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**U.S. Demand for Imported Lamb by Country:
A Two-Stage Differential Production Approach***

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Abstract

Due to a depressed wool industry sheep inventories have been declining resulting in significant increases in lamb and mutton imports. Goals of this paper are to estimate the derived demand and output supply for U.S. lamb imports, estimate demand elasticities, and to determine the impact of TRQ reductions on imports.

U.S. Demand for Imported Lamb by Country: A Two-Stage Differential Production Approach

Since 1975, total use of lamb and mutton in the U.S. has kept pace with the rise in population, enabling per capita consumption to remain fairly stable. However, due to a depressed wool industry, of which lamb and mutton are joint products, sheep inventories have been declining, reducing the number of animals available for market each year. As a result, lamb and mutton imports have significantly risen since the mid-1980's, with very sharp increases since 1994. In 2002, lamb and mutton imports were up 11 percent compared to the previous year and up 440 percent since 1975. Imports, which currently account for more than one-third of U.S. lamb and mutton consumption, are primarily imported from Australia and New Zealand, accounting for 98 percent of all U.S. imports. Lamb imports from both countries have increased dramatically, with imports from Australia showing a much faster rate of growth since 1995 (Jones, Hahn, and Davis).

In July 1999, following the rapid rise in lamb imports in the mid-1990 the U.S. established a 3-year tariff-rate quota (TRQ). The TRQ essentially rations the available supplies among willing domestic consumers by adjusting the price upward by the value of the *ad valorem* duties levied on lamb. The *ad valorem* duty is commonly stated as a percentage of a readily observed international price and is designed to increase the price to domestic consumers and thereby reduce the supply of imported lamb. *Ad valorem* duties were levied for both in-quota and over-quota amounts of imported lamb. Removal of the TRQ, as required by a World Trade Organization (WTO) ruling, could lower domestic prices, and thereby increase domestic consumption of imported lamb. This will likely result in a further increase in imports from strong U.S. competitors such as Australia and New Zealand.

The primary goal of this paper is to derive empirical estimates of conditional and unconditional elasticities of derived demand for imported lamb and mutton differentiated by source country of production (Australia and New Zealand) and type (frozen and chilled) with respect to frozen and chilled prices in Australia and New Zealand, U.S. wholesale lamb price, U.S. wages in the wholesale trade sector, and the total amount of frozen and chilled lamb imported. The impact of the removal of the TRQ on U.S. lamb imports will be assessed as well. Past studies that assessed the demand for imports differentiated by source country of production have used a consumer approach to obtain import demand equations. However, given that imported lamb is purchased by firms, and that a significant amount of transformation and/or value added takes place once imports reach the U.S., this paper estimates import demand from a production approach where lamb imports are inputs into production processes. Specific goals are: (1) to econometrically estimate the conditional derived demand, unconditional derived demand, and output supply for U.S. lamb imports differentiated by source country of production and type; (2) to utilize estimated derived demand parameters to obtain conditional and unconditional elasticities of derived demand and output supply; and (3) to determine the impact of TRQ removal mandated by the WTO.

Methodology

The differential approach to the theory of the firm is comparable to the differential approach to consumer theory proposed by Henri Theil and A.P. Barten in 1965. The empirical application of the differential approach to consumer demand resulted in the Rotterdam model, which has been used extensively in demand studies and to a lesser extent in import demand studies. Using the methodology of Laitinen and Theil, Laitinen, and Theil, the differential production model is used

to estimate the derived demand and supply of imported lamb in the U.S. The differential production model is derived from the differential approach to the theory of the firm where firms maximize profit in a two-stage procedure. In the first stage, firms determine the profit maximizing level of output to produce and in the second stage firms minimize the cost of producing the profit maximizing level of output. According to Laitinen and Theil, and Davis and Jensen, this procedure is consistent with a one-step or direct profit maximization procedure.

In this paper, it is assumed that the U.S. imports lamb and mutton through firms that exclusively import. Essentially these firms import lamb from all possible sources and then sell the output “imported lamb” to other firms within the U.S. If we assume a production function for these firms, then the output of these firms is total amount of imported lamb sold to other firms and the inputs are the factors of production required in wholesale trade and the imported lamb from the exporting countries. If we minimize cost subject to this production function, then part of the system of input demand equations resulting from the optimization procedure will be a system of import demand equations. If we assume product differentiation across source countries, then each import demand equation will represent the demand for a product from a particular source.

In the first-stage, the importing firm seeks to maximize profit by equating marginal cost with marginal revenue. This procedure yields the differential output supply equation (expressed in finite log changes)

$$(1) \quad \Delta X_t = \varphi \Delta p_t + \sum_{j=1}^N \pi_j \Delta w_{jt} + \psi \Delta quota_t + \varepsilon_{it} ,$$

$\Delta X_t = \sum_{i=1}^n \bar{f}_{it} \Delta x_{it}$ where ΔX_t is the finite version Divisia volume input index;

$\Delta p_t = \log(p_t / p_{t-12})$, $\Delta w_{it} = \log(w_{it} / w_{it-12})$ and $\Delta quota_t = \log(quota_t / quota_{t-12})$, where p and the w_i 's represent output price and input prices respectively; $quota$ represent the TRQ in-quota level.¹ φ , π and ψ are the parameters to be estimated, where φ measures the impact of a percentage change in output price on the Divisia volume input index and the π_j 's measure the impact of a percentage changes in input prices on the Divisia volume input index; ε_{it} is the disturbance term.

In the context of this paper, the Divisia volume input index represents the total quantity of imported lamb supplied by U.S. importing firms. p is the wholesale price at which these firms sell to other firm in the U.S., and the w_i 's are the prices paid for lamb imports (frozen and chilled) from each of the exporting countries (Australia and New Zealand) and the price of labor (wages). N is the total number of inputs used which is equal to the number of imported goods plus any additional inputs.

In the second stage, the differential derived demand model is derived, which is used to estimate the system of import demand equations. This model is specified as follows (expressed in finite log changes)

$$(2) \quad \bar{f}_{it} \Delta x_{it} = \theta_i^* \Delta X_t + \sum_{j=1}^n \pi_{ij}^* \Delta w_{jt} + \varepsilon_{it} ,$$

¹ Given that monthly data is used, a 12 period lag (1 year) is used to correct for seasonal variation. The quota term ($\Delta quota$) is added to account for the time period when the TRQ was in place. It is not part of the theoretical construct of equation (1).

$\bar{f}_{it} = (f_{it} + f_{it-1}) / 2$; $\Delta x_{it} = \log(x_{it} / x_{it-1})$ and $\Delta w_{it} = \log(w_{it} / w_{it-1})$, where x_i and w_i represent the quantity and price of imports from source country i ; Like equation (1),

$\Delta X_t = \sum_{i=1}^n \bar{f}_{it} \Delta x_{it}$ where ΔX_t is the Divisia volume input index; θ_i^* and π_{ij}^* parameters to be estimated, where θ_i^* is the marginal factor share coefficient and π_{ij}^* measures the price effects; n is the number of imported goods in the system; ε_{it} is the disturbance term.

In addition to the imports from each individual source country, labor and other inputs may be used in the production process. The labor demand and demand for other inputs are expressed in general terms as

$$(3) \quad \text{Labor} = f(\text{output}, \text{wages}, \text{input price index})$$

$$(4) \quad \text{Other Inputs} = f(\text{output}, \text{wages}, \text{input price index}).$$

Equations (3) and (4) represent the system of derived demand equations for labor and other inputs where these inputs are a function of the total amount to be supplied, wages, and an input price index which represents the price of all inputs except labor and lamb imports. Here we assume that labor and other inputs are independent of the source-specific lamb imports. This is to say that although labor and other inputs affect the total to be imported, these inputs do not directly affect the amount imported from an individual source country.

The differential factor demand model requires that the following parameter restrictions be met in order for the model to conform to theoretical considerations: $\sum_j \pi_{ij}^* = 0$ (homogeneity), and

$\pi_{ij}^* = \pi_{ji}^*$ (symmetry). The second stage procedure results in the conditional own price/cross price elasticity

$$(5) \quad \varepsilon_{xw}^c = \frac{\pi_{ij}^*}{f_i},$$

and the conditional Divisia volume input elasticity,

$$(6) \quad \varepsilon_{xX} = \frac{\theta_i^*}{f_i}.$$

Substituting equation (1) into equation (2) yields the unconditional derived demand system

$$(7) \quad \bar{f}_i \Delta x_{it} = \theta_i^* [\varphi \Delta p + \sum_{j=1}^N \pi_j \Delta w_j + \psi \Delta quota] + \sum_{j=1}^n \pi_{ij}^* \Delta w_j.$$

Dividing through equation (7) by f_i and using equations (5) and (6) we get the unconditional derived demand elasticities. The unconditional elasticity of input demand with respect to output price is

$$(8) \quad \varepsilon_{xp} = \varepsilon_{xX} \varphi.$$

The unconditional own price/cross price elasticity of input demand is

$$(9) \quad \varepsilon_{xw} = \varepsilon_{xX} \pi_j + \varepsilon_{xw}^c.$$

Lastly, we get the unconditional elasticity of derived demand with respect to the price of an input contained in N but not in n

$$(10) \quad \varepsilon_{xw} = \varepsilon_{xX} \pi_j.$$

Inputs contained in N but not in n include labor and other inputs that are not part of the imported lamb group.

Data and Description of Variables

Derived demand and supply equations are estimations using monthly data. The data set covers the time period January 1989 through September 2003. Monthly import quantities and expenditures on frozen and chilled lamb meat were obtained from the U.S. Department of Commerce (DOC). All expenditures are on a CIF basis. Using expenditures and quantities, per-unit values (\$/kg) for New Zealand and Australia frozen and chilled lamb meat were calculated. Per-unit values are used as proxies for import prices. U.S. wholesale lamb prices were provided by the U.S. Department of Agriculture, Agricultural Marketing Service (USDA-AMS). The price of labor was obtained from the Bureau of Labor Statistics, which is the average hourly earning of all individuals in the wholesale trade sector. Imports from countries other than New Zealand and Australia are negligible.

In July 1999, the United States imposed a three-year TRQ on lamb meat imports. For the first implementation year (July 1999-June 2000) the TRQ in-quota limit was 70.2 million pounds. For the period July 2000 through June 2001, the in-quota levels rose to about 72.1 million pounds. Lastly the in-quota level for the final period (July 2001-November 2001) the in-quota level rose to 74 million pounds. On May 1, 2001, an appellate body of the World Trade Organization (WTO) ruled against this policy. As a result, the U.S. agreed to end its TRQ on lamb imports November 2001 (World Trade Organization, 2001). To assess the impact of the TRQ a quota variable was constructed and included in the estimation of equation (1). For all months before and after the TRQ period this variable equals 1 and for the specified months the TRQ was implemented, this variable is equal to the in-quota limit.²

² The estimation of equation (1) requires that the log difference be taken on all relevant variables. When the TRQ variable, $quota = 1$, $\log(quota) = 0$, which indicated no impact on imports during non-TRQ months.

Empirical Results

Table 1 presents the conditional parameter estimates for the derived demand for imports of frozen and chilled lamb into the U.S (equation (2)). All results have homogeneity and symmetry imposed, although Likelihood-Ratio (LR) tests, as well as Laitinen's test indicate a rejection of the homogeneity property. However, given homogeneity, LR test indicated that symmetry could not be rejected. As indicated in the table, all own-price coefficients are negative, as expected and all are significant at the 0.01 significance level. The conditional marginal factor share estimates indicate a positive relationship between the Divisia volume index and source-specific lamb imports. These indicate that as total lamb imports increase, both frozen and chilled lamb from each of the source countries will also increase. Cross-price parameter estimates indicate that all cross relationship are substitutional. Substitutional relationships occur between frozen and chilled lamb from the same source, frozen lamb from different sources, chilled lamb from different sources, and frozen lamb from one source and chilled lamb from the other. Lastly, estimates indicate that the relationship between imports of frozen lamb from New Zealand and the price of frozen and chilled lamb from Australia are insignificant.

Results of first-stage estimation of the output supply equation, equation (1) are presented in Table 2. The output price parameter estimate (0.2653) is positive as expected and significant. This also indicates that as U.S. wholesale prices increase by 1-percent the Divisia volume input index will increase by 0.2653 percent. The parameter estimate for the price of labor (wages) is the only input price estimate with the incorrect sign (3.59). All others indicate an inverse relationship between input/import prices and the Divisia index. Estimates of the impact of the

price of frozen and chilled lamb meat from Australia and New Zealand are -0.020, -0.360, -0.121 and -0.329 respectively. The impact of New Zealand and Australia frozen lamb price changes on the Divisia index is insignificant. Lastly, the estimate for the TRQ effect on total imported is both negative (-0.0041) and significant. This indicates that the implementation of the TRQ had an adverse impact on total imports of lamb.

Table 3 presents the conditional elasticities of derived demand for lamb meat imported into the U.S. The Divisia index elasticities for imports of lamb are 0.843, 0.951, 1.251 and 0.931 for New Zealand frozen, New Zealand chilled, Australia frozen and Australia chilled respectively. All Divisia elasticity estimates are significant at a significance level of 0.01. These elasticities indicate that as the Divisia volume index increases by 1-percent, frozen and chilled imports from both countries will increase by these elasticity values. As total imports increase, the greatest percentage increase will be frozen lamb imports from Australia. The own price elasticities are -0.279, -1.114, -0.751, and -0.864 for New Zealand Frozen, New Zealand Chilled, Australia Frozen, and Australia Chilled, respectively. All are significant at a significance level of the 0.01. These indicate that the demand for chilled imports tends to be relatively more elastic than the demand for frozen imports, this likely due to chilled imports being relatively more expensive and more perishable.

Conditional cross-price elasticities of derived demand for imported lamb meat in the U.S. indicate significant substitutional relationships between frozen and chilled imports from both countries. A 1-percent increase in the price of frozen imports from New Zealand will significantly increase chilled imports from New Zealand, but results show no impact on imports

from Australia. However, a 1-percent increase in the price of chilled imports from New Zealand will result in an increase in frozen import from New Zealand, and frozen and chilled imports from Australia by 0.137, 0.142 and 0.190, respectively. Lastly, increases in the price of frozen and chilled imports from Australia will increase the demand for chilled imports from New Zealand but will have no impact on frozen imports from that country.

Unconditional elasticities of derived demand are reported in Table 4. Results indicate that for every percentage increase in U.S. price (output price), frozen and chilled imports from New Zealand and Australia will increase by 0.224, 0.252, 0.332 and 0.247 percent respectively. The wage coefficient of equation (1) is positive. This positive sign is difficult to reconcile with theory if one believes that imported lamb must be processed within the domestic market.

However, imported lamb is largely cuts and further processed lamb. The U.S. lamb price is a carcass price. Higher U.S. wages would encourage wholesale lamb importers to purchase value-added imports rather than unprocessed U.S. lamb. As expected unconditional own-price elasticities all indicate an inverse relationship between the price charge by exporters and what is imported from that country to the U.S. Results indicate that the demand for New Zealand and Australia chilled lamb meat is elastic (-1.457 and -1.171 respectively). The demand for Australia frozen lamb meat is inelastic but close to unit elastic (-0.902) and the demand for New Zealand frozen is highly inelastic (-0.296). Unlike the conditional cross-price elasticities, unconditional cross-price elasticities indicate that lamb imports from both countries can be either substitutes or complements. An explanation for these results is the result of the unconditional price elasticities incorporating in the impact of prices on total imports into the elasticity. For example if the price of Australia chilled lamb fell, given a fixed total imports, imports from Australia will likely

increase and decrease New Zealand's imports. However, the unconditional elasticity incorporates the impact of the fall in price on total imports. The fall in Australia price could also increase total imports so much so that the impact of total import increases could outweigh the impact of the fall in relative prices.

Summary

In view of increasing lamb and mutton imports and declining domestic supplies, the goal of this paper was to derive empirical estimates of conditional and unconditional elasticities of derived demand for imported lamb and mutton differentiated by source country of production (Australia and New Zealand) and type (frozen and chilled) with respect to frozen and chilled prices in Australia and New Zealand, U.S. wholesale lamb price, U.S. wages in the wholesale trade sector, and the total amount of frozen and chilled lamb imported. The impact of the removal of the TRQ on U.S. lamb imports was assessed as well.

We used the differential approach to the theory of the firm where firms maximize profits in two stages. In the first stage, firms determine the profit maximizing level of output to produce and in the second stage firms minimize the cost of producing this profit maximizing level. We assume that firms import lamb from all possible sources and sell the output to other firms, be it wholesalers or retailers.

The results show that as the U.S. wholesale price of output supply increases, imported lamb increases. Also, the results suggest that the TRQ had a significant and adverse impact on total imports and therefore could have been more effective for U.S. if exchange rates for Australia and

New Zealand were not that favorable during the implementation period. Significant own price elasticities were also obtained for both fresh and frozen in the two countries, with chilled lamb imports being more elastic than frozen lamb. Statistically, significant substitutional relationships between frozen and chilled imports were also seen for both countries.

Table 1. Conditional Derived Demand Parameter Estimates for U.S. Imports of Lamb

Exporting Country/good	Price Coefficients, π_{ij}^*				Marginal Factor Shares, θ_i^*
	New Zealand Frozen	New Zealand Chilled	Australia Frozen	Australia Chilled	
New Zealand Frozen	-0.0838*** (0.0259) ^a	0.0412*** (0.0098)	0.0132 (0.0235)	0.0295 (0.0199)	0.2535*** (0.0281)
New Zealand Chilled		-0.1368*** (0.0122)	0.0411*** (0.0114)	0.0546*** (0.0126)	0.1168*** (0.0109)
Australia Frozen			-0.2178*** (0.0349)	0.1635*** (0.0249)	0.3630*** (0.0318)
Australia Chilled				-0.2476*** (0.0284)	0.2667*** (0.0248)
System $R^2 = .74$					

^a Asymptotic standard errors are in parentheses.

*** Significance level = 0.01.

Table 2. Parameter Estimates for the Supply of Imported Lamb in the U.S.

Input Price Coefficients, π_{ij}					Quota	Output Price Coefficient φ
New Zealand Frozen	New Zealand Chilled	Australia Frozen	Australia Chilled	Wage		
-0.0201 (0.0736) ^a	-0.3607*** (0.0895)	-0.1210 (0.2134)	-0.3291*** (0.0929)	3.5900*** (0.5333)	-0.0041* (0.0024)	0.2653** (0.1158)
$R^2 = .26$						

^a Asymptotic standard errors are in parentheses.

*** Significance level = 0.01.

** Significance level = 0.05.

Table 3. Conditional Divisia and Price Elasticities of the Derived Demand for Imported Lamb

Exporting Country/good	Divisia Index	Conditional Own-Price	Elasticities			
			Conditional Cross-Price			
			New Zealand Frozen	New Zealand Chilled	Australia Frozen	Australia Chilled
New Zealand Frozen	0.843*** (0.093) ^a	-0.279*** (0.086)		0.137*** (0.033)	0.043 (0.078)	0.098 (0.066)
New Zealand Chilled	0.951*** (0.089)	-1.114*** (0.100)	0.336*** (0.080)		.334*** (.093)	0.444*** (0.102)
Australia Frozen	1.251*** (0.110)	-0.751*** (0.120)	0.045 (0.081)	.142*** (.039)		0.564*** (0.085)
Australia Chilled	0.931*** (0.087)	-0.864*** (0.099)	0.103 (0.069)	0.190*** (0.044)	0.571*** (0.087)	

^a Asymptotic standard errors are in parentheses.

*** Significant level = .01

Table 4. Unconditional Elasticities of the Derived Demand for Imported Lamb

Exporting Country/good	Elasticities					
	Output Price	Wages	Unconditional Own and Cross-Price			
			New Zealand Frozen	New Zealand Chilled	Australia Frozen	Australia Chilled
New Zealand Frozen	0.224*** (0.025) ^a	3.027*** (0.336)	-0.296*** (0.087)	-0.167*** (0.044)	-0.058 (0.078)	-0.180*** (0.031)
New Zealand Chilled	0.252*** (0.023)	3.414*** (0.318)	0.316*** (0.002)	-1.457*** (0.099)	0.219** (0.094)	0.1313*** (0.029)
Australia Frozen	.332*** (0.029)	4.492*** (0.393)	0.020*** (0.002)	-0.310*** (0.040)	-0.902*** (0.121)	0.152*** (0.036)
Australia Chilled	.247*** (0.023)	3.342*** (0.310)	0.084*** (0.002)	-0.145*** (0.031)	0.458*** (0.010)	-1.171*** (0.028)

^a Asymptotic standard errors are in parentheses.

*** Significant level = 0.01

** Significant level = 0.05

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