Dynamic adjustment in the US beef market with imports

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Abstract

This paper hypothesizes that while there are important qualitative differences in domestic beef and imported beef, beef and cattle imports also represent attempts by the US beef processing and wholesale sector to adjust to short-run changes in supply and demand. Dynamic production theory is applied to the problem to test for this adjustment process, and presents a production theory approach to meat trade that has previously been included in demand functions. The results of this analysis suggest that the method used provides a reasonable and appropriate representation of the import behavior of the US processing and wholesale beef sector. © 1997 Elsevier Science B.V.

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1. Introduction

Although a large producer of beef, the US imports beef products equivalent to about 10% of its domestic production. In addition to the beef product trade, the US also imports live cattle equivalent to approximately 6% of its domestic slaughter, of which about 47% are cattle-ready for slaughter from Canada (USITC, 1993). However, US-produced beef is a substantially different product from imported beef because the US specializes in concentrate fed beef cattle which results in a superior-quality product compared to grass-fed beef produced by other major beef producing countries (Hayes et al., 1991; USITC, 1993; Unnevehr and Eales, 1991). An additional important characteristic of the US beef market is its slow adjustment to relative price changes as exhibited by the cattle cycle and caused by the long biological production lags inherent in beef cattle (Ginzel, 1988). The intent of this study is to provide a framework for analyzing US beef and cattle imports given these beef market characteristics. To accomplish this, beef and cattle imports are treated as intermediate goods in the production of retail-ready beef products, at which point consumer preferences are confronted. Therefore, US beef and cattle imports are represented in the profit maximization behavior of US processing and wholesale

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firms. This approach assumes that there are important qualitative differences between US beef products and imported cattle and beef because relative input prices allocate the demand for the different products. [1] The production approach applied also explicitly accounts for the adjustment costs inherent in beef production, which, we hypothesize, explains a portion of the US beef and cattle import behavior.

Several studies have examined meat import markets (Wahl et al., 1992; Hayes et al., 1991; Unnevehr and Eales, 1991; Houck, 1974; Moschini and Meilke, 1992; Yang and Koo, 1994). Typically, these studies view meat imports as derived from the domestic consumer demand of the importing country. However, Hayes et al., 1991 make the argument that a production approach to beef trade may be more appropriate. They argue that increased reliance on boxed beef, rather than the entire carcass, allows wholesalers to better satisfy demand conditions by purchasing only those products that are in demand and in short supply. Thus, imported beef is an intermediate product that must be shipped and, in most cases, is further processed and blended with US beef to produce an acceptable ground beef product (USITC, 1993). Clearly, live cattle are better accounted for in a production framework as further processing is necessary. Several previous studies including Burgess (1974), Kohli (1978, 1983), Diewert and Morrison (1988), Pick and Park (1989), Lawrence (1990) and more recently, Davis and Jensen (1994), also advocate the use of production theory for imported commodities. They argue, as we do, that using utility maximization theory to model imports may introduce serious bias when the goods are intermediate and must go through additional production processes.

The current paper expands on production theory as the appropriate method to model imports of intermediate goods by including the adjustment cost hypothesis. The adjustment cost hypothesis is appealing because of the observed cyclical behavior of the cattle industry (Ginzel, 1988). We hypothesize that because of this inherent fixity in the domestic beef market, imports of beef represent a mixed effect of importing for quality differences mentioned earlier and an attempt by beef processors and wholesalers to make short-run input demand and output supply adjustments. To test this hypothesis, we propose the use of a dynamic dual production theory approach originally developed by Epstein (1981) and similar to that used by Howard and Shumway (1988) to analyze the adjustment process in the dairy industry.

The remainder of this paper draws together this broad area of literature to provide a parsimonious representation of beef and cattle imports in the US. First, a conceptual explanation of the problem is presented. This is followed by the theoretical derivation for the empirical analysis from which conclusions are drawn.

2. Conceptual background

We begin by observing that most of the US beef and cattle import decisions are made by the beef wholesale and processing sector (Hayes et al., 1991; USITC, 1993). As defined in this paper, the production value added by this sector includes slaughter of live cattle, procurement, fabrication (disassembly of the beef carcass), storage, and distribution of the beef product. This is also the channel into which domestic beef production

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[1] Goods exported from two different countries may not be perceived as perfect substitutes for each other, or for the domestically produced good in an importing country for two main reasons (Goddard (1988), p. 226). The first is the actual heterogeneity of characteristics in the goods in question as is the current case. The second is 'perceived or actual barriers to trade between countries' or, alternately, 'a difference among suppliers rather than in product characteristics' (Johnson et al., 1979). In the present case, there are clear quality differences due to breed types and feeding conditions in other countries. Canadian cattle are highly similar to US cattle, but the Canadian grading system favors leaner beef than the US grading system (USITC, 1993); so Canadian cattle are likely to be different than US domestic cattle. There is also a distinct difference between fresh and frozen product, and even shipping distances can affect pricing and quality of live cattle due to carcass defects, bruising, etc. Therefore, there is substantial evidence that domestic beef and cattle are different products from foreign beef and cattle.

enters, although these functions may be increasingly undertaken by the meat packer (processor). [2] Beef processors and wholesalers represent a profit-maximizing sector in the beef industry (along with cow/calf producers, cattle feedlots, and the retail sector) which is assumed to operate under perfect competition in all commodity and factor markets. [3] The primary inputs to the processing and wholesale sector are total domestic cattle slaughter (does not include Canadian imports), Canadian live cattle imports, and beef imports. The output of the wholesale sector is total carcass weight disappearance of beef (adjustment from carcass to retail-level is simply a conversion factor employed by USDA). Firms will choose their optimum output mix and their input (including imports) requirements subject to a vector of output and input prices.

Of particular interest for this paper is the adjustment nature of the beef processing and wholesale sector. The domestic input of total commercial cattle ready for slaughter is hypothesized to be quasi-fixed in the short run, meaning that it cannot be immediately adjusted to increase supply should prices favor this activity. This fixity is a result of the previous sectors' (cow calf and feedlot) production decisions and the perishability of beef. Therefore, the processing and wholesale sector, being neither the source of primary beef demand nor primary supply, is a sector caught between potential short-term changes in demand for their primary output (carcass weight beef) and production levels of their primary inputs. As such, it is hypothesized that processors and wholesalers rely on imported cattle and beef as a way to adjust supplies faced by consumers, and to maximize their short-run profits. [4] Therefore, a dynamic profit maximization system is developed to adequately account for these adjustment processes. The production theory approach to trade has also been taken up by Burgess (1974), Kohli (1978, 1983), Diewert and Morrison (1988), Pick and Park (1989), Lawrence (1990) and Davis and Jensen (1994).

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[2] Although the major beef packers increasingly act as slaughterer, processor, and distributor so that our representation is accurate in the current industry (Ward, 1988), this has not always been the case. Previously, packers sold carcasses to wholesalers who undertook the functions of fabrication and distribution, so that our representation would be a reduced form of the two sectors of beef processing and wholesaling.

[3] The assumption of perfect competition in the beef processing and wholesaling market may raise concern given that three firms control about 55% of the US beef slaughter market. However, previous studies of price distortions in the beef processing and packing industry have yielded ambiguous results (for a summary of these studies, see Ward, 1988 or Purcell, 1990). This is likely the case for three reasons: (1) pork and chicken are substitutes so that beef packers have a difficult time extracting consumer surplus; (2) there has been chronic overcapacity in the beef slaughter sector; and (3) the world market for beef is large, relatively unfettered by trade restrictions, and the US, while a major player, is not necessarily dominant. In this broader context, we argue that the assumption of perfect competition is likely reasonable.

[4] In very simplified neo-classical trade theory, two alternative hypotheses for why countries trade are: (1) the two goods traded are not perfect substitutes (product differentiation) or (2) the two goods are perfect substitutes and trade makes up the residual (adjustment hypothesis) in a product which has some fixity when the firm misreads market conditions. Our specification which incorporates the two seems to run counter to their mutual exclusivity. However, the nature of the beef industry is such that the packer/processing/wholesale sector is neither the primary demand or the primary supply of the intermediate product. The adjustment cost problem is a direct result of the adjustment costs reflected by the fixity of the previous domestic sectors (namely, cow/calf and feedlot production) investment decisions, not necessarily within the packers' own choice set. In other words, packers may not require cattle imports if 'production mistakes' were not made by their domestic suppliers which have high adjustment costs. Now to link the differentiation aspect, the inputs (cattle) are imperfect substitutes to the packer, but may be perfect substitutes to the primary consumer. Packers may view the domestic cattle and beef and imported cattle and beef as imperfect substitutes for reasons pointed out by Johnson et al. (1979) ('perceived or actual barriers to trade') rather than the characteristic of the product itself. However, we have pointed out real quality differences in meat which seems inconsistent. We argue that quality differences in fresh meat are much more apparent to the packer than the consumer. Differences in carcass size, weight and fat content can be masked by cutting differently (e.g., 1/4 inch trim equalizes external fat which consumers see; heavier cattle tend to have lower carcass yields resulting in less meat per animal, but the consumer does not see yield as an identifiable product attribute; ground beef is a homogenization of several different qualities of cattle) so that the packer can effectively mask a great deal of the quality differentials faced by consumers. However, the yield characteristics and fat characteristics directly affect the packers' profitability through by-product values and cutting costs. Hence, in this particular circumstance of a completely intermediate product industry (operating on margins) we argue that the melding of adjustment costs with product differentiation is consistent with the structure of the industry.

Epstein developed a model of dynamic firm behavior that has proven useful in developing and testing empirical models of behavior (Vasavada and Chambers, 1986; Howard and Shumway, 1988; Taylor and Monson, 1985; Luh and Stefanou, 1991; Lopez, 1985). The dynamic dual approach, which is used for this study, was formulated by Epstein and has been empirically used or theoretically augmented by Epstein and Denny (1983), Vasavada and Chambers (1986), and Howard and Shumway (1988). In this framework, a representative firm uses variable and quasi-fixed inputs to produce outputs. The variable inputs can be completely adjusted to the optimal level within the current time period. However, quasi-fixed inputs are not completely adjustable in the current time period. The central implication of introducing quasi-fixed inputs is a divergence between short- and long-run production relationships. For generalization, the model developed does not require any factor to be variable, so that all inputs may reveal a certain amount of quasi-fixedness, and the significance of quasi-fixedness may be tested to determine if the hypothesized adjustment process exists (Vasavada and Chambers, 1986; Howard and Shumway, 1988). In the present case, it is hypothesized that all inputs (imported beef, domestic cattle, and imported Canadian cattle) exhibit some degree of quasi-fixedness. Further, knowledge of the three inputs would lead one to expect cattle to exhibit the greatest degree of fixity, with beef imports being the least fixed.

3. Theoretical model

The model employed in this study was originally derived by Epstein; however, the derivation is similar to Howard and Shumway's, and interested readers will find a more detailed derivation there. A profit-maximizing competitive firm will choose variable inputs and fixed or quasi-fixed inputs to maximize the net present value of receipts given the initial stock of fixed and quasi-fixed inputs:

$$J(X,W) = \text{Max}_x \int_0^\infty e^{-rt} \left[F(X(t), \dot{X}(t)) - W(t) \cdot X(t) \right] dt$$

s.t.   (1)

$$\dot{X} = d_X/dt, \ X(0) = X_0, \ X_0 > 0$$

$J(X, W)$ is the optimal value function associated with the firm's problem and represents the present value of a stream of future profits defined as total revenue minus total cost. The production function is represented by $F()$. The vector $X(t) \in \mathbb{R}^n$ is a vector of n inputs (including imports) at time t, and $W(t) \in \mathbb{R}^n$ is the vector of corresponding input prices normalized on output prices. We assume static price expectations, implying that the firm revises price expectations at the beginning of each time period and assumes that the new price levels will remain constant into perpetuity (Vasavada and Chambers, 1986).[5] The inclusion of $\dot{X}$ into the production function reflects the costs of adjusting a quasi-fixed input. All variables are implicit functions of time, and the production function satisfies the conditions that $F(X) > 0$, $F(X)$ is twice continuously differentiable, $F_X(X) > 0$, and $F(X)$ is strictly concave in X. Included in these conditions is the hypothesis that all factors in production are quasi-fixed. This formulation is particularly appealing for including traded goods because the traded goods are treated as inputs to or outputs from the production sector, which recognizes that wholesale beef does not directly enter the consumers' preference structure and that, certainly, live cattle do not directly enter the preference structure. Now, for the value function $J()$ defined in Eq. (1) and assuming that (a) the firm

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[5] We draw on the results of Antonovitz and Green (1990) with respect to the usefulness of more complex price expectations formation and conclude that the added complexity of the system would not be compensated by substantially improved results. In the following empirical specification, the lagged dependent variable implies a distributed lag process on the price variable, so the price expectations are not precisely static in application.

expects disembodied technical change and includes a time variable (T) in the value function (Howard and Shumway, 1988)[6], and (b) given that the plan is revised each period when $t = 0$ is relevant, then the Hamilton–Jacobi–Bellman equation corresponding to Eq. (1) is:

$$rJ(T, X, W) = \underset{X}{\text{Max}} \left[F(X, \dot{X}, T) - W \cdot X + J_X \dot{X} + J_T \dot{T} \right]$$ (2)

where T is the time variable.

The technology dual to this $J()$ can be recaptured by solving the inverse of Eq. (2) (Epstein, 1981), and is represented as:

$$F^*(X, \dot{X}, T) = \underset{W}{\text{Min}} \left[rJ(T, X, W) + W \cdot X - J_X \dot{X} - J_T \dot{T} \right].$$ (3)

Finally, application of the envelope theorem yields the equation:

$$X = -rJ_W + J_{XW} \dot{X} + J_{TW} \dot{T}$$ (4)

and rearranging yields the factor demand equation:

$$\dot{X} = J_{XW}^{-1} \left[rJ_W + X - J_{TW} \dot{T} \right]$$ (5)

Eq. (5) gives the dynamic input demand functions, including import demand functions. By substituting Eq. (5) into Eq. (3), we get the output (Y) supply function:

$$Y = r(J - WJ_W) - (J_X - WJ_{XW}) \dot{X} - (J_T - WJ_{TW}) \dot{T}$$ (6)

The remaining problem is to select a functional form on J which satisfies the regularity conditions so that dynamic duality holds. A quadratic form is adopted, which is a second-order Taylor series expansion of the value function in prices and inputs (Vasavada and Chambers, 1986). The quadratic form is attractive, as its first-order derivatives are linear; this not only allows an easy interpretation, but also makes it relatively simple to estimate.[7] The quadratic value function is specified as:

$$J(X, W, T) = A_0 + \begin{bmatrix} A'_1 & A'_2 & A_3 \end{bmatrix} \begin{bmatrix} X \\ W \\ T \end{bmatrix} + \frac{1}{2} \begin{bmatrix} X' & W' & T \end{bmatrix} \begin{bmatrix} A_{XX} & A_{XW} & A_{XT} \\ A_{WX} & A_{WW} & A_{WT} \\ A_{TX} & A_{TW} & A_{TT} \end{bmatrix} \begin{bmatrix} X \\ W \\ T \end{bmatrix}$$ (7)

where A_0, A_1, A_2, A_3 and A_{ij} ($I, j = X, W, T$) are appropriately dimensioned parameter vectors or matrices, and A_{ij} is symmetric.

A further conceptual problem arises from the fact that the model considers the optimization decision of a single firm. However, in this study we use industry-level aggregate data rather than firm-level data. The behavior of the industry is modeled as a single representative firm using these aggregate data. In dynamic models, the initial level of the state variables (quasi-fixed factors) are arbitrarily allocated across firms. The basic problem is to determine the conditions under which there exists a consistent aggregate or industry-optimal

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[6] Incorporating technical change into the model is not trivial. To maintain theoretical consistency, the value function (Eq. (1)) must be re-specified to include the time variable T, and the input demand and output supply functions must be resolved. This implies that the firm will expect disembodied technical change to occur continuously over the planning horizon. This formulation has been termed the infinite-horizon nonautonomous optimal control problem.

[7] Vasavada and Thijssen (1994) recently raised the issue of pretesting the quadratic adjustment cost specification for misspecification. The shortcomings of the quadratic functional form were recognized early on (Epstein and Yatchew, 1985). However, practical issues such as computational tractability (particularly in the current dynamic dual representation) and ease of estimation have clearly outweighed the known concerns regarding the quadratic specification as evidenced by its widespread adoption in subsequent applications. It is beyond the scope of this study to test and develop alternative functional forms for dynamic specification, and Vasavada and Thijssen offer little guidance on how to proceed to remedy the shortcomings.

value function that depends only on the aggregate level of the state variables, and not on their distribution across firms. This aggregation problem has been treated by Blackorby and Schworm (1982), and by Chambers and Lopez (1984). They showed that it is necessary and sufficient for consistent aggregation across firms that the aggregate value function be affine [8] in the aggregate state variable. The aggregate optimal value function should also be affine in the aggregate state variable. This condition will be imposed in our empirical estimation by imposing the restriction that $A_{XX} = A_{XT} = A_{TX} = A_{TT} = 0$, which primarily affects the parameters of the output supply equations estimated.

4. Empirical estimation and results

Quarterly data were gathered for the years 1970–1990. The data for domestic inputs and outputs (including prices) were obtained from the US Department of Agriculture (USDA-ERS) publications, *Livestock and Poultry Situation and Outlook* and *Livestock Slaughter*. The data for imported beef and its price were taken from *US General Imports and Imports for Consumption* (US Department of Commerce), and the data for live cattle imports from Canada were obtained from the Albert R. Mann Library's electronic database, Cornell University (the primary source of these data was the USDA National Agriculture Statistical Service; USDA-NASS).

The three primary inputs for the processing and wholesale beef sector are the import of carcass-equivalent beef products, imports of live cattle from Canada, and domestic cattle slaughter. The input price of US cattle is the Omaha steer price, the input price of imported beef is the average unit value price of imported beef to the US, and the input price of Canadian live cattle is the average unit value price of imported Canadian cattle to the US. All import prices are unit value prices, which represent customs prices in the US and implicitly include all duties and tariffs. The output from this sector is total US commercial beef supply on a carcass-equivalent basis (as reported in the USDA's *Livestock and Poultry Situation and Outlook Report*, supply and use tables for beef); this may be converted using USDA conversion factors and population, to domestic retail per capita disappearance. As such, this sector is now more clearly defined as encompassing the live cattle to boxed beef component of the beef industry, and the output price is the average wholesale price of beef reported by the USDA. Clearly, there are other inputs to beef production such as labor, capital, and energy. However, we were unsatisfied with quarterly data series available on labor (especially quantities), capital or energy, wherein it was nearly always necessary to contrive quantities for the beef processing and wholesale sector. Second, inclusion of one additional input reduces dramatically the degrees of freedom (e.g., a fourth input adds 24 more parameters to the estimation). Therefore, we could not possibly include all three other factors, and deciding which to omit (energy, labor, or capital) would be arbitrary. However, the variables we have included are intuitively appealing as a 'separable' group (not theoretically testable in this structure) for three reasons: (1) the other factors are likely fixed, based on the high level of fixed costs in the beef processing sector (Ward, 1988), (2) the omitted factors are not sector-specific, whereas the beef products are sector-specific, and (3) normalization by the output price implicitly incorporates the relative prices of the omitted factors.

The explicit forms of the input demand and output supply equations to be estimated are derived from parameterization of Eqs. (5) and (6) and are shown in Eqs. (8) and (9):

$$X_t = B_0 + B_1 X_{t-1} + B_2 W_{t-1} + B_3 T + \varepsilon_X \qquad (8)$$
$(k \times 1)$

$$Y_t = C_0 + C_1 X_{t-1} + C_2 X_t + W'_{t-1} C_3 W_{t-1} + C_4 T + \varepsilon_Y \qquad (9)$$
(1×1)

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[8] Function $F: X \to Y$, where X and Y are in linear space, is said to be a linear function if (i) $f(x + x') = f(x) + f(x')$ for every x, $x' \in X$; and (ii) $f(\alpha x) = \alpha f(x)$ for every $\alpha \in \mathbb{R}$ and $x \in X$. In particular, if $Y \subseteq \mathbb{R}$; that is, if f is a linear real-valued function, then f is called a linear functional. The linear functional f is said to be linear affine and affine if $f(x) - f(0)$ is linear (Takayama, 1985).

Table 1
Hypothesis tests on adjustment process of the processing/wholesale beef and cattle sector

Hypothesis	Restriction imposed	Number of restrictions [a]	Test result
Independent and instantaneous adjustment	$M = -I$	k	$477.46\ (16.92)_9$
Strict fixity	$M = 0$	k^2	$83.65\ (16.92)_9$
Independent and instantaneous adjustment on ith input	$M_{ii} = -1$ and $M_{ij} = 0$	1	
Input: total slaughter (TS)			$367.45\ (7.82)_3$
Input: Canadian cattle imports (CI)			$80.52\ (7.82)_3$
Input: Beef imports (IB)			$7.41\ (7.82)_3$
Strict fixity on ith input	$M_{ij} = 0$	1	
Input: total slaughter (TS)			$16.43\ (7.82)_3$
Input: Canadian cattle imports (CI)			$14.85\ (7.82)_3$
Input: Beef imports (IB)			$49.83\ (7.82)_3$
No overall technical change	$\theta_j = 0$ [b]	k	$27.91\ (9.49)_4$
No technical change for individual inputs	$\theta_{ij} = 0$	1	
Input: total slaughter (TS)			$0.16\ (3.84)_1$
Input: Canadian cattle imports (CI)			$4.38\ (3.84)_1$
Input: Beef imports (IB)			$0.21\ (3.84)_1$
No technical change in output			$24.03\ (3.84)_1$

[a] k: the number of inputs.
[b] θ: the coefficient on the time trend variables.
Numerical subscript is degrees of freedom.
Parentheses contains the critical value for the χ^2 statistic at the 0.05 level of significance.

Eq. (8) represents the form of the three input demand equations (total domestic cattle slaughter, beef imports, and live Canadian cattle for slaughter). W_j represents the respective average factor prices during period t, normalized by the average output price (the wholesale price of beef) during period t. X_t is the inventory at the beginning of period t. Note, as indicated by Howard and Shumway (1988) (p. 840), that $\dot{X}$ is approximated by the discrete representation $X_t - X_{t-1}$, and lagged prices are used as a proxy for expected input and output prices. Eq. (9) represents the output supply equation to be estimated (carcass weight equivalent supply). In both equations, r is the discount rate set at 5% (Howard and Shumway, 1988). As mentioned earlier, the primary advantage of selecting this modeling framework is that this functional form and duality allows for recovery of all the value function parameters as shown in Eq. (10).

$$B_0 = r \cdot A_{XW}^{-1} \cdot A_2 - A_{XW}^{-1} \cdot A_{WT}, \quad B_1 = I + r \cdot I + A_{XW}^{-1}$$
$$B_2 = r \cdot A_{XW}^{-1} \cdot A_{WW}, \qquad B_3 = r \cdot A_{XW}^{-1} \cdot A_{WT}$$
$$C_0 = r \cdot A_0 - A_3, \quad C_1 = (r+1) \cdot A_1', \quad C_2 = -A_1' \tag{10}$$
$$C_3 = -\frac{1}{2} \cdot r \cdot A_{WW}, \qquad C_4 = r \cdot A_3$$

As a result of strong quarterly seasonal components to all variables, the data were seasonally adjusted prior to estimation using the X11 procedure of SAS (SAS Institute, 1984). Eqs. (8) and (9) have a simultaneous recursive relationship, and for the hypothesis tests, it was necessary to impose cross-equation restrictions (as shown in Table 1). Therefore, the model was estimated using three-stage least squares (3SLS). Instrumental variables used were the exogenous variables and their second-order polynomials (Kennedy, 1992).

Table 2
Variable definitions for estimation

TIME	Time trend (1970.00 = 1)
DB	Domestic beef production including beginning stocks (carcass weight equivalents, million lb.)
WIB	Unit value price of imported beef (US$/cwt.)/US wholesale beef price (US$/carcass wt.)
WCI	Unit value price of imported Canadian cattle (US$/cwt.)/US wholesale beef price (US$/carcass wt.)
WTS	Omaha price of slaughter cattle (US$/carcass wt.)/US wholesale beef price (US$/carcass wt.)
CI	US imports of Canadian cattle (thousand head)
TS	US total commercial cattle slaughter (thousand head)
IB	US beef imports, carcass weight equivalent (million lb.)

Table 3
Three-stage least squares parameter estimates of the processing/wholesale beef sector

Variable names	Input			Output
	TS	CI	IB	DB
INT	0.526 (0.165)	− 3.352 (1.714)	− 0.929 (0.896)	− 0.012 (0.052)
TS(− 1)	0.834 (0.048)	0.516 (0.500)	− 0.158 (0.261)	− 0.065 (0.073)
CI(− 1)	0.001 (0.008)	0.699 (0.087)	0.054 (0.045)	0.007 (0.008)
IB(− 1)	− 0.031 (0.020)	− 0.012 (0.215)	0.257 (0.112)	0.009 (0.011)
TS				0.880 (0.086)
CI				0.005 (0.010)
IB				0.041 (0.022)
WTS	− 0.273 (0.165)	3.518 (1.710)	2.036 (0.893)	
WCI	0.006 (0.022)	− 0.460 (0.234)	0.100 (0.122)	
WIB	− 0.056 (0.029)	− 0.193 (0.304)	− 0.305 (0.159)	
WTS × WTS				− 0.149 (0.162)
WCI × WCI				0.046 (0.030)
WIB × WIB				− 0.056 (0.053)
WTS × WCI				0.069 (0.129)
WTS × WIB				0.332 (0.142)
WCI × WIB				− 0.129 (0.077)
TIME	− 0.006 (0.014)	0.298 (0.145)	− 0.052 (0.076)	0.021 (0.007)
Adjusted R^2	0.89	0.74	0.37	0.95

Numbers in parenthesis are standard errors of the estimates.

Table 2 provides a listing of variable names and definitions. Table 3 shows the parameter estimates of the unrestricted (only homogeneity-imposed) [9] processing/wholesale distribution sector.

Results in Table 3 show that all own-price and quantity effects are significant, which is reassuring in estimating a structural system. The cross-price terms are not significant, but this seems to be a recurring dilemma in other similar studies. The beef import equation (IB) has a rather low adjusted R^2 value. However, this study's results are comparable in robustness to other estimated dynamic dual models (e.g., Epstein and Denny, 1983; Howard and Shumway, 1988; Vasavada and Chambers, 1986).

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[9] Homogeneity is imposed by normalizing the input prices by the output price; although homogeneity is implied by the theory of the firm, not at the aggregate level at which the current paper is based. In practical terms, we argue that the major beef processing firms share virtually identical technologies as expected in a very mature, very low margin industry; hence, the imposition of homogeneity is not strict in this case.

4.1. Multivariate accelerators and price response

The primary appeal of our method is the ability to test for the adjustment process in beef production and its impact on import behavior. As asserted earlier, the adjustment coefficients may be directly calculated from the theoretical model and estimated coefficients. Epstein demonstrated that for a value function which takes the form $J_{XW}(X, W) = (M - r)^{-1}$, as the one used here, Eq. (5) can be expressed as a multivariate flexible accelerator of the form:

$$\dot{X} = M(X - \overline{X}) \tag{11}$$

where, according to the current parameterization,

$$M = r \cdot I + A_{XW}^{-1} \tag{12}$$

and

$$\overline{X} = -\left(r \cdot I + A_{XW}^{-1}\right)^{-1} \cdot A_{XW}^{-1} \cdot r \cdot \left(A_2' + A_{WW} \cdot W\right) = -M^{-1} \cdot A_{XW}^{-1} \cdot r \cdot \left(A_2' + A_{WW} \cdot W\right) \tag{13}$$

M represents a multivariate flexible accelerator (Epstein, 1981; Howard and Shumway, 1988; Vasavada and Chambers, 1986) or a rate-of-adjustment matrix, and $\overline{X}$ denotes the long-run optimal input levels.

From the value function in Eq. (7), differentiating with respect to quasi-fixed input X yields the reduced form:

$$J_x = \left[A_1' + W \cdot M^{-1}\right] \tag{14}$$

Where J_X is the adjustment cost of changing the investment structure, A_1' is the vector of estimated coefficients, W is the normalized input price, and M^{-1} is the inverse of the multivariate accelerator interpreted as the rate of adjustment of the quasi-fixed input X. As M approaches -1, the input is completely variable and change can be made instantaneously. As M approaches 0, the change is more costly (note that J_x approaches infinity as M approaches 0) and the input exhibits a high degree of fixity. In the following interpretations, it is also important to recognize that the price term is directly associated with M. Therefore, when M is small (very high adjustment costs), a large change in prices will have a small impact; conversely, when M is large, firms may more readily adjust to those changes. M is typically between -1 and 0, indicating that investment is occurring and approaching the steady state of investment. However, M may be positive, representing the case of disinvestment from a long-run steady state (Epstein, 1981). So, the absolute value of M must be between 0 and 1, but in most growing industries, M will be less than zero.

Table 4 shows the adjustment coefficients (M) for the beef processing/wholesale sector calculated using Eq. (12) and the estimated coefficients in Table 3. The ith row of M represents the adjustment process for the ith input. M_{ii} is the rate of adjustment to long-run equilibrium by which the optimal net investment in input i will occur in each period in response to a change in relative prices given an equilibrium level of other inputs. M_{ij} tells how investment of the ith input is affected by the disequilibrium in the jth input.

As expected, the domestic beef input to the wholesale sector exhibits a high degree of fixity based on the very low value (-0.1655) of the multivariate accelerator. As hypothesized, the high costs of adjustment within the domestic beef sector makes it very difficult to adjust in the short run. This is due to several factors,

Table 4
Estimated multivariate accelerators for the processing/wholesale sector

	TS	CI	IB
TS	−0.1655	−0.0013	−0.0314
CI	0.5159	−0.3006	−0.0124
IB	−0.1578	0.0541	−0.7427

including the time necessary to breed and finish cattle to reach the slaughter stage and the limited storage potential for beef products.

The multivariate accelerator for Canadian cattle imports is somewhat larger than for domestic cattle but is still relatively small (-0.3006). Still, Canadian imports represent a way for the wholesale beef sector to adjust given the greater fixity in the domestic beef sector. However, the low value of the multivariate accelerator also indicates that the imported Canadian cattle face the same sorts of production lags and constraints as the US domestic cattle industry. This higher flexibility, given the same biological constraints as the US industry, may be due to the excess capacity of the Canadian cattle feeding industry relative to the Canadian processing sector (Hayes, 1995). Although not modeled in this paper, the relationships of the estimated adjustment coefficients make it possible to infer that a contraction in the US processing sector would result in contraction of the Canadian feedlot sector, and vice versa. Similarly, an expansion of the Canadian processing sector would reduce the adjustment ability of the US processing/wholesale sector by reducing the excess capacity of the Canadian feedlot sector relative to the Canadian packing sector, and would have short-run negative economic repercussions. This is particularly relevant given the recent decision by two US packers (IBP and Excel) to open large processing plants in Canada.

Finally, the multivariate accelerator estimated for beef imports (-0.7427) suggests the greatest amount of flexibility. This makes intuitive sense for two reasons. First, the world market for beef trade is large. Second, nearly all of the world trade in beef is in frozen form. Therefore, imported beef has greater storability than fresh beef and, therefore, can be used to adjust to unexpected changes in profitability.

Another advantage of this method is the ability to test the significance of the adjustment process. Table 1 provides the empirical hypothesis tests on the structure of the estimated US processing/wholesale beef sector. The appropriate test statistic is the Wald χ^2 statistic (Berndt, 1991; p. 474). Several tests for independent and instantaneous adjustment, strict fixity, and technical change were conducted. Independent and instantaneous adjustment means that each quasi-fixed input adjusts toward its desired level independent of the others, and that it does so very rapidly so that the input would be classified as variable. The null hypothesis of independent and instantaneous adjustment for the sector was rejected, which strengthens the assertion that the processing/wholesale sector is a factor in the availability of imports in making production decisions. Similarly, strict fixity was rejected so that inputs of domestic beef and imports both exhibit quasi-fixity; their levels can be adjusted, but doing so is costly. However, when each input was tested separately, the hypothesis of independent and instantaneous adjustment for beef imports failed rejection. This is consistent with our intuition that beef imports are the most variable input for the processing/wholesale beef sector, and that they can use imports as a mechanism to adjust to short-term market changes. Similarly, strict fixity for beef imports was soundly rejected.

The tests of technical change in the US processing/wholesale beef industry are quite interesting. First, the general test for technical change indicates that, indeed, there has been disembodied technical change for the overall sector as defined here. Closer examination by looking at individual inputs and outputs suggests that much of the technical change is accounted for by the processing/wholesale sector itself (output technical change). The hypothesis of no technical change failed rejection for the imports of Canadian cattle. This occurs because if the domestic cattle industry shrinks, the US beef processors and wholesalers would find it necessary to rely more heavily on Canadian cattle imports. The rejection of no technical change in outputs is entirely consistent with the observed trends and economies of scale regularly attributed to the packing and meat processing industries (Ward, 1988).

Thus far, our analysis has focused on the adjustment process of the US beef industry. However, the system estimated clearly offers an additional benefit of including both short-run (or, more precisely, intermediate-run) elasticities and long-run elasticities. From Eq. (4), we can directly obtain short-run elasticities, and from Eq. (12) we can directly derive long-run elasticities (Berndt et al., 1979). The elasticity formulas used for this study are available from the authors. The estimated elasticities are provided in Table 5.

Two expected results emerge from a general overview of the elasticities in Table 5. First, all own input demand elasticities are negative; this is an improvement over previous studies using an adjustment cost model,

Table 5
Short- and long-run elasticities for the processing/wholesale beef sector

Quantity	Short-run elasticities with respect to the price of			
	TS	CI	IB	DB
TS	−0.2726 (0.0255)	0.0060 (0.0021)	−0.0562 (0.0101)	0.3228 (0.0323)
CI	3.5183 (7.9158)	−0.4601 (0.8941)	−0.1930 (0.4194)	−2.8652 (6.6280)
IB	2.0357 (0.3404)	0.1002 (0.0275)	−0.3054 (0.0771)	−1.8305 (0.2868)
DB	−0.0347 (0.0428)	0.0405 (0.0712)	0.0274 (0.0332)	−0.0332 (0.0415)
Quantity	Long-run elasticities with respect to the price of			
	TS	CI	IB	DB
TS	−1.6476 (0.1542)	0.0364 (0.0129)	−0.3394 (0.0610)	1.9506 (0.1956)
CI	11.7035 (26.3924)	−1.5305 (2.9813)	−0.6421 (1.3985)	−9.5309 (22.0986)
IB	2.7409 (0.4594)	0.1349 (0.0372)	−0.4112 (0.1041)	−2.4646 (0.3871)
DB	−0.9597 (0.0429)	0.0513 (0.0694)	−0.2146 (0.0548)	1.1230 (0.0735)

Elasticities evaluated at the means of the variables.
Numbers in parenthesis denote standard errors of elasticities.

where some have been positive (Vasavada and Chambers, 1986). Second, the long-run elasticities are all greater in absolute value than the short-run, indicating that the Le Chatelier principle holds. Further, although the own output supply elasticity is negative in the short run, it is positive in the long run. This negative short-run elasticity is consistent with previous studies in the beef industry (e.g., see Tryfos, 1974; Marsh, 1994; Kulshreshtha, 1976; Nelson and Spreen, 1978; and Jarvis, 1974 for elasticities). While this is also consistent with the high adjustment costs (Table 4) of the domestic beef industry, it may seem inconsistent with the positive elasticity of output price on total slaughter. However, consider that total domestic slaughter includes both fed and nonfed slaughter. In this situation, an increase in output price is likely to cause marginal cattle (nonfed and lighter weight fed cattle, sometimes called 'green' cattle) to be pulled into the processing and wholesale sector in the short run, so that although slaughter increases domestic beef, yields and weights may decline and actually result in a reduction in the output supply. This is similar to the argument used by Marsh (1994) and indicates the behavior of fed cattle supplies as capital goods. A similar explanation accounts for the short-run negative supply response of both imported inputs. The domestic cattle industry pulls through lower quality cattle in the short run (i.e., nonfed, lighter weight fed cattle, and culls) attempting to adjust. These lower quality US cattle compete with imports of lower quality beef and Canadian live cattle and results in reduced output of beef due to the imported components (USITC, 1993).

With respect to cross-price elasticities, Canadian cattle are clearly substitutes for US domestic cattle. This is as expected because both sectors have similar adjustment costs (Table 4) and, hence, relative price changes in one or the other sector should have similar impacts (Eq. (14)). Further, although Canadian cattle are typically leaner and would not meet US grading standards for high-quality beef, they are likely to be substitutes.

The implications for imported beef products are more complicated. As imported beef prices increase domestic total slaughter declines, resulting in a complementary relationship. The opposite is true for the case of price increases in domestic total slaughter, in that imports decrease and are, therefore, substitutes. However, the adjustment cost model again provides insight into this circumstance. First, notice that the adjustment costs for imported beef are much lower than for domestic beef (Table 4). In this framework, an increase in the relative price of beef imports means that the price of the more flexible input in production has increased. Therefore, firms will lower their demand, all else equal, for the less flexible input (domestic slaughter cattle) because of the high adjustment costs that would be incurred with any subsequent market changes; although the less flexible

input is now relatively cheaper. Thus, as indicated by Eq. (14), the high adjustment cost counteracts the potential substitution effect. This argument is similar to that used in the theory of production under uncertainty. That is, increased uncertainty leads to lower expected returns and, therefore, firms will demand less of an uncertain input. In our framework, firms are adjusting to their long-run equilibrium and would be reluctant to build capacity in a highly quasi-fixed input that would cause potentially high adjustment costs for correction. Conversely, the demand for imports increases when total slaughter prices increase (are substitutes), simply because beef imports are highly flexible inputs and require little in the way of adjustment costs should market conditions change. In addition to the adjustment cost insights, the practical fact that beef imports are lower quality products often blended with domestic beef products to make ground beef can also result in complementary relationships. If the results had been reversed, (i.e., as total domestic slaughter prices increased, imports decreased) the adjustment cost hypothesis would have provided contradictory results.

None of the signs change in the long run compared to the short run, except for the own-output supply response turning positive, which is expected. Essentially the same arguments apply, and the unique relationships of low-quality imports vs. high quality domestic beef holds. Also, in the long run, the US industry continues to expand and to displace imports if the output supply price increases. This result is consistent with previous trade literature. Beef production is said to be domestic input intensive and, as pointed out by Kohli (1978), an increase in the price of output should be accompanied by a higher demand for the domestic input or, more precisely, the factor with more intensive use in production. Therefore, an increase in the output price would result in a lower demand for foreign imports. The reason the US continues to import is because of the high adjustment costs of the domestic industry, not necessarily because of any comparative cost or price disadvantages. Otherwise, imports would play a more prominent role in US beef production.

5. Conclusions

A dynamic production theory approach was used to model the behavior of the US processing and wholesale beef sector with imports. This approach contrasts with previous studies estimating beef import behavior in that they have typically modeled this as consumer demand driven. As estimated, the system provides theoretically consistent estimates of price elasticities and the adjustment behavior of the processing and wholesale sector of the US beef industry, where the bulk of imports enter the US beef product channel.

Of primary importance is the fact that the results confirm our central hypothesis that the processing and wholesale sector of the US beef industry use imports as a way to adjust to market changes because they face significant adjustment costs in their primary domestic input of beef cattle. This contributes towards explaining why a large beef-producing country, such as the US, would continue to be a major producer and importer of beef and cattle. Further, price elasticity results which indicate short-run inelastic supply response is consistent with the high adjustment costs found and with the results of other studies of beef industry supply response. The US and Canadian cattle industries produce substitutable products; however, the market for imported beef products is ambiguous. We assert that the ambiguity is due to the mixed effect of disparities in adjustment costs between US domestic beef cattle and imported beef and the quality differences between US beef and imported beef products.

Although no policy simulations are conducted, a key result suggests that there are very high adjustment costs in the domestic cattle industry. As a result, imported cattle, and, to an even greater extent, imported beef products, can help the processing sector adjust to market changes. Therefore, policies that favor free trade have the potential to lower aggregate adjustment costs and promote growth in the beef processing and wholesale sector. This result depends on the fact that the relative prices of domestic cattle and beef and imported cattle and beef remain unchanged. If the input prices of imported beef and cattle are lowered relative to domestic inputs, the price effect could outweigh the potential benefits gained through reduced adjustment costs.

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