum_{l=1}^{2} \gamma_{ij} lnY_i lnY_l + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \delta_{jk} lnW_j lnW_k + \sum_{i=1}^{2}\sum_{j=1}^{4} \lambda_{ij} lnY_i lnW_j + \sum_{m=1}^{11} \varphi_m Mon_m + \sum_{j=1}^{4}\sum_{m=1}^{11} \omega_{jm} Mon_m lnW_j + \tau Trend$$

[1] For comparison and convenience, notation follows that of Dhoubhadel, Azzam, and Stockton (2015).

where VC is the variable cost, Y_1 and Y_2 denote the outputs of boxed beef and ground beef, respectively. W_j or W_k denote the prices of the four inputs (j, k =1, carcass beef; 2, cull cow beef; 3, beef imports; 4, other inputs). Past studies have incorporated time shift variables to capture changes in costs over time (Ollinger, 2011). Here, seasonality, seasonal interactions and time trend are incorporated to capture changes in production technology, cost seasonality, and seasonality of input prices, where *Mon* denotes the seasonal monthly dummies and *Trend* denotes the time trend variable (*Trend*=1, 2,…, 15), beginning with *Trend* =1 for 2002. Specifically, to be consistent with past work, we let *Trend* denote Hicks-neutral technical change (Ray, 1982). Taking the derivative of the translog cost function with respect to each factor price yields the following factor cost share equations by Shephard's lemma:

(2) $$S_j = \beta_j + \sum_{k=1}^{4} \delta_{jk} lnW_k + \sum_{i=1}^{2} \lambda_{ij} lnY_i + \sum_{m=1}^{11} \omega_{jm} Mon_m$$

for j = 1, 2, 3, 4. Here, S_j denotes the jth inputs cost share of total variable cost.

To be consistent with past analyses the Allen-Uzawa elasticities of substitution (AES) are formulated as:

(3) $$\sigma_{jk} = \frac{\delta_{jk}}{s_j s_k} + 1$$

for j, k = 1, 2, 3, 4, $j \neq k$ where $\sigma_{jk}=\sigma_{kj}$. The own-price and cross-price elasticities of input demand are given by:

(4) $$\eta_{jj} = \frac{\delta_{jj}}{s_j} + S_j - 1$$

and

(5) $$\eta_{jk} = \frac{\delta_{jk}}{s_j} + S_k$$

for j, k = 1, 2, 3, 4, $j \neq k$. It should be noted, that, while AES are symmetric, this is not the case for cross-price elasticities of input demand. Berndt and Wood (1975) note that price elasticities of input demand and AES are allowed to vary with cost shares. Hence, we evaluate elasticities at their corresponding mean shares for each year within the sample period. It has been shown that prices elasticities of demand are related to AES (Allen, 1938; Berndt and Wood, 1975). In general, cross-price elasticities of input demand can be rewritten as:

(6) $$\eta_{jk} = S_j \sigma_{jk}$$

As is typical, the cost function must be homogenous of degree one in input prices, which implies the following restrictions on the system: $\sum_j \beta_j = 1$, $\sum_k \delta_{jk} = 0$; $\sum_k \delta_{jk} = 0$; for j =1, 2, 3, 4, and $\sum_j \lambda_{ij} = 0$; for i = 1, 2.

Data

Data collection procedures follow closely with those from Dhoubhadel, Azzam, and Stockton (2015) with monthly data covering a longer period from January 2000 through April 2016. Negotiated sales of boxed beef are collected from the Livestock Marketing Information Center (LMIC). Specifically, negotiated sales of boxed beef delivered within 21 days and forward sales of 22 days plus are combined to create the first output of the cost function, referred to as boxed beef. Sales of 22 days plus are added as it represents a significant proportion of total boxed beef sales and, therefore, more accurately reflects the full market for beef. Negotiated sales of ground beef, blended ground beef and trimmings are collected from USDA Agricultural Marketing Service (AMS). This research combines ground beef, blended ground beef, and trimmings to create the second output of the cost function, referred to as ground beef.

Quantities of carcass beef and cull cow beef are obtained from the LMIC. Quantities of cull cow beef include those derived from both beef and dairy cows, while quantities of carcass beef include beef derived from steers and heifers. Similarly, prices of carcass beef and cull cow beef are obtained from the LMIC. The price of carcass beef is the steer and heifer five-area weighted average dressed price (Texas-Oklahoma, Kansas, Colorado, Nebraska, Iowa-Minnesota). The five-area weighted average price offers a reasonable representation of prices faced by meat processors as 80 percent of all fed cattle are marketed in the central portion of the country (Johnson and Becker, 2009). The price of cull cow beef is a cutter cow monthly cutout value. Quantities and prices of beef imports are from the USDA Foreign Agricultural Service (FAS) Global Agricultural Trade System (GATS). Ideally, data on labor costs might serve as a better measure of other inputs; however, such data are not collected on a monthly basis for meat processing firms. Similar to Dhoubhadel, Azzam, and Stockton (2015), we let the cost of other inputs be proxied by the farm-to-wholesale beef margin published by USDA Economic Research Service (ERS). Complete summary statistics are included in table 1.

The outlay of each input is obtained by multiplying it's respective per unit price and quantity. The outlay of other inputs is derived by multiplying the farm-to-wholesale beef margin and the quantities of beef used in production. Explained differently, the farm-to-wholesale beef margin is scaled by the total volume of carcass beef, cull cow beef, and imported beef. The cost shares of carcass beef, cull cow beef, imported beef, and others inputs are computed by dividing each inputs respective outlay by total variable cost. Total variable cost is, simply, defined as the sum of the outlays of the four inputs.

A common practice in the literature is to account for fixed costs in the estimation of a translog cost function when feasible. Schroeder (1992) lets the fixed inputs of agricultural cooperatives be measured by the book value of equipment and buildings and rental payments. Ollinger (2011) measures fixed costs of poultry processing plants by capital rental rates.

It could be argued that, given the longer time period used here, a more appropriate representation of a meat processing firm's costs would be one that incorporates fixed costs.

However, we use simplifying assumptions similar to those in Berndt and Wood's (1975) seminal paper. Specifically, we assume, implicitly, the existence of an aggregate production function for all meat processing firms, and by duality, gives an aggregate cost function. Most papers that have incorporated fixed costs have collected firm-level data. Measuring fixed costs of meat processing firms would require aggregate fixed cost data, which to our knowledge is not available for meat processing firms alone.

Results

The translog cost function and cost shares equations are jointly estimated with iterated seemingly unrelated regressions (ITSUR). Joint estimation of the system has the benefit of more efficient parameter estimates and increases the degrees of freedom without adding any unrestricted coefficients (Christensen and Greene, 1976). The fourth share equation is dropped in estimation to reach nonsingularity of the variance-covariance matrix. For an easier interpretation of estimates all right-side variables, input prices and quantities, were scaled by their 2002 sample means (Ray, 1982; Ollinger, 2011). This gives an approximation of the translog cost function around the 2002 time period.

One estimation concern is that of autocorrelation. Following past studies three autocorrelation specifications are considered (Holt and Goodwin, 1997; Piggott and Marsh, 2004; Tonsor and Olynk, 2010), where correlation specifications are summarized by Berndt and Savin (1975). The three specifications considered are: (*a*) a null correction matrix restricting all elements to 0 (no autocorrelation correction; $\rho_{ij} = 0\ \forall_{ij}$); (*b*) a diagonal correction matrix with all off-diagonal elements restricted to 0 and all diagonal elements to be identical ($\rho_{ij} = 0\ \forall_{i \neq j}$ and $\rho \neq 0\ \forall_{i=j}$); and (*c*) a complete correction matrix allowing all elements to differ individually from 0 ($\rho_{ij} \neq 0\ \forall_{ij}$) (Tonsor and Olynk, 2010). In each case, results from likelihood ratio (LR) tests reject the null and diagonal corrections in favor of a full correction matrix.

Table 2 reports parameter estimates of the translog cost function; most are significant at the 0.01 level. Further conditions must be checked to ensure a well-behaved cost function. Formally, a well-behaved cost function must satisfy the conditions of concavity and monotonicity in input prices (Berdnt and Wood, 1975; Christensen and Greene, 1976). Monotonicity is satisfied if cost shares are strictly positive. Hence, the condition of non-negative cost shares is checked for each fitted valued of the sample period. Results show the cost function satisfying monotonicity in the region of the time period investigated. Concavity is satisfied if the Hessian matrix is negative semidefinite. Featherstone and Christev (2007) show that concavity of the Allen-Uzawa partial elasticity matrix implies concavity of the Hessian Matrix[2]. Thus, concavity of the translog cost function is satisfied if the matrix of Allen-Uzawa partial elasticities is negative semidefinite. We find that the condition of concavity holds at the data means. Thus, we can state that our translog cost function is well-behaved.

As expected, carcass beef represents the greatest share of total variable cost with an estimated share of 60.7 percent, respectively. The mean estimated shares of cull cow beef, imported beef, and other inputs are 8.2, 6.5, and 24.7 percent, respectively. The shares of carcass beef and other inputs vary relative to those reported by Dhoubhadel, Azzam, and Stockton (2015); their estimated shares of carcass beef and other inputs are 52.1 and 46.6 percent, respectively. The 8.6% lower average share of carcass beef is reflecting unique market conditions of the shorter period examined by Dhoubhadel, Azzam, and Stockton (2015).

[2] See Featherstone and Christev (2007) for a formal proof.

Elasticity Estimates

Parameter estimates, reported in Table 2, are used to estimate price elasticities of input demand and Allen elasticities of substitution. For comparison, all elasticities are evaluated at the mean share of each year and the mean share of the sample period, hereafter, referred to as average elasticities. Own-price elasticities of input demand are presented in Table 3. All own-price elasticities are negative in sign, with the exception of a few point estimates of other inputs, indicating downward sloping demand curves. The average own-price elasticities of input demand for carcass beef, cull cow beef, imported beef, and other inputs are -0.074, -0.248, -0.512, and -0.109, respectively. In general, cull cow beef and imported beef are more elastic relative to carcass beef and other inputs. Moreover, imported beef appears to be more responsive to a price change with an estimated elasticity ranging from -0.276 in 2012 to -0.539 in 2016. Own-price elasticities presented here are similar to those conventional own-price elasticities of demand for wholesale beef products (Pendell et al. 2010) Pendell et al. (2010) estimate an own-price elasticity of demand of -0.58 for wholesale beef imports, offering a similar result to our own-price elasticity of input demand of -0.539. Similarly, Ollinger (2011) estimates an own-price elasticity of input demand of -0.061 for meat used in the wholesale production of beef. Again, this estimate is similar to our estimate of -0.074 for carcass beef.

Cross-price elasticities are reported in Table 4. Cross-price elasticities can be interpreted as changes in input use, relative to the mean use, in response to a change in the price of another input. Average cross-price elasticities suggest that all inputs are substitutes with the exception of imported beef and other inputs. However, the degree to which these estimates vary is worth further assessing.

It has been argued that imported beef serves as a substitute for domestic beef (Dhoubhadel, Azzam, and Stockton 2015). However, this claim has never been examined over time; meaning, only point estimates have been provided for a selected time period. The average cross-price elasticity between carcass beef and imported beef, denoted by η_{13}, is estimated to be 0.03, while Dhoubhadel, Azzam, and Stockton (2015) report an estimate of 0.085. This disparity gives support to the argument that carcass beef and imported beef are far less substitutable than what previous findings would suggest. Similarly, the average cross-price elasticity between cull cow beef and beef imports (η_{23}) is 0.087. Dhoubhadel, Azzam, and Stockton (2015) report an estimate of 0.285, which further supports the argument that conclusions may vary with the selected sample period and model specification. To further illustrate the point, estimates of η_{13} range from 0.018 in 2003 to 0.057 in 2015. Similarly, estimates of η_{23} range from 0.07 in 2011 to 0.111 in 2015. All of these estimates are lower than those reported by Dhoubhadel, Azzam, and Stockton (2015).

Allen elasticities of substitution (AES) facilitate a complete discussion of substitutability between inputs (Table 5). Most estimates are positive in sign with the exception of AES estimates of imported beef and other inputs. The average AES of carcass beef and cull cow beef (σ_{12}) is 0.170, which indicates low substitutability. This result is not surprising as carcass beef and cull cow beef have two separate and distinct roles in U.S. beef production. Carcass beef is typically used in the production high-valued steaks and roasts. Depending on price seasonality of specific muscle cuts, consumer preference, and export markets, the remainder is used in the production of ground beef. The majority of cull cow beef is used to provide a leaner source of meat in the production of ground beef, which allows processors to hit target lean points.

The average AES of carcass beef and imported beef (σ_{13}) is 0.481 while the average AES of cull cow beef and imported beef (σ_{23}) is 1.394. These findings suggest that the degree of substitution between cull cow beef and imported beef is much greater compared to all other inputs considered. This is consistent with both cull cow beef and imported beef largely being used for a common purpose of producing ground beef products of varying lean percentages. There also appears to be a decline over time in substitutability between cull cow and imported beef as shown in Table 5. Results from cross-price elasticity and AES estimates show meat processing firms responding to prices and substituting towards a cheaper source of lean beef.

Similar to Dhoubhadel, Azzam, and Stockton (2015) we multiply the cross-price elasticities of input demand (η_{13} and η_{23}) by the inverse of their respective own-price derived supply elasticities which translates to meaningful price effects. The most recent estimate from the literature is an own-price derived supply elasticity of 0.424 for wholesale beef (RTI, 2007); we assume carcass beef and cull cow beef elasticities are similar in magnitude as no separate elasticity exists for cull cow beef (Dhoubhadel, Azzam, and Stockton, 2015). The average cross-price elasticity between carcass beef and imported beef is 0.03 which translates to a 0.07% decline in carcass beef prices. Similarly, the average cross-price elasticity between cull cow beef and imported beef is 0.087 translating to a 0.21% decline in the price of cull cow beef. Dhoubhadel, Azzam, and Stockton (2015) report price effects of 0.20% for carcass beef and 0.67% for cull cow beef, respectively. In each case, one could debate if these estimates are economically significant.

Seasonality and Technical Change

Parameter estimates reveal significant seasonality of meat processing costs and price seasonality, as expected. This research accounts for Hicks-neutral technical change by adopting a procedure well documented in the literature (Ray, 1982; Zhang, 2014). That is, we explicitly let technical change be represented by an annual time trend variable, denoted *trend*. The estimate of *trend* is negative and statistically significant indicating a rate of technical change of 0.72% per year. Meaning, beef processing firms have experienced a rate of productivity growth of 0.72% per year from 2002-2016, which is not surprising given the many technological advancements that have occurred within the industry. Marsh and Brester (2003) summarize the many technological changes that have occurred and specifically note improvements in processing methods, new capital equipment, and changes in infrastructure and information systems, leading to significant improvements in labor productivity and per unit costs.

Measures of change in productivity are a common point of discussion in the literature. One point of particular interest is biased technical change where technical change tends to bias towards one factor of production which would improve productivity of a specific input rather than all inputs by some constant amount. The time trend specification and the aggregate nature of the data are desirable as it allows us to assume a constant rate of bias technical change (Zhang, 2014). If, however, firm-level data was used, one might want to investigate different technical change specifications, as firm heterogeneity becomes relevant.[3]

Conclusions

Imported beef is an important component of U.S. beef production. Many have argued that imported beef is a detriment to the domestic market. Thus far, results in the literature are contradictory. To address the many questions regarding the effect of beef imports on domestic beef usage an aggregate meat processing translog cost function is estimated.

[3] Zhang (2014) provides a detailed discussion and review of literature on the topic of technical change and firm heterogeneity.

Once consideration was given towards a larger sample period, seasonality and technical change, results vary considerably when compared to those of past work. Carcass beef and other inputs represent the greatest shares of a meat processing firm's total costs, while these results are consistent, they do vary from those presented by others. Our results reveal significant seasonality and Hicks-neutral technical change. The estimate of Hicks-neutral change is 0.72% per year, which is substantial given the time period.

Results provide some evidence to the claim that domestic beef and imported beef are, in fact, substitutes in production. It appears that cull cow beef and imported beef are quite substitutable with an average cross-price elasticity and AES estimate of 0.087 and 1.394, respectively. However, our estimates show far less substitution occurring relative to those results presented in past work. Moreover, it appears that the degree of substitution has been declining over time. In contrast, carcass beef and beef imports are far less substitutable.

While results may show significant substitutability among inputs, these findings do not explicitly give grounds to the claim that beef imports harm domestic livestock and meat prices. In fact, a firm's ability to substitute towards a cheaper source of lean beef may allow for the production of a more affordable product. Furthermore, the entire wholesale sector benefits from the availability of multiple sources that aid in more stable volumes and increased capacity utilization. Ultimately these effects on production costs are transmitted vertically both to consumers and producers.

One limitation of this research is the use of aggregate data. The use of aggregate data may introduce some level of aggregation bias. However, aggregate data may offer the best representation of a firm's costs given that there may be less heterogeneity across meat processing firms. Further research might consider the use of a less ambiguous measure of the cost of other inputs used in meat production.

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Table 1. Descriptive Statistics of Selected Cost Function Variables, 2002-2016

Variable	Mean	SD	Minimum	Maximum
Boxed beef (sales)	15594.580	2920.620	9695.000	29378.000
Ground beef (sales)	6678.750	2440.190	2664.000	13000.000
Import price ($/lb.)	1.721	0.479	1.002	2.882
Carcass beef price ($/lb.)	1.643	0.415	0.988	2.654
Cull cow beef price ($/lb.)	1.355	0.408	0.787	2.374
Farm-to-Wholesale Margin (cents)	0.362	0.079	0.173	0.569
Carcass beef share (percent)	0.657	0.037	0.568	0.755
Cull cow beef share (percent)	0.090	0.015	0.060	0.123
Imported beef share (percent)	0.062	0.015	0.030	0.104
Other input share (percent)	0.190	0.050	0.068	0.312

Note: n=172.

Table 2. Parameter Estimates of the Translog Cost Function, 2002-2016

Variable	Estimate	Std Err	Variable	Estimate	Std Err
α_0	21.8018***	0.0146	φ_{12}	0.0857***	0.0171
α_1	0.1927	0.0398	ω_{11}	-0.0074**	0.0025
α_2	-0.0997*	0.0309	ω_{13}	-0.0029	0.0025
γ_{11}	-0.7327	0.2027	ω_{14}	-0.0073**	0.0033
γ_{12}	0.7578***	0.1929	ω_{15}	-0.0005	0.0040
γ_{22}	-0.2133	0.0797	ω_{16}	0.0049**	0.0042
β_1	0.6069***	0.0043	ω_{17}	0.0070**	0.0043
β_2	0.0816***	0.0030	ω_{18}	0.0130***	0.0043
β_3	0.0645***	0.0045	ω_{19}	0.0134***	0.0042
β_4	0.2471***	0.0027	ω_{110}	0.0091***	0.0040
δ_{11}	0.1770***	0.0148	ω_{111}	0.0020	0.0038
δ_{12}	-0.0491***	0.0068	ω_{112}	-0.0003	0.0033
δ_{13}	-0.0213	0.0129	ω_{21}	0.0021	0.0009
δ_{14}	-0.1066***	0.0035	ω_{23}	-0.0035***	0.0008
δ_{22}	0.0596***	0.0067	ω_{24}	-0.0065***	0.0011
δ_{23}	0.0022	0.0065	ω_{25}	-0.0120***	0.0014
δ_{24}	-0.0127***	0.0013	ω_{26}	-0.0160***	0.0015
δ_{33}	0.0332***	0.0141	ω_{27}	-0.0141***	0.0015
δ_{34}	-0.0141***	0.0026	ω_{28}	-0.0130***	0.0015
δ_{44}	0.1334***	0.0028	ω_{29}	-0.0082*	0.0015
λ_{11}	0.0054	0.0070	ω_{210}	-0.0046	0.0015
λ_{12}	0.0018	0.0029	ω_{211}	0.0003	0.0015
λ_{13}	-0.0010	0.0057	ω_{212}	-0.0002	0.0012
λ_{14}	-0.0063	0.0050	ω_{31}	0.0066***	0.0018
λ_{21}	-0.0041*	0.0070	ω_{33}	0.0096***	0.0018
λ_{22}	-0.0027	0.0033	ω_{34}	0.0130***	0.0025
λ_{23}	0.0010	0.0062	ω_{35}	0.0092***	0.0030
λ_{24}	0.0059	0.0044	ω_{36}	0.0089***	0.0032
φ_1	0.1120***	0.0157	ω_{37}	0.0077***	0.0032
φ_3	0.1039***	0.0161	ω_{38}	0.0014**	0.0032
φ_4	0.0887***	0.0160	ω_{39}	-0.0029	0.0032
φ_5	0.1697***	0.0264	ω_{310}	-0.0029	0.0031
φ_6	0.1712***	0.0196	ω_{311}	-0.0009	0.0029
φ_7	0.1483***	0.0174	ω_{312}	0.0029	0.0025
φ_8	0.1700***	0.0168	ω_{41}	-0.0183	0.0518
φ_9	0.1150***	0.0161	ω_{43}	-0.0016***	0.0588
φ_{10}	0.1547***	0.0172	ω_{44}	-0.0483	0.0463
φ_{11}	0.0622*	0.0170	ω_{45}	-0.1592	0.0974

Table 2. Parameter Estimates of the Translog Cost Function, 2002-2016 (continued)

Variable	Estimate	Std Err	Variable	Estimate	Std Err
ω_{46}	0.0115	0.0652	rho_{13}	-0.0079	0.1002
ω_{47}	0.0276	0.0660	rho_{21}	-0.0614	0.0304
ω_{48}	-0.0948*	0.0635	rho_{22}	0.8668***	0.0413
ω_{49}	0.1427	0.0527	rho_{23}	-0.1095	0.0354
ω_{410}	0.0432*	0.0519	rho_{31}	-0.1104	0.0631
ω_{411}	-0.0740***	0.0479	rho_{32}	-0.2430***	0.0896
ω_{412}	-0.0120	0.0912	rho_{33}	0.7281**	0.0742
trend	-0.0072*	0.0018			
rho_{11}	0.7155***	0.0856	R^2	0.95	
rho_{12}	0.0351***	0.1301	*LL*	2315.44	

Note: N=172. The equation omitted from the system is the cost share of other inputs. *, **, ***, denote statistical significance at the 10%, 5%, and 1% level, respectively. The R-Squared of the cost shares of carcass beef, cull cow beef, and imported beef, are 0.94, 0.96, and 0.81, respectively. The numbers 1, 2, 3, and 4 denote the inputs carcass beef, cull cow beef, imported beef, and other inputs, respectively.

Table 3. Own-Price Elasticities of Input Demand, 2002-2016[a]

Year	η_{11}	η_{22}	η_{33}	η_{44}
2002	-0.099	-0.111	-0.405	-0.220
2003	-0.089	-0.107	-0.408	-0.210
2004	-0.085	-0.163	-0.311	-0.151
2005	-0.078	-0.124	-0.487	-0.138
2006	-0.088	-0.124	-0.473	-0.197
2007	-0.065	-0.182	-0.381	-0.105
2008	-0.080	-0.263	-0.375	-0.152
2009	-0.085	-0.255	-0.324	-0.171
2010	-0.077	-0.293	-0.324	-0.131
2011	-0.058	-0.325	-0.307	-0.017
2012	-0.050	-0.349	-0.276	0.113
2013	-0.049	-0.323	-0.358	0.083
2014	-0.049	-0.309	-0.359	0.177
2015	-0.069	-0.319	-0.480	0.078
2016	-0.080	-0.270	-0.539	-0.076
2002-2016	-0.074	-0.248	-0.512	-0.109

Note: Own-price elasticities are point estimates, evaluated at the mean share of each year and the mean share of the sample period.

[a]The numbers 1,2, 3, and 4 denote the inputs carcass beef, cull cow beef, imported beef, and other inputs, respectively.

Table 4. Cross-Price Elasticities of Input Demand, 2002-2016[a]

Year	η_{12}	η_{13}	η_{14}	η_{21}	η_{23}	η_{24}	η_{31}	η_{32}	η_{34}	η_{41}	η_{42}	η_{43}
2002	-0.007	0.028	0.079	-0.061	0.093	0.079	0.272	0.108	0.028	0.190	0.023	0.007
2003	-0.005	0.018	0.076	-0.045	0.083	0.069	0.223	0.115	-0.026	0.195	0.021	-0.006
2004	0.002	0.043	0.041	0.013	0.104	0.046	0.357	0.108	0.022	0.125	0.017	0.008
2005	-0.001	0.040	0.038	-0.010	0.103	0.031	0.359	0.105	0.009	0.123	0.011	0.003
2006	-0.003	0.026	0.066	-0.029	0.089	0.064	0.273	0.112	-0.003	0.178	0.020	-0.001
2007	0.008	0.027	0.030	0.064	0.086	0.031	0.309	0.119	-0.052	0.107	0.013	-0.016
2008	0.017	0.020	0.043	0.115	0.077	0.071	0.246	0.134	-0.057	0.135	0.031	-0.014
2009	0.014	0.020	0.051	0.099	0.077	0.079	0.237	0.133	-0.046	0.150	0.033	-0.011
2010	0.023	0.019	0.035	0.150	0.074	0.069	0.240	0.141	-0.074	0.116	0.034	-0.019
2011	0.033	0.018	0.007	0.214	0.070	0.041	0.251	0.150	-0.125	0.029	0.026	-0.038
2012	0.040	0.026	-0.016	0.251	0.077	0.021	0.322	0.149	-0.112	-0.084	0.017	-0.047
2013	0.034	0.026	-0.011	0.226	0.078	0.019	0.323	0.143	-0.107	-0.055	0.014	-0.043
2014	0.031	0.044	-0.026	0.212	0.096	0.001	0.412	0.131	-0.062	-0.142	0.001	-0.037
2015	0.029	0.057	-0.018	0.189	0.111	0.019	0.427	0.128	-0.015	-0.082	0.014	-0.010
2016	0.018	0.049	0.014	0.121	0.105	0.043	0.385	0.121	0.006	0.051	0.023	0.003
2002-2016	0.015	0.030	0.028	0.112	0.087	0.049	0.316	0.125	-0.036	0.097	0.023	-0.012

Note: Cross-price elasticities are point estimates, evaluated at the mean share of each year and the mean share of the sample period.
[a]The numbers 1,2, 3, and 4 denote the inputs carcass beef, cull cow beef, imported beef, and other inputs, respectively.

Table 5. Allen Elasticities of Substitution 2002-2016[a]

Year	σ_{12}	σ_{13}	σ_{14}	σ_{23}	σ_{24}	σ_{34}
2002	-0.099	0.445	0.311	1.483	0.312	0.110
2003	-0.071	0.353	0.309	1.584	0.283	-0.108
2004	0.020	0.560	0.197	1.370	0.222	0.107
2005	-0.015	0.552	0.190	1.407	0.153	0.044
2006	-0.045	0.432	0.282	1.501	0.271	-0.014
2007	0.096	0.460	0.160	1.467	0.166	-0.276
2008	0.178	0.382	0.208	1.448	0.340	-0.271
2009	0.155	0.373	0.235	1.455	0.362	-0.212
2010	0.230	0.369	0.178	1.436	0.347	-0.371
2011	0.313	0.367	0.042	1.430	0.251	-0.766
2012	0.360	0.462	-0.120	1.353	0.154	-0.822
2013	0.324	0.463	-0.078	1.373	0.137	-0.754
2014	0.303	0.591	-0.203	1.293	0.008	-0.491
2015	0.284	0.642	-0.123	1.240	0.135	-0.108
2016	0.188	0.597	0.079	1.289	0.241	0.035
2002-2016	0.170	0.481	0.148	1.394	0.257	-0.190

Note: Allen elasticities of substitution are point estimates, evaluated at the mean share of each year and the mean share of the sample period.
[a]The numbers 1,2, 3, and 4 denote the inputs carcass beef, cull cow beef, imported beef, and other inputs, respectively.