International Food and Agribusiness Management Review
Volume 23, Issue 3, 2020; DOI: 10.22434/IFAMR2019.0204

Received: 4 December 2019 / Accepted: 13 April 2020

How important are product attributes for U.S. lamb imports?

RESEARCH ARTICLE

Danielle Ufer[a], Amanda M. Countryman[ⓘb] and Andrew Muhammad[c]

[a]*Graduate Research Assistant, Agricultural, Food and Resource Economics, Michigan State University, 458 W Circle Dr, Michigan State University, East Lansing, MI 48824, USA*

[b]*Associate Professor, Department of Agricultural and Resource Economics, Colorado State University, 1200 Center Ave. Mall, Colorado State University, Fort Collins, CO 80523-1172, USA*

[c]*Professor, Department of Agricultural and Resource Economics, University of Tennessee Institute of Agriculture, 2621 Morgan Circle, 310 Morgan Hall, Knoxville, TN 37996, USA*

Abstract

The U.S. lamb industry has changed in the last decade, impacting the structure of imports, which have become necessary to meet domestic demand. Product differentiation plays an important role in determining lamb imports. This research examines the importance of source (country or origin) and product attributes such as boneless versus bone-in cuts and chilled versus frozen products in determining U.S. demand for imported lamb. Overall, boneless and bone-in products show evidence of separability, which is an indication that preferences are independent based on these characteristics. For other product attributes, preferences were not independent, implying their aggregation in trade analyses may be justified. For agribusiness importers and wholesalers, our results and a better understanding of the importance of product origin, quality and form are useful to inform pricing and product substitution strategies.

Keywords: imports, lamb, product differentiation, separability, Rotterdam model
JEL code: F14, Q11, Q17

ⓘCorresponding author: amanda.countryman@colostate.edu

1. Introduction

The decline in U.S. lamb production has resulted in a significant rise in imports to meet domestic demand (Williams *et al.*, 2008). Since 1989, U.S. lamb imports increased from US$ 42 million to US$ 806 million in 2017, an increase of more than 1,800% (USDA, 2016a). U.S. lamb imports, primarily from Australia and New Zealand, have grown steadily over the past three decades (Figure 1). Lamb production in Australia and New Zealand is pasture-based, rather than grain-fed, as is the conventional American method of production, which contributes to Australia and New Zealand having a comparative advantage in lamb production. Imports have increased over time to meet domestic demand as American lamb producers have shifted production away from sheep toward more profitable enterprises such as beef cattle. Indeed, domestic production has shrunk at such a rate that imports now surpass domestic lamb production. As imports have become increasingly important to meeting U.S. demand, this research seeks to better understand the factors that determine U.S. lamb imports.

The availability of higher frequency and detailed trade data allows for analyses that can account for specific product attributes assumed inconsequential in previous research. In this study, we estimate U.S. demand for imported lamb using higher frequency and more detailed data that allow for an examination of the importance of specific product attributes (boneless, bone-in, chilled, and frozen). This is important because if product distinctions such as boneless and bone-in are important to importers or consumers, then it could be argued that previous studies of a more aggregated product could be biased. This is because aggregating across product characteristics for analysis implies that preferences and consumption behavior are the same

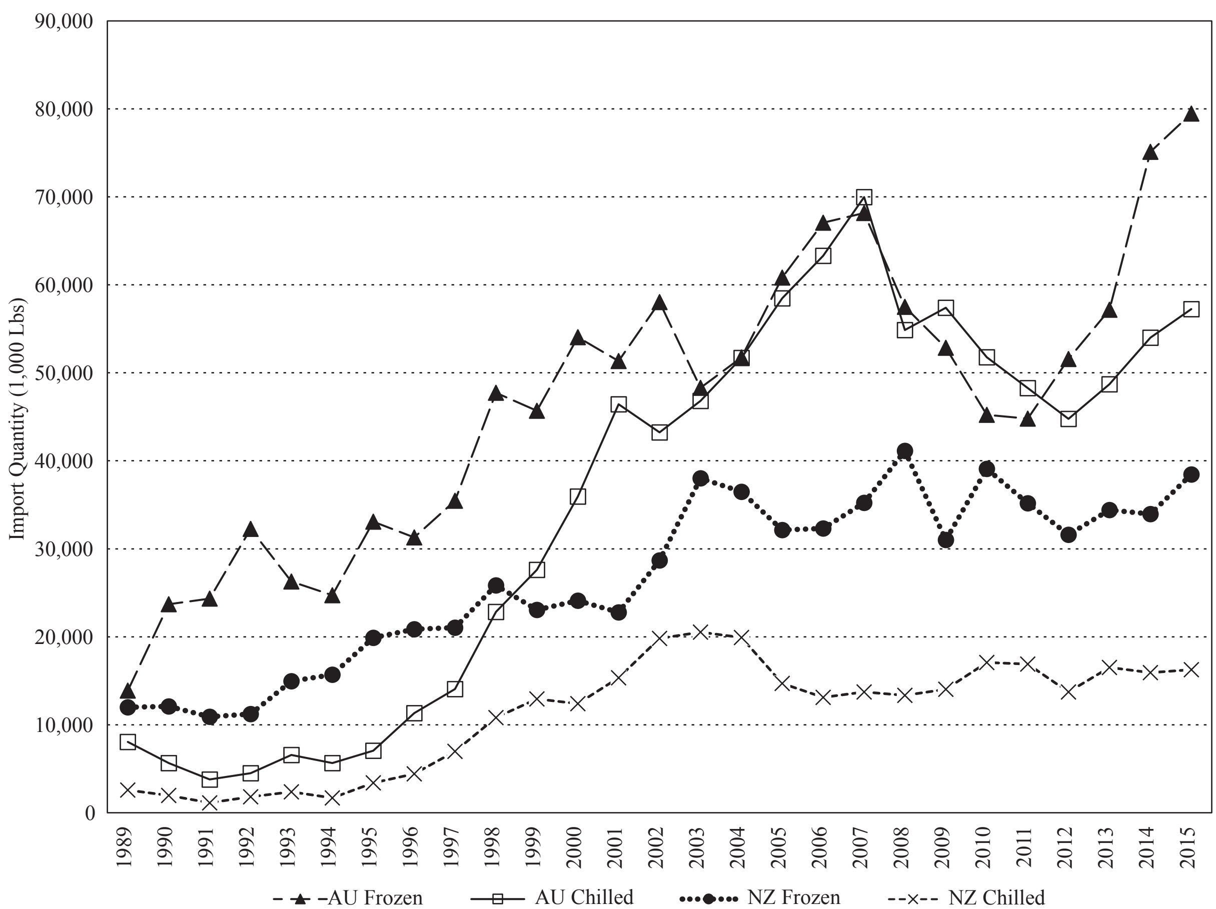

Figure 1. Total annual import quantity by source and product (chilled or frozen) (USDC, 2017).

regardless of these product attributes. To ignore these attributes when individuals are not indifferent can result in significant information loss and biased demand estimates (Muhammad and Jones, 2011).

A number of studies have examined the importance of product attributes in demand and their influence on importing and consumption behavior. In some cases, products are aggregated across traits, where no distinctions are made for product form, packaging, or storage, as has been observed in coffee imports (Sellen and Goddard, 1997). In other cases, import purchase decisions are separable by product attributes, where expenditures are allocated by attribute rather than across the commodity as a whole. For example, in catfish imports, fresh catfish is treated as a different product from frozen catfish, rather than import decisions being made across the broader category of 'catfish' as a single product (Muhammad and Hanson, 2009). Similarly, salmon of different origins is treated separately in import decisions, where salmon from one country is not interchangeable with salmon from another (Muhammad and Jones, 2011). Yet another example is the packaging style used for the product, where bulk wine and bottled wine constitute different products for import decision making in China (Capitello *et al.*, 2015). Knowing which product attributes are relevant in differentiating products for import decisions is invaluable to the study and understanding of import demand. Failure to treat products which importers view as differentiated, and instead aggregating over product categories for analysis can bias estimates and severely limit the validity of results.

This paper also contributes to the broader U.S. meat import demand literature. U.S. meat imports have historically been subject to tight restrictions owing to various policies such as the 1964 Meat Import Act and 1979 Meat Import Law which imposed import quotas. As such, U.S. meat industries, particularly beef and pork, had little influence from imports, leading to relatively little research in those markets (Brester, 1996). Nevertheless, as trade policies have gradually changed and liberalized, some studies have been conducted on U.S. meat import demand. Mutondo and Henneberry (2007) conducted an analysis of the importance of source-differentiation in the major meat markets in the U.S., both domestic and imported, finding source-differentiation is necessary for U.S. meat import analysis. Their study also identified the competitive advantage of U.S. beef and pork in the domestic market, generally limiting the importance of imports to meet specific cut demand, such as beef trimmings for ground beef and pork spare ribs. In the 'minor meats' of goat, lamb and mutton, Sande and Houston (2007) found import demand to be inelastic, driven by increasing ethnic populations in the U.S. and insufficient domestic production. Muhammad *et al.* (2007) examined U.S. demand for imported chilled and frozen lamb by source but did not test for the importance of other product attributes in determining demand.

We examine the importance of product differentiation by considering lamb import demand by differentiating not only by source country, but also by other important meat attributes: whether lamb is chilled, frozen, boneless, or bone-in. These particular traits are of interest because they are indicators of quality, with chilled lamb generally considered fresher and, as such, more desirable than frozen; and can have meaningful implications for the types of cuts demanded. In beef and pork, the same cut of meat can often come in both a boneless and bone-in form, while in lamb, the standard for most cuts is to be either boneless or bone-in. For example, top loin steaks in beef can be either boneless or bone-in while loin chops in lamb are, nearly without exception, bone-in.

Having a solid understanding of the importance of product origin, quality and form could be essential for agricultural commodity importers and wholesale firms in determining their pricing and product substitution strategies. For instance, if consumers are indifferent to bone-in versus boneless cuts, then importers can aggregate their import decisions across these product qualities and more easily substitute bone-in for boneless cuts without facing severe price consequences. In contrast, if products are treated differently by consumers depending on origin, quality or form, then pricing strategies must be formed to reflect narrower product categories. Importers may thus need to make strategic pricing decisions to guard against the increased risk of fewer available substitutes among the separable products. Additionally, as is demonstrated by Bekkerman *et al.* (2019), having accurate estimates of relationships between products and their attendant elasticities is vital to agribusinesses and policymakers in determining optimal strategies for future market decisions and actions.

Furthermore, understanding trade patterns and import decisions is of the utmost importance as we navigate the uncertainties generated under the current trade environment. Trade disruptions can have far-reaching impacts and their evaluation is dependent on a solid understanding of the trade infrastructure in which they are enacted. In the particular case of lamb, where only two foreign markets bear considerable relevance, the assumption that both markets are essentially the same could lead to substantial issues if a trade policy is enacted that impacts relations with one country but not the other. That is, if the structure of imports is essentially the same from both countries, then reducing imports from one could easily be compensated for by increasing imports from the other. However, if imports from one country are not easily substitutable with those of another, with preferences over traits like frozen, chilled, boneless and bone-in differentiating products, such trade policies could quickly lead to an upheaval in the import market. Thus, a solid understanding of the structure of the lamb import market and the determinants of importer decisions is essential to informing trade policies to optimize trade outcomes.

2. Background

Imports have become integral to the supply of lamb in the U.S. Several factors have contributed to a changing market, with multiple noteworthy events and policies shaping American lamb supply and consumption over the past century. Accordingly, we describe the influences and circumstances that have led to the current state of the U.S. lamb market, including the decline of domestic production and shifts in demand which have necessitated a growing dependence on imports.

The portrait of the American lamb consumer has changed over the past few decades, owing in part to influences such as an increased population of ethnic consumers and changes in household consumption patterns. Shiflett *et al.* (2010) determined that ethnic consumers, defined as consumers not fitting the traditional Caucasian-American consumer profile consumed 58% of all lamb in the country, both domestic and imported, in 2010. While ethnic consumers appear to prefer domestic lamb products, domestic production is not available to meet demand, forcing many ethnic consumers to turn to imported products. The combined growth of the ethnic population and decline of domestic lamb production further increased U.S. dependence on imports. The reduction in lamb consumption by the traditional American consumer demographic was influenced by the Great Recession's impact on red meat consumption. Darko and Eales (2013) determined that the recession had a significant impact on both real food expenditures and meat demand, particularly due to decreases in away-from-home food consumption. As Shiflett *et al.* (2007) found that lamb was increasingly being consumed in away-from-home settings, particularly in high-end restaurants, the recession may have had an even greater effect on the lamb industry than on those of other meats commonly prepared at home.

Despite a changing consumer landscape, promotion has been a major point of focus for the industry in attempting to maintain or garner more consumer interest. Capps *et al.* (2010) determined that promotional efforts by the American Lamb Board were successful and beneficial to producers; however, Shiflett *et al.* (2007) highlighted the lack of visible evidence of these effects on the industry. Promotional efforts on the part of exporters may have also influenced domestic demand. Clemens and Babcock (2004) found that country of origin labeling requirements helped create brand recognition for New Zealand, associating New Zealand lamb with high quality and influencing global consumer perceptions in favor of New Zealand imports. However, the same report determined that branding had not been quite as successful in the U.S. as in other countries, prompting New Zealand and Australia to join a coalition with the U.S. to jointly promote lamb.

The domestic production of lamb has been subject to a variety of influences, some the same as those which have influenced consumption. Population increases of the ethnic demographic has driven growth in the non-traditional supply chain of lamb, with direct sales resulting in more on-farm slaughter, drawing lamb away from traditional harvest and reporting facilities. It was estimated that between 2004 and 2008, these non-traditional, ethnic markets were responsible for nearly one third of lamb slaughter in the U.S. which went unaccounted for in government reports (Shiflett *et al.*, 2010). The increase in non-traditional slaughter subsequently skewed domestic production data downward such that the actual decline in the domestic industry, while still on trend, may be overstated. Independent promotional efforts by exporters may also have been of indirect benefit to domestic producers, with Paarlberg and Lee (2001) finding that decreased trade barriers in the lamb industry would help protect both producers and consumers from the potential oligopoly and oligopsony power of a highly-consolidated processing sector. Domestic policy has also influenced lamb production, with subsidy policies like the Wool Act supporting prices and incentivizing production. However, domestic policy reform in the 1990s included the elimination of those subsidies and the removal of market distortions and production incentives, which led to decreased domestic lamb production and allowed imports to gain a larger market share (Whipple and Menkhaus, 1990).

Shrinking governmental support for the U.S. domestic industry is not the only cause for decreased sheep production. The increasing value of livestock production resources, such as high-quality rangeland, in tandem with increasing costs of production after long seasons of drought, have driven U.S. producers away from the relatively low returns of lamb production, with producers switching to higher-return livestock production. Sheep are also viewed as more labor-intensive, given the addition of shearing costs, higher predation losses than experienced in cattle production, and specialized labor needs for sheepherding (Williams *et al.*, 2008). The subsequent decline in domestic lamb production owing, in part, to these factors has been met with a coinciding increase in imports. Though total annual lamb disappearance in the U.S. has only decreased slightly from 1980 to 2015, the share of imported lamb has increased from less than 15% of total disappearance in 1980 to more than half in 2015. Though total annual lamb disappearance in the U.S. has only decreased slightly from 1980 to 2015, the share of imported lamb has increased from less than 15% of total disappearance in 1980 to more than half in 2015 (USDA, 2016b; USDC, 2017).

3. Methods

This analysis follows Muhammad and Jones (2011), Muhammad and Hanson (2009), and Mutondo and Henneberry (2007) that use the Rotterdam model (Theil, 1980; Theil and Clements, 1987) to test the significance of product and source-specific attributes as import demand determinants. The Rotterdam model has been used in import demand studies extensively in the past (for example Davis and Dyck, 2015; Feleke and Kilmer, 2009; Seale *et al.*, 1992). To evaluate the role of product attributes on lamb imports, data are disaggregated by source country (Australia or New Zealand) and product form (chilled or frozen), with further differentiation for either boneless or bone-in product, for a total of eight classes or types of lamb.

3.1 Base model

The absolute price version of the Rotterdam model is used for the analysis and is specified as follows:

$$\bar{w}_{m_i t}\Delta q_{m_i t} = \theta_{m_i}\Delta Q_t + \sum_{n=1}^{4}\sum_{j=1}^{2}\pi_{m_i n_j}\Delta p_{n_j t} + \varepsilon_{m_i t} \quad (1)$$

The terms m and n denote the product attribute: m,n = {chilled, frozen, boneless, bone-in}; i and j denote the source country (Australia and New Zealand). $w_{m_i} = (p_{m_i}q_{m_i} / \sum_m\sum_i p_{m_i}q_{m_i})$ is the share of each class or product type in total expenditures on imported lamb; $\bar{w}_{m_i t} = (w_{m_i t} + w_{m_i t\text{-}1})/2$. Note that p_{m_i} is the price of lamb of class m from country i and q_{m_i} is the corresponding quantity. $\Delta q_{m_i t} = \log(q_{m_i t} / q_{m_i t\text{-}1})$ and $\Delta p_{m_i t} = \log(p_{m_i t} / p_{m_i t\text{-}1})$. ΔQ_t is the Divisia volume import index:

$$\Delta Q_t = \sum_{m=1}^{4}\sum_{i=1}^{2}\bar{w}_{m_i t}\Delta q_{m_i t} \quad (2)$$

Note that ΔQ_t is a measure of change in total expenditures on all lamb imports. θ_{m_i} and $\pi_{m_i n_j}$ are treated as fixed parameters for estimation, which are the marginal import share coefficient and conditional price effect, respectively. $\varepsilon_{m_i t}$ is the error term assumed randomly distributed.

Equation 1 represents the demand for lamb of class *m* from country *i* given total expenditures on all lamb imports (ΔQ_t) and the price of each class by source ($\Delta p_{m_i t}$). Homogeneity and symmetry[1] are imposed on the model, in accordance with economic theory, and tested using likelihood ratio tests.

3.2 Product aggregation

Equation 1 assumes that preferences for lamb imports differ across the defined classes. If the distinction between boneless and bone-in product, for instance, were irrelevant to importers, these product classes could be aggregated for analysis and the following would hold true (Mutondo and Henneberry, 2007; Yang and Koo, 1994):

$\theta_{m_i} = \theta_{n_i}$; *m,n* = {boneless, bone-in}

$\pi_{m_i n_j} = \pi_{n_i m_j}$; *m,n* = {boneless, bone-in}

These restrictions indicate that the effects of total expenditures or prices on import demand are the same regardless of whether the lamb product is boneless or bone-in. Note that similar restrictions can be derived to test the importance of chilled versus frozen lamb as well as source (Australia vs New Zealand).

3.3 Product separability

Product separability can be viewed as the opposite of aggregation. While aggregation suggests that products are identical and can be aggregated for analysis, separability indicates that not only are products dissimilar, but are different enough to warrant their own 'separate' analysis (e.g. the demand for boneless lamb could be estimated separate from the demand for bone-in lamb).

We test for separability using the relative price version of the Rotterdam model:

$$\bar{w}_{m_i t} \Delta q_{m_i t} = \theta_{m_i} \Delta Q_t + \sum_{n=1}^{4} \sum_{j=1}^{2} \upsilon_{m_i n_j} \left(\Delta p_{n_j t} - \Delta P_t^* \right) + \varepsilon_{m_i t} \quad (3)$$

Where $P^*_t = \sum_m \sum i \theta_{mi} \Delta p_{mi}$ is the Frisch price index for all lamb imports; $\upsilon_{m_i n_j}$ is the Frisch price effect. If any two products are separable, then their Frisch cross-price effect is zero. For instance, if boneless and bone-in lamb are separable, then $\upsilon_{m_i n_j} = 0$; *m,n* = {boneless, bone-in}. Since Equation 3 (with separability restrictions) is nested in Equation 1, we can test for separability using likelihood ratio tests based on the two specifications (Seale *et al.*, 1992).

4. Data and descriptive statistics

We used monthly data (January 1989 - February 2017) from the Foreign Agricultural Service, U.S. Department of Agriculture for the analysis and considered the following Harmonized System (HS) classifications: 0204.23 Cuts, Chilled, Boneless, 0204.43 Cuts, Frozen, Boneless, 0204.22 Cuts, Bone In, Chilled, and 0204.42 Cuts, Bone In, Frozen. Data were collected for Australia and New Zealand, as imports from other sources are zero or negligible. Per-unit values were calculated (US$/cwt) and used as proxies for import prices, all on a cost, insurance, and freight (CIF) basis.

Descriptive statistics are presented in Table 1. The classes with the highest mean price per hundred weight (cwt) are mostly bone-in products, which is somewhat counterintuitive, given that bone-in meat products generally have lower processing costs and higher waste. However, in the case of lamb, many of the highest priced cuts, such as frenched rib chops, crown roasts and bone-in leg of lamb, are bone-in cuts. With New

[1] $\sum_m \sum_i \pi_{m_i n_j} = 0$ (homogeneity) and $\pi_{m_i n_j} = \pi_{n_j m_i}$ (symmetry).

Zealand lamb having branded itself as a particularly high-quality product, it is not surprising that the highest prices are for New Zealand bone-in lamb at US$ 311.53 (frozen) and US$ 347.05 (chilled) per cwt.

Despite higher prices, imports are mostly comprised of bone-in products, with an average combined total of 5.43 million pounds of bone-in lamb imported monthly compared to 1.88 million pounds of boneless lamb. It is important to note that these quantities do not include carcasses, which could be destined for bone-in or boneless retail cuts. However, U.S. carcass imports are relatively small by comparison. The combination of the highest average per unit prices and highest average quantities naturally results in bone-in cuts having the highest average values, and larger expenditure shares. Overall, the majority of imported lamb is bone-in product, with boneless lamb only comprising approximately 20% of imports, on average.

5. Results

We estimated the models as specified by Equation 1 and Equation 3 and conducted likelihood ratio tests to determine the significance of the homogeneity and symmetry restrictions and importance of product attributes. Results are presented in Table 2. Homogeneity and symmetry were each tested against the unrestricted model and were rejected at the 1% level. Despite their rejection, they remain imposed, as is precedent in

Table 1. Summary statistics: January 1990 - February 2017.[1]

Statistic	Boneless				Bone-in			
	Australia		New Zealand		Australia		New Zealand	
	Chilled	Frozen	Chilled	Frozen	Chilled	Frozen	Chilled	Frozen
Price (US$/cwt)[2]								
Mean	292.39	209.35	304.97	228.16	327.68	187.27	347.05	311.53
St. dev.[2]	84.58	89.61	103.03	99.46	128.02	91.64	142.60	133.41
Min	154.77	54.29	123.29	41.70	106.84	63.27	121.66	103.14
Max	595.52	515.07	620.44	640.12	693.79	568.33	832.60	881.98
	Monthly quantity (million pounds)							
Mean	0.70	0.67	0.29	0.22	2.19	1.14	0.65	1.45
St. dev.	0.56	0.67	0.22	0.24	1.54	0.57	0.38	0.64
Min	0.16	0.01	0.00	0.01	0.13	0.13	0.04	0.29
Max	2.69	3.83	1.05	2.57	6.18	4.05	1.65	3.51
	Monthly value (million US$)							
Mean	2.19	1.82	0.93	0.42	8.30	2.42	2.53	4.92
St. dev.	2.04	2.30	0.80	0.31	6.78	2.13	1.93	3.37
Min	0.04	0.02	0.00	0.02	0.21	0.10	0.12	0.40
Max	10.17	11.44	5.03	1.73	26.38	11.27	9.18	18.96
	Market expenditure share							
Mean	0.08	0.06	0.03	0.03	0.31	0.12	0.11	0.26
St. dev.	0.03	0.04	0.02	0.03	0.09	0.06	0.03	0.10
Min	0.02	0.01	0.00	0.00	0.09	0.03	0.04	0.06
Max	0.16	0.22	0.08	0.17	0.51	0.38	0.27	0.55
	Boneless market expenditure share				Bone-in market expenditure share			
Mean	0.37	0.29	0.17	0.16	0.39	0.15	0.14	0.32
St. dev.	0.12	0.13	0.08	0.15	0.12	0.08	0.04	0.11
Min	0.09	0.04	0.00	0.00	0.11	0.04	0.05	0.08
Max	0.64	0.64	0.39	0.66	0.46	0.46	0.31	0.62

[1] Imported data obtained from the U.S. Census Bureau (USDC, 2017).

[2] cwt = hundred weight; st. dev. = standard deviation.

the literature (Bera, 1982; Johnson *et al.*, 1986; Kastens and Brester, 1996; Laitinen, 1978; Meisner, 1979; Moschini and Moro, 1993). Adding-up[2] is satisfied by construction (Seale *et al.*, 1992). Aggregation was tested for corresponding boneless/bone-in pairs, first for each pair individually and then for all products jointly. Aggregation was rejected both on the individual level as well as for all products jointly.[3]

Product separability tests were conducted by comparing the log-likelihood values of separability-restricted Equation 3 to Equation 1. Separability was mostly rejected, regardless of significance levels. However, we did find evidence of separability between boneless and bone-in products. This is indication that preferences for boneless and bone-in lamb may be independent or at the very least, weakly separable. Weak separability suggests that while the products may not be independent, substitutability is significantly limited (Seale *et al.*, 1992). Given these results, import demand for boneless and bone-in lamb can be estimated separately.

5.1 Empirical results

A system of equations was estimated for all classes of boneless imports and all classes of bone-in imports, with homogeneity and symmetry imposed on both systems. Estimation results for all models are presented in Tables 3 (boneless lamb) and 4 (bone-in lamb).

The marginal share coefficients (θ_{m_i}) for boneless lamb are all positive and significant and indicate a preference for frozen lamb from New Zealand and chilled lamb from Australia. Note that for every dollar spent on boneless lamb, US$ 0.32 is allocated to chilled lamb from Australia and US$ 0.31 is allocated to frozen lamb from New Zealand. The estimates for frozen lamb from Australia (0.210) and chilled lamb from New Zealand (0.158) are smaller by comparison. The own-price coefficients ($\pi_{m_i m_i}$), presented along the diagonal in Table 3, are all negative, as expected, and statistically significant at the 1% level. With the exception of frozen lamb from Australia, the cross-price coefficients ($\pi_{m_i n_j}$) indicate that boneless products are substitutes. The price coefficients are better understood when expressed as elasticities, which are discussed later in this section.

[2] Adding up indicates that $\sum_m \sum_i \theta_{m_i} = 1$.
[3] Although unreported, aggregation was also rejected for source country as well as chilled and frozen pairs.

Table 2. Likelihood ratios test results.

Model	Log likelihood value	Chi-square[1]	*P*-value
Unrestricted	7,148.35		
Homogeneity	7,128.20	40.31 (7)	0.0000
Symmetry	7,125.26	46.18 (21)	0.0012
Source separability	7,117.16	62.39 (28)	0.0002
Frozen/Chilled separability	7,119.52	57.67 (28)	0.0008
Boneless/Bone-in separability	7,129.31	38.08 (28)	0.0969
Boneless/Bone-in aggregation			
Australia frozen	7,092.76	33.72 (8)	0.0000
Australia chilled	6,856.85	505.53 (8)	0.0000
New Zealand frozen	7,099.08	21.07 (7)	0.0037
New Zealand chilled	7,006.34	206.54 (8)	0.0000
All products	6,747.67	723.90 (25)	0.0000

[1] The number of parameter restrictions are in parenthesis. Separability test are based on comparisons to the unrestricted model (Moschini *et al.*, 1994).

Table 3. Demand parameters for U.S. boneless lamb imports.[1]

	Conditional price coefficients ($\pi_{m_i n_j}$)				Marginal share (θ_{m_i})
Exporting country/good	New Zealand frozen	New Zealand chilled	Australia frozen	Australia chilled	Marginal share
New Zealand frozen	-0.1065*** (0.0201)	0.0405*** (0.0092)	0.0037 (0.0159)	0.0623*** (0.0155)	0.3056** (0.0221)
New Zealand chilled		-0.1897*** (0.0157)	0.0096 (0.0167)	0.1397*** (0.0167)	0.1575*** (0.0103)
Australia frozen			-0.1159*** (0.0343)	0.1026*** (0.0268)	0.2120*** (0.0189)
Australia chilled				-0.3046*** (0.0301)	0.3249*** (0.0173)

[1] Standard errors are in parentheses; R^2 (AUC) = 0.56; R^2 (AUF) = 0.28; R^2 (NZC) = 0.49; R^2 (NZF) = 0.42; significance levels: * P = 0.10; ** P = 0.05; *** P = 0.01.

Similarly, the marginal share coefficients (θ_{m_i}) for bone-in lamb are all positive and significant and indicate a preference for frozen lamb from New Zealand and chilled lamb from Australia. However, the corresponding estimates are relatively larger: for every dollar spent on bone-in lamb, US$ 0.43 is allocated to chilled lamb from Australia and US$ 0.33 is allocated to frozen lamb from New Zealand. The own-price coefficients ($\pi_{m_i m_i}$), presented along the diagonal in Table 4, are all negative and statistically significant at the 1% level, with the exception of frozen lamb from Australia which is significant at the 5% level. Similarly, with the exception of frozen lamb from Australia, the cross-price coefficients ($\pi_{m_i n_j}$) indicate that bone-in products are substitutes.

5.2 Conditional expenditure and compensated price elasticities

From Equation 1, the conditional expenditure ($\eta_Q = \theta_{m_i} / \bar{w}_{m_i}$) and compensated price elasticities ($\eta_p = \pi_{m_i n_j} / \bar{w}_{m_i}$) are easily derived (Table 5). The conditional expenditure elasticities indicate the % change in the quantity of a class of imports given a 1% change in total expenditures for the system. For boneless imports, the conditional expenditure elasticity is inelastic for Australia, chilled (0.873) and frozen (0.721) and chilled New Zealand lamb (0.905), but is elastic for frozen New Zealand lamb (1.910). This indicates that frozen New Zealand lamb is one of the most rapidly expanding classes of lamb imports, with a 1% increase

Table 4. Demand parameters for U.S. bone-in lamb imports.[1]

	Conditional price coefficients ($\pi_{m_i n_j}$)				Marginal share (θ_{m_i})
Exporting country/good	New Zealand frozen	New Zealand chilled	Australia frozen	Australia chilled	Marginal share
New Zealand frozen	-0.0770*** (0.0281)	0.0181* (0.0103)	-0.0078 (0.0148)	0.0668*** (0.0240)	0.3275*** (0.0206)
New Zealand chilled		-0.1011*** (0.0114)	0.0128 (0.0085)	0.0703*** (0.0121)	0.1148*** (0.0075)
Australia frozen			-0.0415** (0.0165)	0.0365** (0.0173)	0.1321*** (0.0130)
Australia chilled				-0.1736*** (0.0287)	0.4256*** (0.0185)

[1] Standard errors are in parentheses; R^2 (AUC) = 0.67; R^2 (AUF) = 0.24; R^2 (NZC) = 0.45; R^2 (NZF) = 0.43; significance levels: * P = 0.10; ** P = 0.05; *** P = 0.01.

in boneless lamb expenditures resulting in a 1.91% increase in the total quantity of boneless frozen New Zealand lamb imports.

The compensated own- and cross-price elasticities for boneless lamb all conform to economic expectations. These elasticities indicate the % change in demand for the i^{th} class of imports given a % change in the price of the j^{th} class of imports, capturing only the substitution effect. All compensated own-price elasticities are negative, significant at the 1% level and all are inelastic except chilled New Zealand lamb (-1.090), which is very close to unit elasticity. These indicate that a 1% increase in the price of frozen boneless New Zealand lamb, for example, will result in a 0.67% decrease in the demand for frozen boneless New Zealand lamb. All compensated cross-price elasticities are positive and statistically significant at the 1% level except for those between New Zealand lamb, both frozen and chilled, and frozen Australian lamb, which are statistically insignificant, despite all being positive. This indicates a lack of responsiveness in both directions for frozen Australian lamb. That is to say, a change in the price of frozen Australian lamb appears to have no effect on the quantities of lamb imported from New Zealand, and the prices of New Zealand lamb have no effect on frozen Australian lamb imports. This finding persists through all calculated elasticities and supports the idea of a dwindling frozen Australian lamb market.

Similar to the boneless lamb system, the conditional expenditure elasticities for bone-in lamb are all positive and significant at the 1% level. For all four classes of bone-in lamb, the conditional expenditure elasticities are slightly inelastic or near unit elasticity. This indicates that a 1% increase in bone-in import expenditures results in an approximately proportionate increase in each of the classes of imports, with a slightly higher increase for frozen New Zealand (1.028) and chilled Australian (1.083) lamb, and slightly lower for chilled New Zealand (0.850) and frozen Australian (0.861).

Compensated own-price elasticities for bone-in product are all negative, inelastic and statistically significant at the 1% level, except frozen Australian lamb which is significant at the 5% level. Relative to boneless own-price elasticities, bone-in product is even more inelastic and insensitive to own-price changes. Again, chilled New Zealand lamb appears to be the most responsive to own-price changes with an own-price elasticity of -0.749. Cross-price elasticities indicate a similarly decreased responsiveness compared to boneless products, with all statistically significant positive cross-price relationships being of far smaller magnitudes than their boneless counterparts. This indicates that importers are less inclined to import more or less bone-in product based on a change in price of other bone-in products, especially compared to boneless imports. The cross-price relationship between New Zealand chilled and frozen lamb (0.134) is only statistically different from zero at the 10% level and only for a change in chilled New Zealand quantity imported given a change in frozen New Zealand lamb price. This means that, except for the one relationship between the New Zealand classes, all statistically significant relationships in the bone-in market are between chilled Australian lamb and the other classes. This signals that chilled Australian lamb is a market driver in the bone-in market, however it is also responsive to prices of all other classes of lamb. Again, results indicate that frozen Australian lamb evinces no statistically significant relationships with New Zealand lamb in any way.

6. Discussion and conclusions

First and foremost, among the findings of the AP Rotterdam models is the presence of weak separability in the imported lamb market on the basis of boneless/bone-in product differentiation. Accordingly, boneless and bone-in lamb products should not be treated as a homogenous product but rather must be distinguished. The finding of separability is of greater interest when one considers the dissimilarity of the findings of the two estimated Rotterdam systems and their calculated elasticity estimates. The conditional elasticities for boneless lamb reveal a much more interdependent market, as well as a generally more elastic market than bone-in lamb. The wider variability of responsiveness to changes in expenditure in the boneless market further indicates the importance of considering boneless and bone-in lamb as differentiated products.

Table 5. Conditional expenditure and price elasticities.[1]

Exporting country/ good	Expenditure	Compensated own- and cross-price			
		New Zealand frozen	New Zealand chilled	Australia frozen	Australia chilled
Boneless lamb					
New Zealand frozen	1.910*** (0.138)	-0.666*** (0.126)	0.253*** (0.057)	0.023 (0.100)	0.390*** (0.097)
New Zealand chilled	0.905*** (0.059)	0.233*** (0.053)	-1.090*** (0.090)	0.055 (0.096)	0.802*** (0.096)
Australia frozen	0.721*** (0.064)	0.012 (0.054)	0.033 (0.057)	-0.394*** (0.117)	0.349*** (0.091)
Australia chilled	0.873*** (0.047)	0.168*** (0.042)	0.376*** (0.045)	0.276*** (0.072)	-0.819*** (0.081)
Bone-in lamb					
New Zealand frozen	1.028*** (0.065)	-0.242*** (0.088)	0.055 (0.034)	-0.025 (0.046)	0.211*** (0.075)
New Zealand chilled	0.850*** (0.056)	0.134* (0.076)	-0.749*** (0.084)	0.095 (0.063)	0.521*** (0.090)
Australia frozen	0.861*** (0.085)	-0.051 (0.097)	0.083 (0.055)	-0.271** (0.108)	0.238** (0.113)
Australia chilled	1.083*** (0.047)	0.170*** (0.113)	0.179*** (0.031)	0.093** (0.044)	-0.442*** (0.073)

[1] Standard errors are in parentheses; elasticities are derived at average expenditure shares; significance levels: * $P = 0.10$; ** $P = 0.05$; *** $P = 0.01$.

For both boneless and bone-in lamb, import class interactions largely conform to economic expectations. All own-price elasticities indicate that increases in the price of a class of imports results in a decreased quantity demanded of that same import product. When a statistically significant relationship does exist between two classes of imports, the results indicate that it is invariably a substitute relationship. Both models indicate a relative insignificance of frozen Australian lamb to its respective boneless or bone-in market. Frozen Australian lamb is shown to exert no influence over demand for New Zealand lamb and also to not be affected by the price of New Zealand lamb. Results indicate that frozen Australian lamb is only impacted by its own price and that of chilled Australian lamb, within its respective quality differentiated market.

Finally, the results support a few major findings independent of the influence of boneless/bone-in quality differentiation. First, while weak separability was identified for boneless and bone-in product differentiation, we find no evidence of separability among frozen and chilled products. The emerging trend of decreased frozen Australian lamb market expenditure share in favor of a preference for frozen lamb from New Zealand and chilled lamb from Australia is found in both Rotterdam models, regardless of quality differentiation. However, an analysis of summary statistics may indicate that this is primarily due to the pull of the large bone-in market, while the smaller boneless market may have yet to experience such preferential influence on market expenditure shares. This further highlights the importance of thoroughly evaluating how importers may make decisions and which products may be viewed as substitutable. Where boneless and bone-in lamb can vary in the cuts used and the subsequent market destinations, frozen and chilled products bear no such implications and so may more easily be substituted for one another. Hence, importer expenditures need not be separated based on frozen and chilled distinctions. Despite these results, maintaining the differentiation in analysis can still be helpful in identifying trends in sourcing, as our analysis demonstrates the trend for a preference for frozen lamb from New Zealand and chilled lamb from Australia.

Second, our results suggest that import demand is relatively less elastic than previous studies indicate. All but one of the compensated own-price elasticities were inelastic. Given the higher quality designation of New Zealand lamb and the targeted branding campaign for New Zealand lamb (Clemens and Babcock, 2004), it is possible that the potentially more 'luxury'-oriented bone-in market is less sensitive to price changes and more responsive to other factors not evaluated herein. Conversely, the boneless market, being less associated with the traditionally 'luxury' lamb cuts, could be more dependent on the quantitative factor of price. Regardless of the cause, the results clearly demonstrate that the demand for lamb imports is inelastic.

One of the most important findings of this work is the separability of boneless and bone-in lamb. As imported lamb has traditionally been treated as a homogenous product, differences in boneless and bone-in import preferences have not previously been investigated in the literature. However, both aggregation and separability tests indicate that importers treat boneless and bone-in lamb as separate products. This has important implications for agribusiness and trade policy. For agribusiness managers and import firms, this provides greater understanding of import preferences to inform pricing strategies and to account for the increased risk of boneless and bone-in lamb cuts not being substitutes. From a trade perspective, policy can have unintended consequences when the market in which it is applied is not fully understood. Trade policies targeted at a market for which analysis is skewed by aggregation when products should be treated separately may not have the intended effects. Trade policies which may impact boneless lamb but not bone-in could have much greater impacts than expected as our results indicate boneless lamb imports are much more price responsive than bone-in. Future efforts in agricultural trade relations between the U.S. and Australia and New Zealand should consider these determinants of importer decisions to ensure optimal outcomes for U.S. agribusinesses and consumers. Further analysis to better understand the structure of trade decisions is warranted for trans-Pacific agricultural imports to best inform future trade policies.

References

Bekkerman, A., G.W. Brester and G.T. Tonsor. 2019. An alternative approach to measuring demand changes in meat markets. *International Food and Agribusiness Management Review* 22(3): 397-412.

Bera, A.K. 1982. A note on testing demand homogeneity. *Journal of Econometrics* 18(2): 291-294.

Brester, G.W. 1996. Estimation of the US import demand elasticity for beef: the importance of disaggregation. *Review of Agricultural Economics* 18(1): 31-42.

Capitello, R., L. Agnoli and D. Begalli. 2015. Chinese import demand for wine: evidence from econometric estimations. *Journal of Wine Research* 26(2): 115-135.

Capps Jr, O., G.W. Williams and T. Dang. 2010. *Effects of lamb promotion on lamb demand and imports*. Report No. 1406-2016-117308 – Agribusiness, Food and Consumer Economics Research Center, Department of Economics, Texas A&M University. College Station, TX, USA.

Clemens, R. and B. Babcock. 2004. *Country of origin as a brand: the case of New Zealand lamb*. Center for Agricultural and Rural Development (CARD), Iowa State University, Ames, IA, USA.

Darko, F.A. and J.S. Eales. 2013. *Meat demand in the US during and after the Great Recession*. AAEA & CAES Joint Annual Meeting. August 4-6, 2013. Washington, DC, USA.

Davis, C.G. and J. Dyck. 2015. Shocks to a trading system: northeast Asia poultry trade and avian influenza. *International Food and Agribusiness Management Review* 18: 99-114.

Feleke, S.T. and R.L. Kilmer. 2009. The Japanese market for imported fruit juices. *International Food and Agribusiness Management Review* 12(4): 1-28.

Johnson, S.R., R.D. Green, Z.A. Hassan and A.N. Safyutrlu. 1986. Market demand functions. In: O. Capps and B. Senauer (eds.) *Food demand analysis: implications for future consumption.* Virginia Polytechnic Institute and State University, Blacksburg, VA, USA.

Kastens, T.L. and G.W. Brester. 1996. Model selection and forecasting ability of theory-constrained food demand systems. *American Journal of Agricultural Economics* 78(2): 301-312.

Laitinen, K. 1978. Why is demand homogeneity so often rejected? *Economics Letters* 1(3): 187-191.

Meisner, J.F. 1979. The sad fate of the asymptotic Slutsky symmetry test for large systems. *Economics Letters* 2(3): 231-233.

Moschini, G. and D. Moro. 1993. *A food demand system for Canada.* Research Paper No. 12753. Department of Economics, Iowa State University, Ames, IA, USA.

Moschini, G., D. Moro and R.D. Green. 1994. Maintaining and testing separability in demand systems. *American Journal of Agricultural Economics* 76(1): 61-73.

Muhammad, A. and K.G. Jones. 2011. Source-based preferences and U.S. salmon imports. *Marine Resource Economics* 26(3): 191-209.

Muhammad, A. and T.R. Hanson. 2009. The importance of product cut and form when estimating fish demand: the case of US Catfish. *Agribusiness* 25(4): 480-499.

Muhammad, A., K.G. Jones and W.F. Hahn. 2007. The impact of domestic and import prices on US lamb imports: a production system approach. *Agricultural and Resource Economics Review* 36(2): 293.

Mutondo, J.E. and S.R. Henneberry. 2007. A source-differentiated analysis of US meat demand. *Journal of Agricultural and Resource Economics* 32(3): 515-533.

Paarlberg, P.L. and J.G. Lee. 2001. US trade policy on lamb meat: who gets fleeced? *American Journal of Agricultural Economics* 83(1): 196-208.

Sande, D.N. and J.E. Houston. 2007. US import demand for goat meat, sheep and lamb, and other lesser meat. *Journal of Food Distribution Research* 38: 134-140.

Seale Jr, J.L., A.L. Sparks and B.M. Buxton. 1992. A Rotterdam application to international trade in fresh apples: a differential approach. *Journal of Agricultural and Resource Economics* 17(1): 138-149.

Sellen, D. and E. Goddard. 1997. Weak separability in coffee demand systems. *European Review of Agricultural Economics* 24(1): 133-144.

Shiflett, J.S., G. Williams and P. Rodgers. 2010. *Nontraditional lamb market in the United States: characteristics and marketing strategies*. Research Report No. CM-02-10 – Agribusiness, Food and Consumer Economics Research Center, Department of Economics, Texas A&M University, College Station, TX, USA. Available at: http://afcerc.tamu.edu/publications/Publication-PDFs/CM-02-10%20Nontraditional%20Lamb%20Market%20Study-TCG2_FINAL.pdf

Shiflett, J.S., W.D. Purcell, D. Marsh and P. Rodgers. 2007. *Analysis of lamb demand in the United States.* American Lamb Board, USDA, Washington, DC, USA.

Theil, H. 1980. *The system-wide approach to microeconomics.* The University of Chicago Press, Chicago, IL, USA.

Theil, H. and K.W. Clements. 1987. *Applied demand analysis: results from system-wide approaches*. Vol. 7. Ballinger Publishing, Pensacola, FL, USA.

United States Department of Agriculture (USDA). 2016a. *Global agricultural trade system*. Foreign Agricultural Service, USDA, Washington, DC, USA. Available at: https://apps.fas.usda.gov/Gats/

United States Department of Agriculture (USDA). 2016b. *Redmeats yearbook.* Economic Research Service, USDA, Washington, DC, USA.

United States Department of Commerce (USDC). 2017. *Foreign trade statistics.* U.S. Census Bureau, Washington, DC, USA.

Whipple, G.D. and D.J. Menkhaus. 1990. Welfare implications of the Wool Act. *Western Journal of Agricultural Economics* 15(1): 33-44.

Williams, G.W., D. Bailey, O. Capps Jr, L.A. Detwiler, H.A. Glimp, T. Hammonds, D.D. Hedley, H.H. Jensen, P.S. Kuber and D.L. Thomas. 2008. *Changes in the sheep industry in the United States: making the transition from tradition*. National Academies Press, Washington, DC, USA.

Yang, S.R. and W.W. Koo. 1994. Japanese meat import demand estimation with the source differentiated AIDS model. *Journal of Agricultural and Resource Economics* 19(2): 396-408.