GLOBAL SUPPLY CHAIN ANALYSIS OF U.S. LAMB PROMOTION

A Dissertation

by

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ABSTRACT

The United States sheep industry has suffered an almost constant decline in sheep and lamb inventories; a record of 56 million head in the early 1940s to only 5.54 million head in 2011. The steady decline of the industry can be attributed to a confluence of many factors, amongst which is the discontinuation of the U.S. Wool Incentive payment program. With the discontinuation of the program in 1996/97, an unsuccessful effort was made to pass a mandatory checkoff program through a producer referendum. Six years later, in 2002, to enhance the demand for lamb, the Lamb Promotion, Research, and Information Order, better known as the American Lamb Checkoff Program, was established under the Commodity Promotion, Research and Information Act of 1996. The main objective of this research was to measure the effectiveness of the Lamb Checkoff Program by determining the extent to which the program has been able to shift out the demand for U.S. lamb and how much of the promotion benefit, if any, has been transmitted back through the supply chain to the different stakeholders of the lamb industry. This research investigated questions dealing with the demand, supply and trade of sheep and lamb through the global supply chain.

This analysis used a seventy equation, non-spatial price equilibrium model to estimate the parameters of interest using the OLS method of estimation. After estimating the parameters, a simulation model was conducted over the sample period (1987 - 2011) as a means of validating the model. After validating the model using some within sample

simulation statistics, the “with” and “without” lamb checkoff expenditure scenarios were developed to measure the effects and benefits of the program.

The results of this study clearly indicated that not only did the lamb checkoff program increase the demand for lamb, the program tended to lift the entire supply chain in the process with every stakeholder group benefitting from it.

DEDICATION

I dedicate this work to my parents and husband.

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CHAPTER I

INTRODUCTION

The United States sheep industry is multifaceted, rooted in history and tradition, and one of the most complex industries in animal agriculture. Sheep provide lamb and mutton for consumption, wool and pelts for textiles, and milk by the dairy sheep industry. Despite the sheep industry's versatility, the dominant feature has been its steady decline since the mid-1940s. From a record high of 56 million head in 1942, inventories in January 1, 2013 slumped to 5.53 million head, the lowest level in recorded history (USDA 2013d). The decline in the number of sheep and lamb has been a major cause of concern for sheep producers and policy makers over the years.

The downward trend of sheep inventories is the result of a confluence of factors, events, and policies. Although specific events such as the end of World War II and the repeal of the National Wool Act are often held responsible for the current state of the sheep industry, Williams et al. (2008) cite a number of events and issues that have been possible contributing factors, including:

- lower returns and higher risks relative to other livestock and crop enterprises;
- the increasing cost and scarcity of qualified sheep shearers;
- uncertainties in U.S. and foreign trade policies;
- the discontinuation of the U.S. Wool Incentive payment program in 1996/97;
- grazing allotment policies for public lands;
- restrictions on predator control;

- greater technological development of other meat processing industries especially poultry and pork; and
- a shift in consumer tastes and preferences toward other meats.

Although most of these factors are out of their direct control, producers have strived to revive the industry through various means, including: (1) legal steps to remedy a perceived problem of oligopoly power by packers, breakers, and others in the marketing channel; (2) encouragement of producer cooperatives, and (3) promotion of the retail demand for lamb. The first two efforts have had limited success. Industry efforts to enhance consumer demand for lamb, however, have met with some success over the years. Demand-side efforts to deal with the shrinking market began in the 1950s with a modest lamb promotion program operated by the American Lamb Council (ALC) of the American Sheep Industry Association, Inc. (ASIA) using funds made available under the Wool Incentive Program. The annual nominal expenditures on lamb promotion activities by ASIA grew from $1.2 million in 1978/79 to a high of $4.2 million in 1988/89 before declining to $1.2 in 1996/97 as the phase-out of the Wool Incentive Program began to take effect.

When the Wool Incentive Program and, hence, expenditures for lamb promotion were phased out in 1996/97, an unsuccessful effort was made that year to pass a mandatory checkoff program through a producer referendum. Six years later in 2002, to enhance the demand for lamb, the Lamb Promotion, Research, and Information Order, better known as the American Lamb Checkoff Program, was established under the Commodity Promotion, Research and Information Act of 1996. Since its inception in

July 2002 through 2011/12, the American Lamb Board has spent a total of $13 million on lamb advertising and promotion. Administrative costs are kept low so that most of the collected checks off funds are used for promotional purposes (Williams Capps and Dang 2010).

The main goal of the current Lamb Checkoff Program is to increase the market share of “American” lamb. Over the last decade, the share of U.S. lamb demand accounted for by imports has increased dramatically reaching to more than 50% of total U.S. lamb demand. It is an effort to “brand” U.S.-produced lamb as made in America and differentiate it from imported lamb as a higher quality and value product. The success of the program, and its predecessors can be measured by determining the extent to which the associated expenditures to promote lamb have been able to shift out the demand for U.S. lamb and how much of the promotion benefit, if any, has been transmitted back through the supply chain to stakeholders, primarily producers, feeders, and slaughterers. This research will investigate these questions taking into consideration the demand, supply and trade of sheep and lamb through the global supply chain.

Literature Review

Although some research has been done to measure the advertising and promotion impacts on lamb demand, little has been done to trace those effects back to those who have paid for the promotion (the industry stakeholders, including producers, feeders, and packers). Most of the previous research work on lamb demand has focused mainly on understanding the economic determinants of the retail level demand for lamb. Williams

Capps and Dang (2010) provide a detailed review of prior lamb demand studies, including Byrne et al. (1993), Schroeder et al. (2001), and Capps and Williams (2006). The parameters of the demand functions postulated in these studies are estimated using regression analysis with an emphasis on measuring price and income elasticities. The factors most often found to be statistically significant in explaining changes in per capita lamb demand over the years include the real retail price of lamb, the real retail prices of beef and pork, and seasonality. Most studies have concluded that income is not a statistically significant variable in explaining lamb demand.

Analyzing data from earlier time periods, Whipple and Menkhaus (1989a) and Carman and Maetzold (1971) found high own price elasticities based on per capita lamb consumption of -2.0 to -3.0. The estimated own-price elasticities across most recent studies have been consistently smaller, ranging from -0.5 to -0.8 except for Schroeder et al. (2001) who report a relatively high own price demand elasticity of -1.1. Thus, most recent studies provide evidence that lamb demand is not highly responsive to price changes.

The range of statistically significant estimated beef cross-price elasticities is even more narrow (from 0.5 to 0.6). Schroeder et al. (2001) found pork price to be marginally statistically different from zero (p value$<$0.26) with an elasticity of 0.17. Byrne et al. (1993) found similar results indicating pork to be a weak substitute. Williams, Capps, and Dang (2010) found statistically significant cross-price elasticities between lamb and beef (0.63) and lamb and pork (0.34). At the same time, RTI (2007) and Williams, Capps, and Dang (2010) concluded that lamb and chicken are independent commodities in consumption. Shiflett et al (2010) states thatgoat meat could serve as a substitute for lamb meat especially in the ethnic/religious segment of the market.

The results for the income elasticity of lamb demand are mixed. Schroeder (2001) found a negative income elasticity of -.54. Purcell (1989) also found an inverse relationship between income and lamb consumption. Byrne (1993) and Williams et al. (2010) found income not to be statistically significant driver of lamb demand. Shiflett et al. (2007) initially concluded the same but then added a trend variable to their model and found a positive and statistically significant relationship between per capita lamb demand and income. Williams, Capps, and Dang (2010) argue that the Shiflett et al. result is likely to be spurious due to collinearity of the income and trend variables used in their analysis. The lack of broad evidence of a statistically significant relationship between income and lamb purchases may be the result of either the relatively small amount of lamb purchased or the fact that most lamb is purchased by ethnic and other consumers primarily for special occasions during the year.

Seasonality is another variable that all studies using at least quarterly data have found to be a statistically significant determinant of per capita lamb demand Byrne, Capps, and Williams (1993) and Shiflett et al. (2007) both use quarterly data in their analyses and find seasonality to be a significant determinant of per capita lamb demand. Both studies conclude that lamb consumption typically is highest in the first and fourth quarters of the year. Based on monthly data, Williams et al. (2008) econometrically analyzed the relationship between religious holidays (Orthodox Easter and Muslim holidays like Ramadan and Eid-al-fitr) and lamb slaughter. They find that these religious holidays held during certain periods of the year significantly affect monthly and annual lamb consumption and that their effect is increasing over time. The above findings along with the seasonality results suggest that lamb purchases are more a function of religious and ethnic considerations than income.

The responsiveness of the demand for many commodities to their respective checkoff-funded advertising and promotion programs has been the subject of numerous studies. Williams and Nichols (1998) provide a historical summary of advertising and promotion elasticities estimated over a broader range of commodities. Kinnucan and Zheng (2005) report checkoff advertising and promotion elasticities for dairy, beef, pork, and cotton. Rusmevichientong and Kaiser (2009) studied the effect of export promotion on rice exports. The estimates of advertising and promotion elasticities vary widely for the same commodity across different studies. A broad range of research over many checkoff commodities has demonstrated that advertising and promotion can, but does not always, effectively increase commodity sales. The estimated checkoff promotion elasticities across these studies vary widely between about zero and 0.10 even for the same commodity. For example, Murray et al. (2001) estimated the cotton checkoff advertising and promotion elasticity at 0.023 while Ding and Kinnucan (1996) found the elasticity to be about 3 times higher at 0.066 (Ding and Kinnucan 1996). More recently, Capps and Williams (2006) found a retail level checkoff promotion elasticity of 0.05 for cotton. Williams, Capps, and Bessler (2004) estimated the checkoff promotion elasticity at 0.127 compared to 0.027 reported by Ward (1998) and 0.01 by Lee and Brown for orange juice. Williams and Capps (2009) estimated checkoff promotion elasticities of domestic soybean, soyoil, and soymeal at 0.04, 0.02, and 0.03 respectively. The estimated promotion elasticities for foreign market demands for soybeans, soymeal, and soyoil ranged from 0.029 to 0.063, 0.03 to 0.06, and 0.02 to 0.05, respectively, depending on the country or region of promotion.

To date, there has been limited attention to advertising and promotion as a driver of lamb demand. Among all previous lamb demand studies, Carman and Maetzold (1971) is the earliest study to explicitly recognize the potential omitted variable bias from excluding lamb promotion and advertising as an explanatory variable but did not include such a variable in their analysis. Capps and Williams (2005) first incorporated the influence of the American Lamb Board (ALB) Checkoff Program into their lamb demand model as a three-period moving average of inflation adjusted ALB advertising and promotion expenditures. Using this model, they found that the ALB program had a positive, but not highly significant effect on lamb demand. They reported an advertising elasticity of 0.02 between 1978-1979 and 2001-2002 (the pre-ALB period) and 0.031 between 2002-2003 and 2004-2005 (the ALB period). Though small, these advertising elasticities are consistent with those found by many other researchers across a wide variety of agricultural commodity checkoff programs (Williams and Nichols 1998; Capps and Williams 2011).

In a more recent analysis of lamb demand, Capps and Williams (2011) modified their earlier model by using a polynomial distributed lag (PDL) process to capture the advertising carryover effects. In addition, a square root transformation of the advertising variable was used to allow for both diminishing returns and zero expenditures in advertising expenditures at certain time periods. The results indicated a statistically significant effect of ALB promotion on lamb demand with an advertising elasticity of 0.03 which is consistent with those estimated for other checkoff commodities.

Some checkoff commodities, like lamb, compete with imports. The U.S. is a major importer of frozen lamb from Australia and New Zealand. From 1993 to 1997, the number of lamb-producing establishments in the U.S. declined by 20% (USITC 1999). To meet the steady domestic market needs for lamb in the face of declining domestic supplies, imports from Australia and New Zealand began to grow, especially that of frozen meat. About 35% of U.S. lamb imports are supplied by New Zealand and 65% by Australia. In 2012, lamb imports amounted to around 140 million pounds, almost 47% of the domestic lamb supply (USDA 2013b). The United States trade policy on imports from those countries has been relatively open because they meet U.S. sanitary standards.

Relatively few studies have econometrically examined the behavior of imports relative to total U.S. lamb consumption. Using data from 1950-1985, Whipple and Menkhaus (1989a) estimated a lamb import equation which was driven by U.S. and import prices for lamb and Australian and New Zealand lamb production. Ribera (2004) concluded that the primary determinants of U.S. lamb imports are Australian lamb production, the U.S.-Australian exchange rate, and the tariff imposed on lamb imports following a Section 201 trade complaint. Muhammad et al. (2004) used a two stage differential production approach to estimate the derived demand and output supply of U.S. lamb imports. The study also analyzed the impact of the U.S. tariff- rate quota (TRQ) in the 1990s on U.S. lamb imports and concluded that the policy had a positive impact rather than the expected negative impact on imports due to exchange rate movements during that period which increased the purchasing power of U.S. dollars.

Generic advertising and promotion that shifts out the domestic demand of a commodity that competes with imports may encourage greater imports and divert some of the gains from advertising to foreign producers. This potential free-rider effect of advertising and promotion is accounted for in few analyses of checkoff programs. The free rider problem of imports has been analyzed in the case of orange juice advertising (e.g., Brown et al. 1996, Williams, Capps and Bessler 2004) and a few other commodities like cotton (Capps and Williams 2006) and pork (Davis et al. 2001). Williams, Capps and Dang (2010) incorporated lamb advertising and promotion expenditures as a potential explanatory variable in their import share specification and concluded that lamb advertising increases imports, but a lower rate than domestic consumption leading to a declining import share of domestic lamb consumption.

There few published analyses of the supply side of the sheep industry and even fewer specifically of the U.S. sheep industry. Reynolds and Gardiner (1980) developed a model of the Australian sheep industry based on the work of Jarvis (1974) for the Argentine cattle sector. Jarvis' dynamic model of the Argentine cattle sector treated cattle as capital goods and producers as portfolio managers. He showed that the short-run response to slaughter price changes was negative because calves must be held for future output. The long-run response was positive. Reynolds and Gardiner built a similar model for the Australian sheep industry to analyze sheep producer decision making regarding annual supplies of wool, mutton, and annual changes in the inventory levels of sheep, lambs, and ewes maintained for breeding purposes. Their analysis showed that wool prices had a long- term effect on the sheep flock but mutton and lamb prices were responsible for short-run changes in the flock composition. Seasonal conditions proved to be an important factor for short-run shifts in supply thus affecting both numbers and composition within a sheep flock. Elasticities were not calculated, but the model suggested that the wool price drives the Australian sheep industry. Reynolds and Gardiner report an elasticity of the Australian supply for wool of between 0.19 and 0.47.

Other studies that explicitly modeled factors affecting supply response in the U.S. sheep industry include the work done by Whipple and Menkhaus (1989b, 1990). They developed a dynamic supply model which incorporates restrictions on fixed capital and demographic characteristics of the breeding flock. The characterization of the sheep population dynamics used in their study suggested that the size and age demography of the breeding flock are related to lamb slaughter/retention rates and stock sheep culling rates. The authors estimated four equations in their model: (1) lamb slaughter/retention, (2) stock sheep retention, (3) lamb live weight, and (4) fleece weight coupled with two identities for total outputs to complete the system. They used annual data from 1924 to 1983 to estimate the supply response by simulating changes in factors of interest over different time horizons. The long-run supply responses for lamb and wool production were more responsive than those over the short run. The lamb production own-price elasticity ranged from 0.01 at a 1 year time horizon to 11.38 at a 30 year time horizon. Similarly the wool production own-price elasticity ranged from 0 at 1 year to 11.53 at year 30. Breeding flock retention elasticities were calculated with respect to lamb price, wool price, cull sheep price, hay price, and labor price. All these variables had calculated elasticities of 0 at a 1 year time horizon suggesting supply response in the sheep industry occurs slowly. For longer time horizons, the breeding sheep retention responded positively to lamb and wool prices and negatively to cull sheep price, hay price, and labor price. The responsiveness of lamb price to breeding flock retention was more than to wool price.

Burton and Wollo (1986) concluded that cattle and sheep can compete with each other over the base grazing resource. They found that net income from a combination of beef and sheep farming could be increased by substituting more beef production for sheep when beef prices were high. Beef prices are expected to be negatively related to ewe flock size. However, Whipple and Menkhaus (1989b) found a positive relationship between beef price and breeding flock retention. They hypothesized that the unexpected statistical relationship may have resulted from a high positive correlation between beef and lamb prices over the sample period.

Purcell et al. (1991) developed a single-equation U.S. sheep supply model in which they specified January 1 breeding ewe inventory as a function of total returns per ewe, calf price, principal crop acreage, hay price, and percent of small scale farms. Total returns per ewe were calculated using lamb prices, lambing percentages, wool prices, average fleece weights, and wool incentive payments. The calf price and the crop acreage variables represented returns to competitive enterprises. Hay price represented the relevant cost to the farms and percent of part-time farms reflected the subjective factors related to sheep production. Their model parameters were estimated using annual data from 1953 to 1984 for the entire U.S. and for each of seven sub-regions to account for regional differences in operation types and production practices. The results did differ by region. The crop acreage variable exhibited a positive influence on sheep numbers in several of the regional models and also in the national model. Total returns had expected positive effects on breeding flock inventories. Unlike Whipple and Menkhaus (1989b), the Purcell et al. (1991) results suggested that increases in cattle price have the theoretically expected negative impact on sheep numbers. Hay price negatively influenced sheep numbers in their study as well.

The national model was re-estimated by Purcell et al. using data through 1988. They found that the long -run supply elasticity with respect to sheep returns was significantly smaller (1.754) than that reported by Whipple and Menkhaus (1989b). The elasticity with respect to calf price was -0.939. Hay prices significantly influenced the breeding sheep flock with an elasticity of -1.839. The long run elasticity with respect to the proportion of part time farms was -2.788 supporting the hypothesis that resource constraints have an impact on long-run breeding inventories. The authors concluded that the fixed nature of many of the inputs have an asymmetric influence on the supply response.

Jones and Schroeder (1998) estimated a U.S. ewe inventory supply response model using data from 1965 to 1995. The ewe inventory equation was explained by lagged inventory, grazing, feed costs and ewe inventory cyclicality. The inventory was explained by lamb price, lamb crop, and wool price. Grazing fees were included to account for the grazing costs other than the feed cost. Feed cost was modeled on hay price, grain sorghum price, and soybean meal price. They estimated the model using iterative generalized least squares correcting for first order autocorrelation. The explanatory power of the model was 0.997. Short-run, intermediate-run and long-run elasticities were calculated for different variables included in the model. The lamb price and wool price elasticities were high in the long run, but significantly lower than that of Whipple and Menkhaus (1989b). The authors concluded that in the short run, revenue increases had little effect on the size of the U.S. lamb industry. Ewe inventories were responsive to grazing fees over a long time period and wool price had less effect on the sheep industry compared to lamb prices.

Anderson (1994) and Ribera (2004) are the only studies which have estimated supply and demand models simultaneously for the U.S. sheep and mohair industries. They used annual data from 1973 to 1992 to estimate a supply and demand model of the sheep industry. Using OLS, they estimated the parameters of two models, an aggregate model and a regional model, to compare which model performed best. The aggregate model used national data while the regional model used state level data. For the regional model, the nation was divided into three sheep producing regions: (1) western states, (2) Texas, and (3) eastern states. Both models used econometric equations and biological identities. The supply and demand side of the model was solved simultaneously. The aggregate model outperformed the regional model. The endogenous variables in the aggregate sheep supply model included lamb crop, ewe lambs, sheep death loss, sheep slaughter, lamb dress weight, fleece weight, lamb slaughter, lamb imports, and wool imports. The R-square values for all equations were high, ranging from 0.65 to 0.98. They reported the dynamic short-run and long-run stock ewe responses to a 10% simulated change in the price of lamb to be 1.4% and -0.3%, respectively, and 0.0% and -0.1%, respectively, for a 10% change in the wool price.

Ribera (2004) developed a global demand, supply, and trade model to analyze sheep and mohair industries based on work done by Anderson (2004). He used OLS estimation techniques to estimate the parameters. Although his study focuses on the impact of wool policies on the sheep industry, he concluded that lamb production drives the U.S. sheep industry

In summary, this literature review explores studies that have focused on the determinants of sheep and lamb demand, supply, and import share. To measure the impact of lamb promotion expenditures on all stakeholders along the U.S. sheep and lamb supply chain will require a complete global supply chain model to adequately capture measure the transmission of the retail level effects of lamb promotion on stakeholder welfare and profits given the free rider effects from imports. Although an initial effort was made by Williams, Capps and Dang (2010) to measure the producer benefits due to the checkoff program, more detailed work needs to be done to consider the effects at different points along the U.S. sheep and lamb supply chain in the context of the global sheep, lamb, and wool supply chain within which it operates.

Objectives

The purpose of this dissertation is to determine the effects of the lamb promotion expenditures over the years, including those under the current Lamb Checkoff Program and those in previous years, on the global supply chain of the lamb industry with particular emphasis on the benefits of the program to U.S. sheep industry stakeholders, primarily sheep producers, feeders, and slaughterers. The specific objectives of this study include the following:

1. Conduct a qualitative analysis of the U.S. sheep and lamb industry and U.S. lamb promotion efforts and their role in the global lamb supply chain as background to a more in-depth quantitative analysis. The qualitative analysis constitutes chapter two of this dissertation.
2. Develop a conceptual model of the U.S. sheep and lamb industry and its interface with the global supply chain based on the qualitative analysis and then use the model to develop hypotheses regarding the effects of a lamb-promotion-induced shift in the retail demand for lamb. The conceptual model is presented in chapter three of this dissertation.
3. Develop a mathematical representation of the conceptual model of the U.S. and global sheep and lamb supply chain based on the conceptual model, statistically estimate the parameters of the behavioral equations using econometric procedures, and validate the full econometric structural model through a check on the dynamic, within-sample simulation statistics. The econometric model and related discussion is included in chapter four of this dissertation.
4. Use the validated econometric model to conduct a simulation (counter-factual) analysis of the lamb promotion program to determine the impacts of changes in the

level of the checkoff on the model variables. The simulation analysis is discussed in chapter five of this dissertation.

5. Use the results of the simulation analysis to calculate the benefit–cost ratio (BCR) for all lamb promotion efforts over the years and to the current Lamb Checkoff Program specifically to measure the benefits accruing to stakeholders. The benefit-cost analysis is included in chapter five of the dissertation.
6. Summarize the conclusions and implications of the study results for the U.S. sheep industry and the current Lamb Checkoff program and provide suggestions for future research. The last chapter achieves this objective.

CHAPTER II

QUALITATIVE ANALYSIS OF U.S. AND GLOBAL SHEEP-LAMB-WOOL SUPPLY CHAINS

The sheep-lamb-wool (SLW) industry of any country is generally comprised of those establishments primarily engaged in breeding and raising sheep and lambs, feeding lambs for slaughter, slaughtering fed sheep, further fabricating lamb meat, wholesaling and retailing lamb, and transforming wool into textile products. Sheep are ruminant animals that are slaughtered for meat and shorn for their wool. The United States was the world's fifth largest wool-producing nation in the 1940s. At the time, wool was considered to be the primary product of sheep production with lamb and mutton as byproducts of wool production. As the fortunes of the U.S. sheep industry declined over the years, the relative return to wool production also diminished dramatically. Recent studies indicate that wool production is no longer a significant driver of the sheep industry (Williams 2008). As a consequence, sheep producers and researchers have turned their attention to improving lamb and mutton production. Today, the United States accounts for less than one percent of the world's wool production (Anderson et al. 2007). To understand the dynamics of the lamb meat industry, wool account will also need to be examined.

Meat derived from sheep is generally separated into two categories - lamb and mutton. Lamb generally refers to meat from sheep that are less than one year old and accounts for about 85% of U.S. sheepmeat production (IBISWorld 2013). Mutton refers to meat from sheep aged one year or older and accounts for about 15% of U.S. lamb meat production. The major services and products of this industry are feeder lambs, slaughter sheep, lamb meat, wool, and related products. According to IBIS World (2013), 91% of the industry revenue is earned from the sale of sheep and lamb for meat. The rest primarily comes from wool and other products.

Global Lamb Supply Chains

The description quoted below by Smith (2001) of the cattle and beef supply chain could be adapted to the lamb supply chain also

> *" A system by which the 'sectors' involved in lamb production (seedstock generators, sheep/feeder lamb producers, stockers/backgrounders, feedlot operators, packers, breakers, processors, supermarket operators, and food-service providers) become 'segments' because – no longer isolated from but mutually dependent upon, those in other sectors – they become 'links' in a chain (segments in a supply chain). "*

The sheep and lamb supply chains of the U.S., Australia, and New Zealand generally consist of sheep and lamb production, lamb processing, retailing/wholesaling, and final consumers. In each country, there are a few fully integrated supply chains that are linked to major supermarkets. These are sheep moving from farms or feedlots to processors who transform them into end products of lamb and then directly to end consumers. For the most part, lamb supply chains are only partially integrated involving activities only from slaughtering to end customers or from producing to slaughtering. This chapter reviews the supply chains of Australia, New Zealand, and the U.S. as background to the conceptual and quantitative analyses in the following chapters.

Australia Lamb Supply Chain

The size of the Australian and New Zealand sheep industries dwarf that of the United States (figure 1). In 2011, the total stock of sheep in U.S. was only about 5 million head compared to 75 million head and 30 million head in Australia and New Zealand, respectively. Although huge in comparison to that U.S. sheep industry, the Australian and New Zealand supply chains are structurally similar with the exception of some differences in the feeding sector. Most of the sheep and lamb in Oceania (Australia and New Zealand combined) are grass-fed whereas most lambs are grain-fed in the U.S.

Australian Sheep Producing Regions and Feedlots

The Australian Bureau of Agricultural and Resource Economics identify eleven sheep production regions across Australia (DAFF 2006). Among them, the three largest regions by sheep population are the Southern High Rainfall Region, the Eastern Wheat Sheep Region, and the Western Wheat Sheep Region. These three regions combined account for almost two thirds of the national flock. (DAFF 2006) further categorizes the types of sheep production in Australia into five production enterprises:

- Self replacing wool (SRW) – exists where sheep purchases represent less than 10% of the average number of sheep in a flock. This sector has its own ewe replacements and the replacement rams are the only sheep purchases made. The producers in this sector are increasingly penetrating the more profitable lamb market.

- Self replacing meat (SRM) – exists where sheep and lamb receipts are greater than 50% of total receipts. This sector puts more emphasis on carcass attributes of sheep rather than wool. This enterprise includes the traditional meat sheep

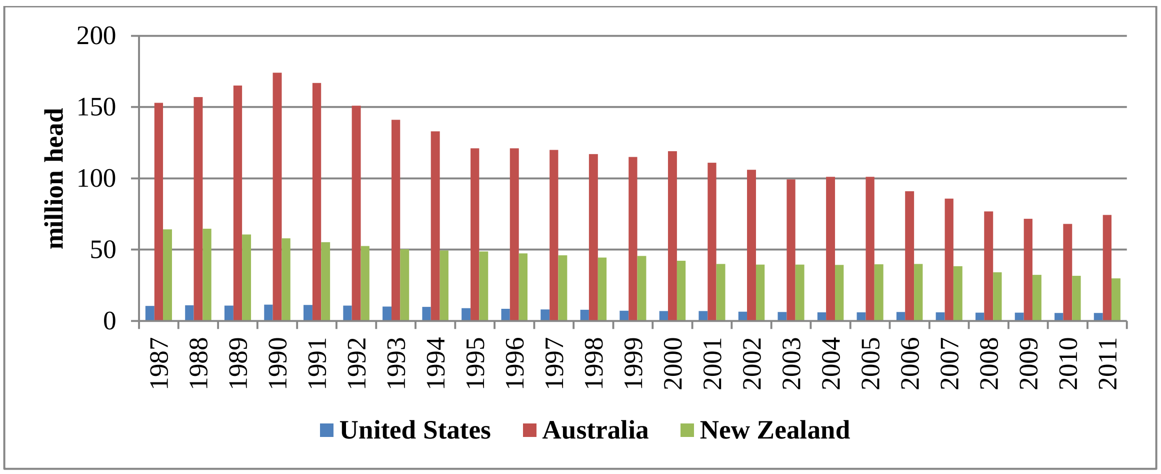

Figure 1. Sheep Inventories in the U.S., Australia, and New Zealand, 1987-2011

breeds such as the White Suffolk and Dorset as well as recently imported breeds like Dorper and Damara that do not produce harvestable wool.

- Wethers (W) – exists where wethers (castrated rams) consists more than 50% of opening and closing sheep numbers.
- Cross bred (XB) – exists where cross bred ewes consists more than 30% of ewes mated. In this sector the replacement ewes are purchased with all young sheep sold as lambs.

- Traders and other (TO) – sheep not belonging to any of the above enterprises.

By far the largest sheep production sector in Australia is the self-replacing wool (SRW) enterprise, accounting for just over half of the Australian flock (54%). Also, a quarter of the flock belongs in self-replacing meat (SRM) enterprises. The distribution of the five Australian production sectors is determined by environmental factors which influence the quality of the pastures. Sheep production systems that derive the majority of their income from the prime lamb market requires productive, high protein pastures for lambs to reach market weights over a short time period. High rainfall regions like the wheat/sheep areas have good environmental conditions and proper irrigation that serve as good pastures for lamb production. Conversely, harsh climate of the pastoral region of Australia with rainfall less than 350mm per year makes the environment not always suitable for the production of quality prime lambs.

In such cases, Meat and Livestock Australia (MLA) encourages producers to concentrate on breeding lambs for up to 12 to 14 weeks and then send them to feedlots for proper finishing.

Feedlots are generally located in the Wheat Sheep regions of Australia. In regions of high rainfall, the sheep are generally not suitable for feedlots as they are usually smaller framed. Producers do not try to join them to a terminal sire to produce a more suitable lamb for the feedlot. When lamb prices are high and grain prices are low, feedlots provide a mechanism to move young sheep predominantly intra-regionally.

Packers and Slaughterers

Vertical disaggregation of the lamb meat supply chain beyond the farm gate consists of processing and marketing sectors. The majority of sheep sold to saleyards are sold to an abattoir or meat processor. In Australia, around 32 million sheep are killed in abattoirs each year for human consumption (both domestic and export).

Meat processors are located across much of Australia except the Northern Territory. Of the 49 abattoirs that had their locations enlisted with ABARE, 14 are in Queensland, 12 in New South Wales, 11 in Victoria, and the remainder in South Australia, Tasmania, and Western Australia. These abattoirsare of varying sizes and capacities. Hence, the processing sector undertakes all slaughtering and processing activities necessary to produce lamb and mutton for the export and domestic markets.

Retailers and Domestic/Foreign Demand for Lamb

The domestic marketing and retail sector processes the carcasses and packages the lamb products for sale to final consumers. This sector comprises supermarkets, butchers and integrated abattoirs. Despite the decline in domestic demand for red meat, beef and lamb consumption in Australia are high compared to consumption in many other countries. Growth in meat demand is largely driven by income and population growth (MLA 2012). An increase in incomes and population in developing countries, particularly in Asia, supports the demand for lamb meat from Australia.

Recent growth in the export demand for Australian lamb can be attributed to the liberalization of U.S. lamb imports, falling production in key lamb markets (particularly the United States and the European Union), limited growth in exports from New Zealand, and rising demand in Asia as consumers look for alternative meats in the wake of disease outbreaks affecting beef and poultry. Export markets for Australian lamb are highly segmented with the largest single market, the United States, accounting for majority of the total exports. During recent years, the Middle East and Greater China overtook the U.S. their shares of Australian lamb exports by a slight margins (MLA 2012). Another important Australian lamb export market is the European Union. There are also a large number of export markets for Australian mutton. Major markets include the Middle East, Asia, South Africa and the United States.

New Zealand Lamb Supply Chain

The New Zealand sheep industry gained its "New Zealand brand" with the introduction of refrigerated transport in 1880 from U.K. In high rainfall regions of the North Island, the Merino breed proved to be a failure because of fleece rot and discoloration. Crosses with English breeds like Lincoln, English Leicester, and Border Leicester were more successful. Similar changes happened in the southern part of the South island. The changes in breed composition started before 1882 but were hastened after the introduction of lamb and mutton trade. From the viewpoint of meat production, ewes of the Halfbred, Corriedale, Lincoln, and Romney breeds were more productive for breeding fat lambs than the pure-bred Merino ewe.

Special meat breeds, called 'Down breeds' in the UK gradually became more popular in New Zealand. These breeds, (the Southdown is the classic example), became the basis of the export of “New Zealand” or “Canterbury” lamb that is recognized for quality. They are still used to cross onto other breeds and all their progeny go for meat. For this reason, they are called “terminal sires” where they are the last to be used in a breeding program. For more lean meat, milk production, and fertility, New Zealand sheep breeders developed “new” breeds, like the Corriedale, Coopworth, Perendale, Borderdale, Dorset Down, and South Suffolk. These breeds were crossed onto existing breeds to produce what are called “composites”. Other breeds from the Middle East were also imported in the 1990s to for their potential for live sheep trade.

Fattening Farms in New Zealand

Fattening farms are concentrated generally in places of high fertility in New Zealand such as the coastal plains and river valleys of both islands, e.g., the Waikato basin, the Poverty Bay flats, the Hawke's Bay, Manawatu, Canterbury, and Southland plains. The differences in the climatic conditions between the North and South Island influences the type of feed produced. On the North Island, pasture is common as the diet and in the drier areas of the South Island, special crops, such as rape, are grown for feeding lambs. On the North Island, ewes of fat-lamb flocks are predominantly of Romney breeding. They are retained for one or two seasons on the fattening farm or feedlot and are then sold for slaughter. On the South Island, the ewes are more mixed in type (apart from Southland where conditions in many ways resemble the North Island). Halfbred, Corriedale, Romney crossbred, are all included. Although the Southdown ram is widely used, Border Leicester, Suffolk, South-Suffolk, and Southdown × Border Leicester rams are also common. Fattening farms vary considerably in area and size. Lambing percentages vary but average is from 100 to 120 lambs per 100 ewes mated. The aim of the farmers is to sell a high proportion of these lambs with carcass weights around 28–36 lb. The amount of meat produced per acre on fattening farms averages about 120–140 lb per acre.

Abattoirs in New Zealand

Some small abattoirs in New Zealand supply lamb 12 months a year to the meat market They are able to take advantage of the earlier lambs in drier areas and the later lambs in the upland country which are sold as store lambs and finished by special finishing farms. Processing lamb for 12 months allows the abattoirs to be efficient. Most abattoirs look for farmers who produce 18kg carcasses, with the majority of lambs being a Romney crossed with a terminal sire. The lambs are classified based on weight and fat only.

There are also some huge farmer-owned co-operatives in New Zealand which process around 8.5 million lambs per year. The biggest problem is the sheer size of the abattoirs. Since New Zealand lamb is based purely on a grass and forage based system, the abattoirs can only run for about 6 months in season because the lamb supply runs out when grazing is poor. This results in efficiency problems. These large slaughter houses seek to increase efficiency by extending slaughter season through encouraging an increase in the weights of lambs supplied to the abattoirs.

Retailers and Domestic/Foreign Demand

As in Australia, the mutton and lamb from New Zealand slaughter houses are marketed to wholesalers, supermarkets, and restaurants. About 90% of the domestically produced New Zealand lamb is exported to foreign markets. New Zealand lamb exports reached 291,063 metric tons (tonnes) in 2010 (MLA 2011) which was down 3% compared with 2009.

The European Union (EU) has preferential access to New Zealand lamb exports. The EU accounted for 50% of New Zealand lamb exports as of 2010. China continued to enter and grow as an export destination for New Zealand lamb in 2010, up 6% year-on-year to 42,338 tonnes (up 29% on the five year average). While most New Zealand lamb cuts exported to China are relatively lower value, the volume makes up an important revenue source to New Zealand. The Middle East also remains an important market for New Zealand lamb.

The U.S. Sheep and Lamb Supply Chain[1]

The U.S. lamb supply chain can be characterized by large number of individuals at both ends of the chain. Downstream are millions of consumers who decide how much lamb to consume at prevailing market prices and, therefore, how much lamb will move through the supply chain at what time of the year. At the other end of the chain are thousands of producers of sheep and lamb who decide how much to produce based on signals passed through the supply chain from consumers. The center of the channel is

[1] Much of this section is based on Williams et al (2008).

quite narrow in places, with relatively few firms involved in changing the form and adding value to the lamb at particular stages as it makes its way from the producer end of the supply chain to the consumer end. The closer that lamb moves to the retail level, the larger the number of firms involved in handling, fabricating, and distributing the product.

The U.S. supply or value chain through which sheep and lamb and their products flow from production to end use is complex. The supply chain consists of six primary components: (1) farm production, (2) feedlot finishing, (3) harvesting and further processing, (4) retailing and food services, (5) trade (export and import), and (6) end use (consumption and industrial use).

U.S. Sheep Production

There are two primary types of commercial sheep operations in the U.S.: (1) range sheep operations and (2) farm flocks. Purebred operations are a third type of operations located throughout sheep producing states. Range sheep operations are found principally in the central and western states where flocks are maintained on native and improved pastureland. Sheep production in Texas, Wyoming, Colorado, Utah, Montana, Idaho, New Mexico, Arizona, and Nevada typify these extensive large-scale range operations. There are two types of range operations – range bands and fenced rage. Range band operations are typically located in the 11 Western states and South Dakota where there are vast unfenced public grazing lands. Since most of the grazing land is unimproved, native high-mountain and desert pastures, range bands often move long distances from season to season. The other type of range operation is fenced range used mainly in Texas, New Mexico, Oklahoma, Kansas, North Dakota where there is relatively less publicly-owned land. Unlike range band sheep operations, fenced range producers do not normally use on-site herders.

Farm flocks are the other type of U.S. commercial sheep operation. These operations predominate in the Midwest and in the East on confined, higher-quality pastures. Farm flocks are generally smaller than range flocks. The average flock size in all the states east of the Mississippi is about 50 head. Flock sizes in California typically are much larger and the sheep are raised in both confined pasture conditions and extensive range conditions.

Purebred sheep operations are located throughout the sheep producing states. Some producers maintain small purebred flocks as well as large commercial herds for the production of purebred breeding rams for sale or replacement, purebred ewes for sale to other producers, and for showing.

Range operations in the more arid rangeland states have little capacity to finish lambs for harvest on the ranches where the lambs are dropped. Those lambs are taken to large-scale feedlots where they are fed with high quality rations for finishing before harvest. About half of the annual U.S. lamb crop is from range operations. Lambs are usually born in spring months and remain in pasture for the entire summer. In some states like California, Arizona, and some parts of Texas, fall lambing is common. They are pastured in the winter months before moving into light lamb trade or as feeder lambs into feedlots or high quality pasture for finishing.

U.S. Lamb Feeding Operations

Lamb feeding in the United States is characterized by both feedlot and field (pasture) finishing operations. The majority of the feedlot operations are located in Colorado, Kansas, Texas, Wyoming, and the Midwestern states. The pasture operations are concentrated in California, Oregon, and Washington. Feedlot operations usually feed lambs all year round. Pasture feeding is seasonal in nature. Higher quality feeder lambs, weighing 23-36 kg, are often direct marketed through brokers and buyers to the light lamb markets for commercial harvest, most often for consumers in urban areas. Additionally, there is a market for lambs and mature animals of different weights for sale directly to customers at the farm gate. Ewes retained as replacements amount to about 20% of the mature ewe flock each year, both in range and farm flock operations.

Slaughterers and Breakers

In the traditional supply chain, lambs move directly from farms and feedlots to harvesters through auction markets and contract arrangements with growers. The packers occupy an important middle position in the lamb supply chain. On one side are the thousands of farmers and ranchers raising sheep and lamb. On the other side, purchasing lamb carcasses and boxed primals from the packers, are the breakers and distributors. The few number of packers in the United States is due mainly to the decline in the number of slaughter animals over the years. The decline in the number of packers buying sheep has led to both regional and structural concentration in sheep and lamb slaughter. In 2011, the four largest slaughtering firms accounted for 59% of the federally inspected lamb slaughter (USDA 2013c), down from a high of 75% to 80% in the 1990's, following some mergers in the meat packing industry (Williams et al. 1991, USDA 2007).

Most lamb packing facilities are located close to the lamb feeders, consumers, or both. The majority of the finished lambs are purchased by packers for slaughter. They separate the pelts and offals from the lamb carcasses which are inspected by the Food Safety Inspection Service (FSIS). Packers have traditionally marketed their products as hanging carcasses. Carcasses are further broken down and moved to breakers or further processors in different locations. Breakers act as middlemen, purchase lamb carcasses and boxed primals from packers and sell them to wholesalers and retailers. The breakers are located primarily on the East and West Coasts where the majority of the lamb consumption takes place. Breakers also serve the valuable function of distributing the various cuts across the market where individual retailers cannot purchase or sell lamb in carcass proportions.

Lamb Retail Operations and Consumption

Lamb retailers vary widely in type and include large national chain food stores, local chain and independent food stores, local butcher shops, and foodservice groups such as hotels, restaurants, health care and similar institutions, and even the government. Although government data concerning lamb at the retail level are limited, useful case studies are available from the National Meat Case Study (NMCS). Sealed Air's Cryovac Food Packaging Unit, the Beef Checkoff Program, and the National Pork Board conducted an extensive audit of the nation’s meat cases in 2010. Their research was benchmarked against the same study conducted in 2002, 2004, and 2007 to provide insight into the nation’s emerging retail trends. Surveyers audited 124 retail supermarkets and nine club stores in 51 metro markets across 31 states on various days of the week at random times. This summary only addressed more than 160,000 packages representing more than 288,000 pounds and 21,000 SKUs (stock keeping units) of meat products that were captured in U.S. supermarkets to understand the growing transformation in the retail meat case. The study found that lamb products increased their share of space in meat cases between 2002 and 2010. Because of the increasing consumer demand for convenience products, the share of boneless product packages has been increasing. According to the study, nutrition labeling was a big story for lamb, doubled to 36% of lamb packages sold. Ground lamb increased 4 percentage points to 13% of lamb packages (Williams et. al. 2008).

The increasing penetration of lamb in the retail market is good news for the lamb industry especially since the ethnic and the specialty markets are not included in these surveys. Although per capita lamb consumption has been declining over the years, the growing ethnic population in U.S. and their increasing lamb demand sends a positive signal to the lamb industry.

U.S. Lamb Market Price Mechanism

In each segment of the sheep and lamb supply chain, the interaction of demand and supply determines the price of the corresponding product. Increased consumer preference for lamb of a particular cut or with certain quality characteristics is reflected in a higher price for that product, signaling the need for an expansion of lamb meat production, lamb slaughter, lamb feeding, feeder lamb supplies, and eventually, sheep inventories. At the same time, an increase in the availability of lamb meat relative to consumer preferences would be reflected in a lower price signaling the need to reduce the supply of and demand for lamb and sheep at each segment along the supply chain. If there is no obstruction in the supply chain, the value of products offered by sellers as perceived by buyers will be communicated efficiently. Unfortunately, different market conduct, structures, and price discovery processes at each level of the lamb industry create difficulty for value preferences to migrate from consumers back along the supply chain to producers. The middle of the current lamb market structure is narrow and obstructed. The large number of producers at one end and consumers at the other end of the supply chain are basically price takers. Packers, breakers, and retailers operate in more of a bilateral oligopoly structure in which competition is based largely on non-price factors. Price is not a highly efficient means of communicating the preferences along the lamb supply chain from consumers to producers.

U.S. Lamb and Mutton Trade

International trade issues have and continue to be a fundamental component of the overall health of the U.S. sheep industry. Despite the decline in lamb production since the 1940s, imports have become a prominent force in the industry only in recent years. During the period of 1987 to 2011, an increase in lamb imports occurred just as domestic lamb production began another sharp decline, leading to more or less constant domestic consumption (figure 2). Between 1987 and 2007, imports increased from roughly 37 million pounds (lbs) on a carcass weight basis to approximately 175 million lbs.

Australia accounts for about 70% and New Zealand about 30% of U.S. lamb imports (figure 3). The principle of "comparative advantage" in production allows Australia and New Zealand lamb producers to be competitive with U.S. producers despite the great distance between the two markets. The principle suggests that countries gain by producing those commodities in which they have greatest relative marginal cost advantage. Comparative advantage is defined as the ability of a country to produce goods and/or services at a lower opportunity cost than other countries. Comparative advantage allows the country to sell goods or services at a lower price than its competitors to achieve gains from free trade. Both Australia and New Zealand have suitable climates and land for sheep grazing throughout the year. Specialized labor

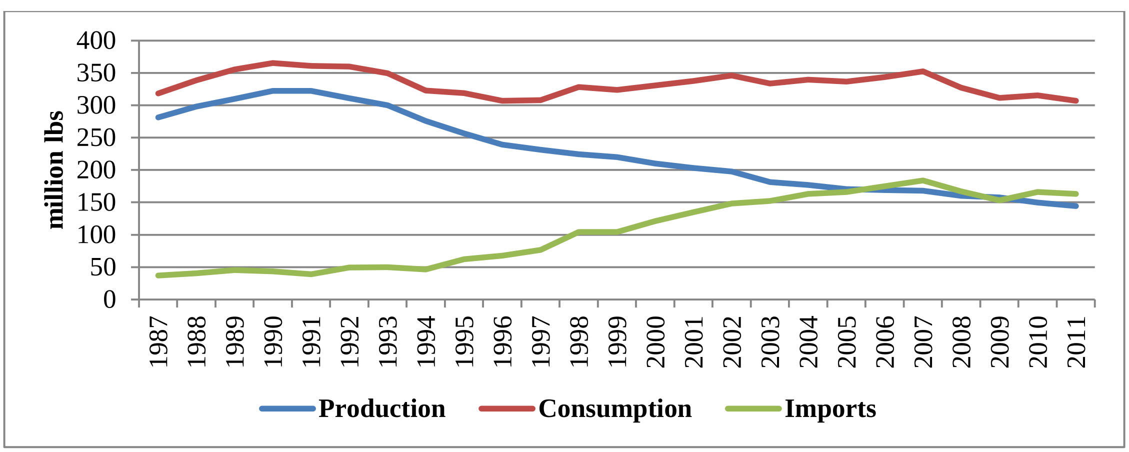

Figure 2. U.S. Lamb Production, Consumption, and Imports, 1987-2011

related to sheep production and suitable capital structure in both these countries makes them global competitors with the U.S. sheep industry. Until recently, U.S. lamb imports have been increasing rapidly (see figure 2). The import share of the U.S. lamb supply increased from about 35% in 2002 to 50% in 2007. Relative to 2002, U.S. lamb imports were up 20% percent in 2007 to 203 million lbs. Over the same period, imports from Australia were up 15% while imports from New Zealand were down 1% (figure 3) Relative to 2007, U.S. lamb imports from all sources were down 24% in 2012 to 154 million lb (Australia down 8% and New Zealand down 14%). The volume of U.S.

Figure 3. U.S. Lamb Imports by Source Country, 1989-2011

lamb exports over the period 1987 to 2011 are extremely small compared to lamb imports. U.S. exports mainly consist of mutton mostly shipped to Mexico and Japan. The mutton shipped is usually low value cuts which are not desired by domestic consumers. Mexico is the largest importer of mutton from U.S.

Changes in the exchange rate between the U.S. dollar and Australian and New Zealand currencies are often cited as important factors determining the level of U.S. lamb imports from those countries (Williams et al. 2008). For example, during 1999 and 2001, the U.S. dollar appreciated against Australian and New Zealand currencies by 20% and 25%, respectively (figure 4). As a result, the lower cost of foreign exchange to U.S.

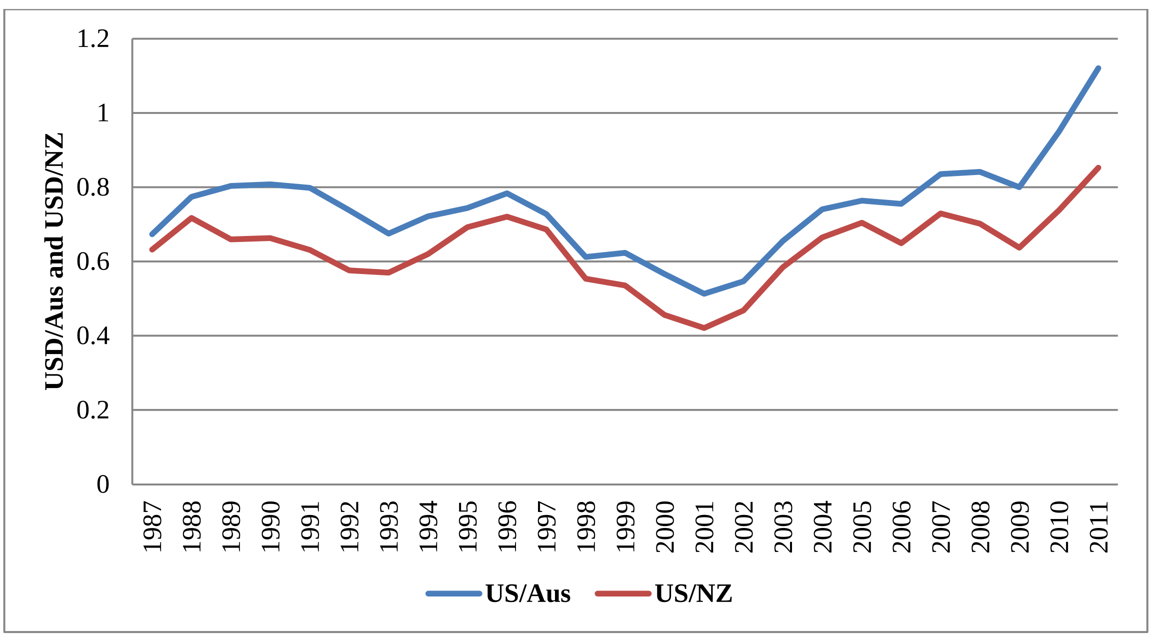

Figure 4. U.S. Exchange Rates, 1987-2011

lamb buyers diminished, thereby effectively lowering the import prices and increasing the demand for imported lamb in the domestic U.S. market. Hence, the appreciation of U.S. dollars made the imports cheaper to U.S. consumers and contributed to stronger than expected import demand during that period despite the U.S. tariff rate quota on lamb imposed in 1999-2001. The gradual fall in imports in recent years is likely the result of the rise in the value of the Australian and New Zealand currencies against the U.S. dollar.

U.S. Lamb Promotion and Advertising Efforts

A lamb promotion program has been in place in most years since the late 1970s. Beginning in the about 1978/79, the American Sheep Industry Association (ASIA) operated a lamb promotion program with voluntary deductions from government payments to lamb producers and feeders under the Wool Incentive Program. The deductions were authorized by producer referendum under section 708 of the 1954 National Wool Act. The annual nominal expenditures on lamb promotion activities by ASIA (ASIA 2013) grew from $1.2 million in 1978/79 to a high of $3 million in 1993 before declining to $1.2 in 1996/97 as the phase-out of the Wool Incentive Program began to take effect (figure 5). ASIA spent most of the funds allocated to lamb promotion to support promotional activities in four main areas: (1) retail marketing and promotion activities aimed primarily at the retail food store trade (theme promotions and contests, recipes, conventions, etc.); (2) consumer communications/relations including a wide variety of tasks and publicity efforts to promote directly to current and potential lamb consumers and users (newsletters, news releases, photography, and other media/promotional support, etc.); (3) food service promotion, including the development and placement of advertising with food service establishments, exhibits at culinary promotional events, etc.; and (4) support programs for buyers and merchandisers such as tours and staff training, technical and educational services, etc. (Williams et al. 2011). During 1990s, ASIA shifted most of the available promotion funds to retail promotion with spending on little else except a few special projects in a few years.

In the interim years before the current lamb checkoff program was established in 2002/03, promotion funds were made available by a section 201 trade complaint by the United States International Trade Commission (USITC). In 1998, ITC ruled in favor of the U.S. Sheep industry against Australia and New Zealand, finding that those two countries harmed the domestic sheep industry. As a result, a tariff rate quota was imposed on the lamb imports from Australia and New Zealand for three years (1999,

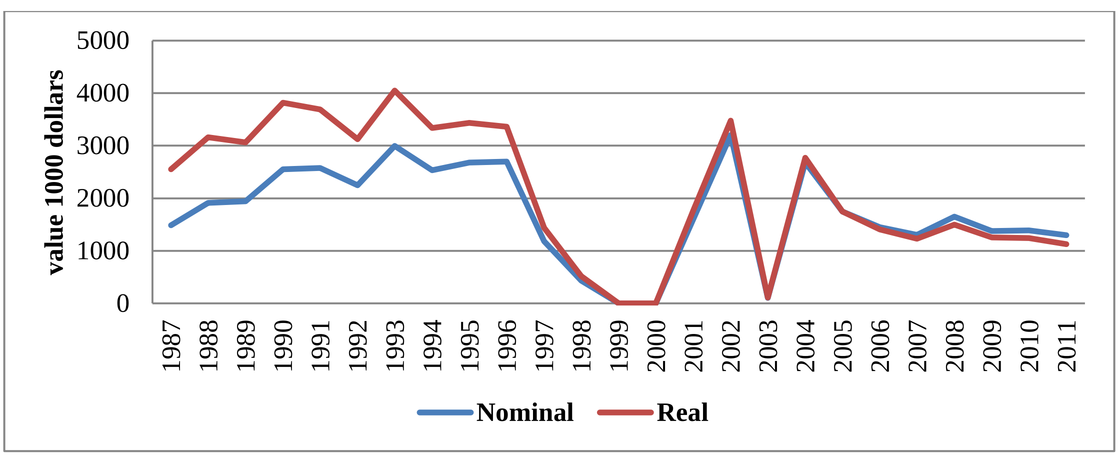

Figure 5. Lamb Promotion Expenditures, 1987-2011

2000,and 2001). An assistance package of $4.8 million was given to the domestic lamb industry for funding 23 lamb marketing and promotion projects between 2000/2001 and 2002/2003. Most of the funds were allocated to ASIA for lamb identification and food service promotion and retail promotion. The rest of the funds were allocated to packers, breakers, and processors to promote lamb products to retailers and food service outlets.

The current Lamb Checkoff Program was initiated in 2002 following a producer referendum. Since that time through 2011, the American Lamb Board (ALB), charged with the use and management of the lamb checkoff funds, spent a total of $12.9 million on lamb advertising and promotion, about $1.6 million per year, lower than the $2 million to $3 million spent each year on lamb promotion during the 1990s by ASIA. The American Lamb Board is comprised of 13 individuals representing the U.S. lamb supply chain including producers, feeders, seed stock producers, and processors who are appointed to the Board by the Secretary of Agriculture. The work of the American Lamb Board is overseen by the U.S. Department of Agriculture and the board’s programs are supported and implemented by a small staff in Denver, Colorado.

The main objective of the current Lamb Checkoff Program is to increase demand for “American” lamb rather than lamb in general which includes imported lamb (American Lamb Board, ALB 2012). The program is funded by an assessment on all feeder and market lambs and all breeding stock and cull animals. In general, the purchaser collects the assessment with a deduction from the sales proceeds of the seller. The funds are then carried forward to the point of slaughter or export market and then collected and sent to the Board. Those who are assessed include producers (including seedstock producers), exporters, feeders and direct marketers, and slaughter plants (including ethnic and custom slaughter operations). The small number of imported sheep and lambs are also assessed on weight gain in U.S. The assessment is $0.007 per pound of ovine animals (any age) sold by producers, exporters, and feeders and 42 cents ($0.42) per head of lambs purchased for slaughter by first handlers. Marketing agencies are not assessed a checkoff fee but they must collect assessments from the sellers and pass them on to the purchasers. Direct marketers who are both producers and first handlers are required to pay an assessment of one-half cent per pound on the live weight at the time of slaughter and also $0.42 per head as an additional assessment.

Compared to the value of lamb purchases each year, the amount of funds that the lamb checkoff program collects for the promotion of lamb is extremely small. The annual lamb advertising-to-sales ratio (often referred to as the investment intensity ratio) over the 1979 to 2011 period ranged from a minimum of zero in 1999/2000 and 2000/01 to a high of 0.39% in 1988/89, averaging 0.21% between 1978/79 and 1995/96 but only 0.07% since the current Lamb Checkoff Program was established (figure 6).

The lamb advertising intensity has declined in recent years primarily because fewer promotion funds have been made available through the current program than what was formerly spent on lamb promotion by the ASIA under the Wool Incentive Program. Administrative costs are kept low so that most of the collected checkoff funds are used for promotional purposes.

International Wool Markets

Wool is an important joint product of sheep production in the U.S. as well as in Australia and New Zealand. This section provides some background on wool markets as a means of informing the model to be described in the following chapters.

U.S. Wool Market

The production of wool is a continuous, year round process influenced by genetics, nutritional status, lactation, and other stress factors. The U.S. production of wool has been declining since the 1940s. Today, U.S. wool output accounts for less than one

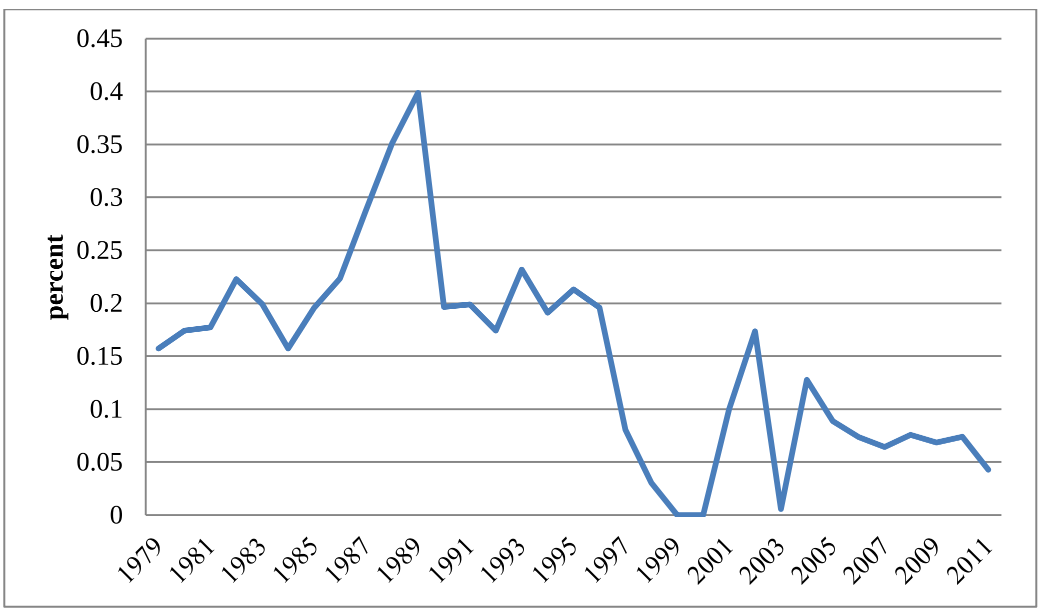

Figure 6. Lamb Advertising-to-Sales Ratio, 1979-2011

percent of the world's wool production mostly because of the decline in sheep inventories and a change in breeding and production emphasis on the more profitable meat products. Geographically, wool production is correlated closely with the number of sheep. The leading wool producing states are Texas, California, Wyoming, Colorado, and Utah (USDA 2013d).

The geographical distribution of wool production by quality varies considerably. The fiber diameter describes the quality of the wool. All international wool markets describe fiber diameter in microns with superfine wool as low as 14-17 microns up to coarser wool from 27-35 microns. In the lower micron ranges, the quality of fabric increases and is used mainly for clothing and apparel. Some wool apparel is produced domestically in the U.S. but most is imported (Williams et al. 2008). At the mill level, wool competes with a large number of artificial fibers. Due to changing consumer demands, non-cellulosic fibers like nylon and dacron have been developed and now dominate fiber markets. Synthetic fibers accounted for an average of 69.9% of all fibers used by U.S. mills with cotton accounting for 28.7% (USDA 2010). Wool accounted for an average of only 0.6%. The domestic mill use of all fibers, including wool, has been on a downward trend in recent years (figure 7). The downward trend can be attributed to the rising concentration of textile industries in low wage developing countries. Domestic mill use of wool has also suffered from the continuing decline of the number of sheep shorn, the rise in the promotion of cotton and other synthetic fibers, and a shift in consumer taste and preferences from wool to synthetic cotton fibers.

The Australian Wool Industry

The Australian wool industry has been characterized by low wool returns, declining sheep numbers, falling wool production, and rising lamb returns (DAFF 2011). The decline in the Australian wool industry has been driven by a long-term decrease in global raw wool demand and competition from alternative fibers. As a result, the industry has experienced significant structural adjustment, including a shift from wool and mutton production towards lamb meat production. Of the five sheep production sectors in Australia as defined earlier, by far the largest is the self-replacing wool enterprise (SRW) accounting for just over half of the national flock.

Australian wool production increased by 4% to 446,000 tonnes in 2011/12 reflecting an increase in the number of sheep shorn and relatively high wool cut per head.

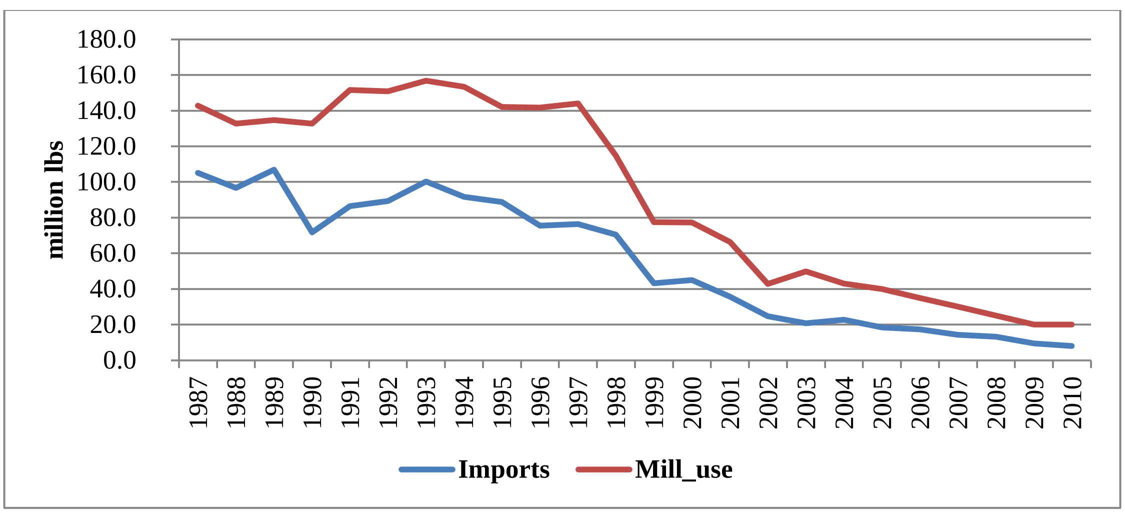

Figure 7. U. S. Raw Wool Imports and Mill Use, 1987-2011

Following favorable climatic conditions in the primary sheep growing areas of eastern Australia, combined with relatively favorable wool and sheep meat prices, the flock increased by 9% between 2009/10 and 2010/11 to 74.3 million head. While there were large increases in the sheep flock in all eastern states, sheep numbers in Western Australia declined slightly following adverse seasonal conditions in 2010/11.

There has been subdued economic growth in key wool apparel consuming countries which has contributed to a slowdown of Australian greasy wool exports (DAFF 2011). Consumer spending on apparel is affected by slowing economic growth in Western Europe and modest economic growth in the United States. Competition from alternative fibers like cotton has also led to the decline in exports of raw wool. China is the major importer of greasy wool followed by Italy.

China's exports of woven wool apparel declined in the first eight months of 2011 reflecting a sharp reduction in exports to the European Union and the United States (DAFF 2011). The decline in export demand for woven wool products was reflected in reduced import demand for fine and superfine wool by Chinese mills. Imports of Australian wool of less than 19 microns fell by 28% year-on-year to 16,227 tonnes (greasy equivalent) in the three months to September 2011. Despite the recent slowdown of Chinese demand for greasy wool imports, the Chinese demand is expected to remain steady in the near future (DAFF 2011).

The New Zealand Wool Industry

Wool was New Zealand's main export earner from the 1850s until the start of the 20th century and produced almost 90% of total export income in 1860. Since then, wool has fallen in importance. In 2006, wool accounted for only 2.73% of New Zealand exports with a value of $839 million. However, New Zealand remains the world's second largest exporter of wool, accounting for 20% of the world's exports by volume, after Australia (52%).

The Merinos were the first sheep breeds brought to New Zealand from Australia which was already dominant with the Merino sheep breeds. The 1840s to 1860s saw the influx of Merino sheep from Australia but not all Merinos were of good quality. So the New Zealanders began importing sheep from Germany, France, the U.K., and the U.S. to improve the stock. Although Merinos were the dominant breed type in New Zealand by the 1880s, they were highly susceptible to different diseases in the North Island which has a warm moist climate. Also, the Merino breed was not good for meat. So, new breeds were introduced in New Zealand like Halfbred, Corriedale, and Romney crossbreeds which are used today both for meat and wool. The wool from different sheep breeds have different qualities based on the fiber diameter. The specific use of wool depends on the fineness of the fiber. Coarse wool is used in the interior textile industry and fine wool in the apparel industry. New Zealand's wool exports are, by volume, 5% fine wool, 15% medium, 33% fine crossbred, and 47% coarse crossbred.

Since Australia and New Zealand are major exporters of raw wool to the world, economic conditions outside those two countries affect their wool markets. Like

Australia, New Zealand is also a major exporter of greasy wool to China and Hong Kong. The increase in demand in the apparel market in China has increased the import demand for greasy wool from Oceania to an extent. China and Hong Kong's share of New Zealand's total wool export volume increased from 22% in calendar year 2003 to 54% percent in calendar year 2012 (MLA 2012).

Raw Wool Trade Between Oceania and the United States

In general, the United States exports some fibers, both natural and synthetic, but also imports some raw fibers like wool. Raw wool imports into the United States have traditionally been larger than U.S. wool exports making the country a net raw wool importer. Nearly 80% of coarse U.S. raw wool imports (not finer than 46s) comes from New Zealand (figure 8). On the other hand, Australia accounts for 70% of U.S. imports of finer wool (48s and finer) (figure 9). Other major exporters of coarse raw wool to the U.S. are United Kingdom, Argentina, and Uruguay (USDA 2010).

Summary and Conclusion

This chapter provides a qualitative analysis of the U.S., Australian, and New Zealand sheep-lamb-wool supply chains. The U.S. lamb promotion effort initiated in 2002 is an effort to promote the growth and development of the U.S. sheep and lamb industry. To the extent that the activities of the American Lamb Board effectively shift out the U.S. demand for lamb, changes all along the interconnected global sheep-lamb-and lamb chain would be expected. The next chapter provides a conceptual analysis of those markets to guide the quantitative analysis of those markets in the following chapter.

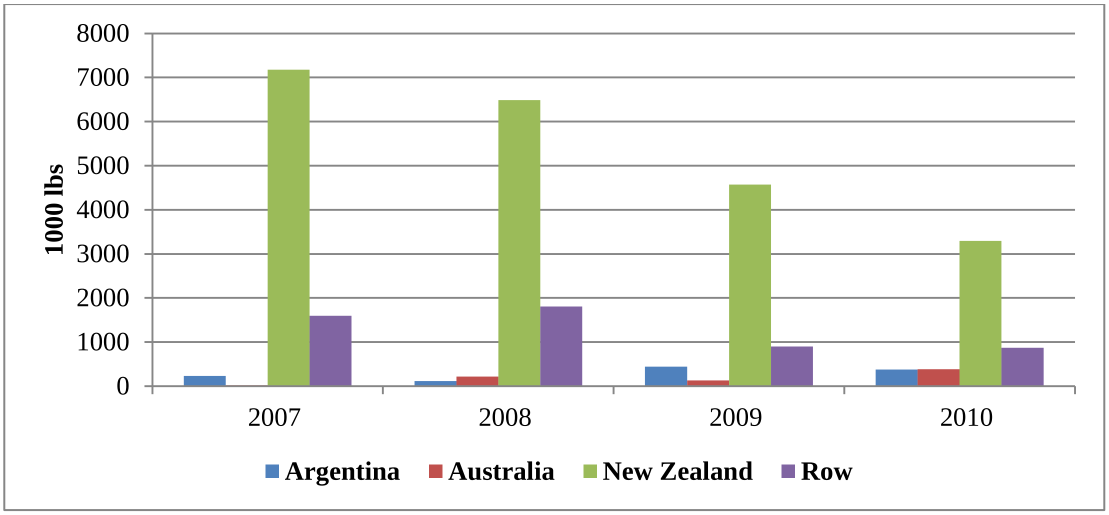

Figure 8. U.S. Imports of Raw Wool (Not Finer Than 46) by Source, 2007-2010

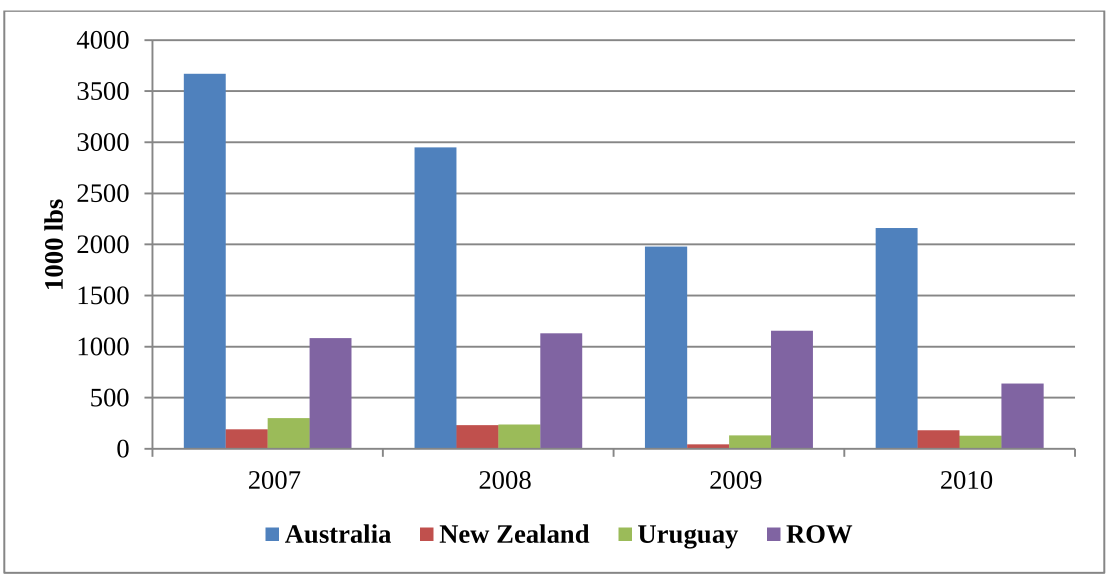

Figure 9. U.S. Imports of Raw Wool (48s and Finer) by Source, 2007-2010

CHAPTER III

CONCEPTUAL MODEL OF THE GLOBAL SHEEP, LAMB, AND WOOL SUPPLY CHAIN

Over the years, the objective of lamb promotion efforts in the U.S. has been to enhance the profitability of the U.S. sheep and lamb industry by increasing the retail demand for lamb. The current Lamb Checkoff Program has focused also on boosting the demand for "American" lamb rather than lamb in general which includes imported lamb (American Lamb Board 2012). Thus, the success of lamb promotion efforts may be measured by considering: (1) how effectively lamb promotion expenditures over the years have shifted out the demand for lamb, (2) the extent to which the U.S. market share of domestic lamb consumption has been enhanced in the case of the current checkoff program, and (3) the share of any increase in revenues achieved that has been transmitted up the supply chain from the retail level where the promotional efforts have occurred to stakeholders along the supply chain (producers, feeders, and slaughterers).

As indicated in Chapter I, all the research to date on lamb promotion has focused on the extent of the shift in the retail demand for lamb resulting from lamb promotion programs. Benefits at the retail level have been estimated assuming no supply response or market price effects (see. e.g., Williams, Capps, and Dang 2010). Measuring the returns from the program to stakeholders is much more complicated and requires a supply chain approach to the analysis in which price effects are enabled and allowed to be transmitted from the retail level through the processing level to the producer level of the industry and to generate responses of supply and demand at each level.

In existing studies of the effects of lamb promotion, promotional expenditures are allowed only to shift out the quantity of lamb demand assuming a perfectly elastic supply of lamb so that price does not change. However, the promotion-induced increase in the retail demand for lamb could be expected to be large enough to increase not only the quantity of lamb purchased at retail but also the retail price of lamb which would trigger changes in supply and demand at every level of the supply chain and potentially attract additional foreign lamb to the market. As the benefits of promotion pass back along the supply chain in terms of higher prices and quantities, operations at each level gain some of the benefit, both those who have paid for the promotion and those who have not (commonly referred to as free riders).

How much of the benefit actually ends up in the hands of stakeholders and in what proportion is an empirical question that can only be answered by measuring the price and quantity responses of all operations along the global supply chain, including foreign sheep operations. For that reason, this chapter develops a conceptual supply chain model of world sheep, lamb, and wool markets that allows for global price and quantity adjustments that may result from a shift in the U.S. demand for lamb due to promotion programs. The conceptual model developed will be used in the next chapter to develop a statistical model capable of reliably measuring the transmission of checkoff promotion benefits along the global chain to stakeholders.

In this chapter, a graphical model of world sheep, lamb, and wool markets is first developed. Then a mathematical representation of the graphical model is developed.

Graphical Model of World Sheep, Lamb, and Wool Markets

The graphical representation in figure 10 is a simplification of global sheep and lamb markets. To keep the graphical analysis tractable for expositional purposes, the graphical representation of the model focuses only on the key relationships in the supply chain. The mathematical model that is presented later in this chapter provides a more robust representation of world sheep, lamb, and wool markets.

The left column of graphs in figure 10 represents the U.S domestic sheep and lamb supply chain while the right column represents the supply chain in the rest of the world in which Australia and New Zealand are treated as one aggregate country (ANZ) for expositional purposes only. The mathematical model developed later in this chapter treats them as separate countries.

The middle column of figure 10 has only one graph representing the world market for lamb which is the only point of global intersection between the U.S. sheep and lamb supply chain and those of Australia and New Zealand. In that graph, the intersection of the excess demand for lamb by the United States and the excess supply of lamb from Australia and New Zealand (represented jointly as ANZ in figure 10) determine the equilibrium international prices of lamb and the trade quantity ($PL_0^{US} = PL_0^{ANZ}$ and QM_0, respectively). The top-left graph of figure 10 represents the activities of U.S. sheep

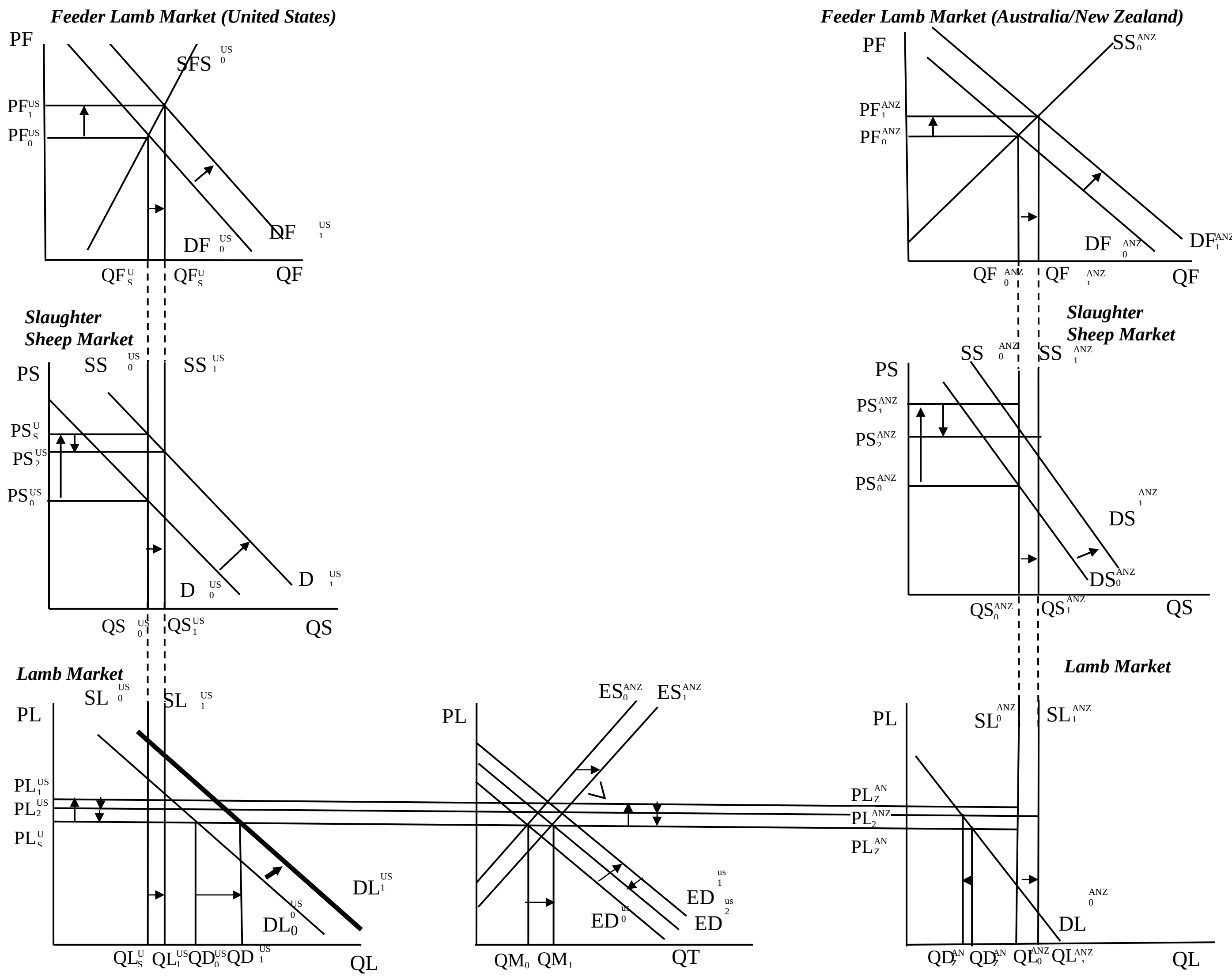

Figure 10. World Sheep and Lamb Model and the Effects of U.S. Lamb Promotion

producers in supplying feeder lambs to the market represented by the feeder lamb supply curve (SF_0^{US}) and the demand for feeder lambs by feedlots and for direct sale (DF_0^{US}). The interaction of the supply and demand for feeder lambs determines the market price for feeder lambs (PF_0^{US}). The largest portion of feeder lambs enter feedlots and are transformed by feeding into slaughter lambs (represented by the dotted line between the two graphs in the top left of figure 10).

The supply of slaughter lambs is the number of lambs placed on feed (minus death loss) and is represented by a perfectly vertical supply curve (SS_0^{US}) in the middle-left graph of figure 10. The vertical nature of the slaughter sheep supply curve is a graphical device to depict the fact that the quantity supplied of slaughter sheep can increase when the price of slaughter sheep increases only if: (1) feedlot operators first respond to the higher slaughter sheep price by demanding more feeder lambs from producers to be able to produce additional slaughter lambs (rightward shift of the demand for feeder lambs in the top-left graph of figure 10) which drives up the price of feeder lambs and (2) producers respond by retaining more ewes and supplying more feeder lambs to the market which takes time. Once more feeder lambs become available and are fed, the vertical slaughter sheep supply curve would then shift to the right. The intersection of the demand by lamb packers for slaughter sheep (DS_0^{US}) and the supply of slaughter sheep (SF_0^{US}) determines the market price for slaughter sheep (PS_0^{US}). Slaughter sheep are then transformed by packers into lamb (represented by the dotted line between the middle-left and bottom-left graphs in figure 10).

The lamb supplied by packers, breakers, and others to the market is represented by the vertical lamb supply curve (SL_0^{US}) in the bottom-left graph of figure 10. Again, the vertical nature of the lamb supply curve in the bottom-left graph of figure 10 is a graphical device to depict the fact that the packers can supply more lamb to the market in response to an increase in the price of lamb only if they first demand more slaughter sheep from feeders which drives up the slaughter price of sheep. Feeders, cannot supply additional slaughter sheep to packers without first feeding more lambs. Their demand for more feeder lambs from producers drives up the price of feeder lambs, sending a signal to producers to retain more ewes and produce more feeder lambs which takes time. Only when additional feeder lambs are available, fed, and then slaughtered, can packers supply more lamb to the market. The result would be a rightward shift in the vertical lamb supply curve in the bottom-left graph of figure 10. Thus, in the domestic sheep and lamb supply chain, an increase in the demand for more lamb at the retail level requires that the resulting increase in the lamb price be transmitted along the supply chain all the way back to producers. Otherwise, retail price increases will have no effect on the domestic supply of lamb available in the market.

Note that in the domestic U.S. lamb market (bottom-left graph of figure 10) the domestic demand for lamb (DL_0^{US}) is greater than the domestic quantity supplied at most prices resulting in a demand for foreign lamb represented by the excess demand for lamb (ED_0^{US}) in the middle-bottom graph of figure 10. The interaction of the U.S. excess demand for lamb and the foreign supply of lamb represented by the excess supply of lamb from Australia and New Zealand (ES_0^{ANZ}) in the bottom-middle graph of figure 10 determines the retail price of lamb (PL_0^{US}) in the U.S. market as shown in the bottom-left graph of figure 10.

The sheep and lamb supply chains in Australia and New Zealand function in the same way. The main difference is that in those markets, more lamb is produced than can be consumed by their own consumers leading to an excess supply of lamb available for export represented by the export supply curve ES_0^{ANZ} in the bottom-middle graph of figure 3-1 which is the difference between the domestic Australia-New Zealand supply of lamb (SL_0^{ANZ}) and their domestic demand for lamb (DL_0^{ANZ}) at every price. The actual volume of lamb exported by Australia-New Zealand to the U.S. and imported by the U.S from Australia-New Zealand (QM_0) is determined by the interaction of the excess supply and excess demand for lamb in the world market as depicted in the bottom-middle graph of figure 10.

Note that in Australia and New Zealand, as in the U.S., the supply of lamb is depicted as perfectly vertical (SL_0^{ANZ}), because the quantity supplied of lamb cannot change when retail price changes without an increase in lamb slaughtering. Additional lambs cannot be slaughtered without an increase in the supply of fed lambs which cannot increase without an increase in feeder lambs. The quantity of feeder lambs cannot increase without an increase in the lamb crop which takes time. Thus for an increase in the retail price to increase the supply, the retail price increase must transmit all the way up the supply chain to producers who eventually can respond by producing more feeder lambs.

Figure 11 depicts the world wool market. The domestic U.S. demand for wool (left graph of figure 11) is represented by DW_0^{US} which is greater than the domestic quantity supplied (SW_0^{US}) at most prices, resulting in a demand for foreign wool represented by the excess demand for wool (ED_0^{US}) in the middle graph of figure 11.

The main difference between the wool markets in the United States and in Australia and New Zealand is that in the latter countries more wool is produced than can be consumed by their own mills such that the supply of wool in those countries SW_0^{ANZ} is greater than the domestic demand for wool DW_0^{ANZ} at most prices in those countries (right graph of figure11). The difference between the supply and demand for wool in Australia and New Zealand is the Australia/New Zealand excess supply of wool (ES_0^{ANZ} in the middle graph of figure 11).

The interaction of the U.S. excess demand for wool ED_0^{US} and excess supply of wool from Australia and New Zealand ES_0^{ANZ} in the middle graph of figure 11 determines the price of wool in the U.S. $PW_0^{US}$and in Australia and New Zealand PW_0^{ANZ} and the volume of wool traded QW_0.

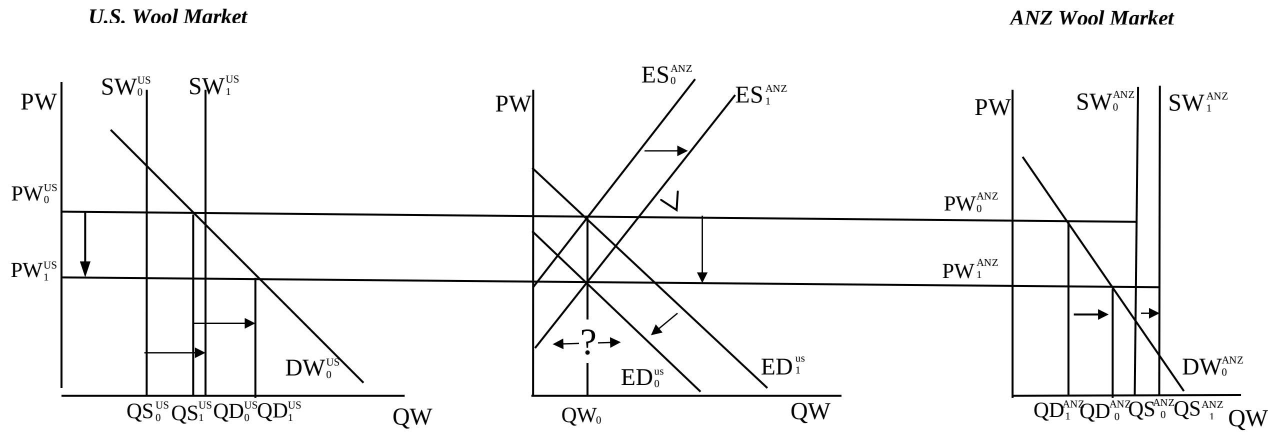

Figure 11. World Wool Market Model and Effects of U.S. Lamb Promotion

Analysis of the Global Supply Chain Effects of U.S. Lamb Promotion

Assuming that lamb promotion operates as intended, the programmatic activities of the American Lamb Board under the current lamb checkoff program (or those that were funded earlier by the Wool Incentive Program) can be represented as a rightward shift of the U.S. domestic demand for lamb (shown as a shift of $DL_0^{US}$to DL_1^{US} in the bottom-left graph of figure 10). As a result, the U.S. excess demand for lamb shifts from ED_0^{US} to ED_1^{US} in the bottom-middle graph of figure 10. Initially, the U.S. price of lamb increases to PL_1^{US}sending the signal to U.S. packers to supply more lamb. As a result, the demand for slaughter lambs increases (DS_0^{US} to DS_1^{US} in the middle-left graph in figure 10) which increases the price of slaughter sheep (PS_0^{US} to PS_1^{US} in that same graph of figure 10). Feeders respond to the higher price of slaughter sheep by demanding more feeder lambs (a shift of the feeder lamb demand from DF_0^{US} to DF_1^{US} in the top-left graph in figure 10). The consequence is an increase in the price of feeder lambs (PF_0^{US} to PF_1^{US} in the same top-left graph of figure 10) and an increase in replacement ewes and in the subsequent lamb crop. The eventual increase in feeder lambs (QF_0^{US} to QF_1^{US} in the top-left graph of figure 10) allows an increase in supply of slaughter sheep (SS_0^{US} to SS_1^{US} in the middle-left graph of figure 10) along with some downward adjustment in the slaughter price (PS_1^{US} to PS_2^{US} in that same middle-left graph of figure 10) and eventually an increase in the supply of domestically produced lamb in the market (SL_0^{US} to SL_1^{US} in the bottom-left graph of figure 10). The increase in the domestic supply of lamb shifts the U.S. excess demand for lamb back to the left some extent (ED_1^{US} to

ED_2^{US} in the bottom-middle graph of figure 10) and softens the lamb price increase (decline in the price from PL_1^{US} to PL_2^{US} in the bottom row of graphs in figure 10).

Just as the checkoff-induced increase in the price of lamb sets off a chain of events resulting in additional domestically produced lamb, that same price increase from the increased U.S. import demand for lamb sets off a similar chain of events in Australia and New Zealand resulting in additional production of lamb in those countries, making additional lamb available for export in an effort to benefit from the increased import demand for lamb by the United States. The result is a rightward shift in the excess supply of lamb from Australia and New Zealand (ES_0^{ANZ} to ES_1^{ANZ} in the bottom-middle graph of figure 10), further expanding the inflow of lamb into the U.S. and further dampening the price of lamb (PL_2^{US} to PL_0^{US} in the bottom row of graphs in figure 10).

The analysis implies that a checkoff-induced increase in the U.S. demand for lamb will unambiguously increase U.S. imports of lamb (QM_0 to QM_1 in the middle-bottom graph of figure 10). Whether or not the price of lamb will increase, is not clear and depends on the magnitude of the supply responses in <u>both</u> the U.S. and foreign countries to the checkoff-induced increase in the U.S. demand for lamb. In other words, the lamb checkoff could theoretically result in a higher, lower, or unchanged price of lamb in the U.S. and foreign markets. The middle-bottom graph in figure 10 shows the case of no net effect on the price of lamb following the check-off induced lamb demand as a result of the lamb supply response in both the U.S. and foreign markets.

The checkoff-induced increase in the U.S. demand for lamb meat which increases the number of sheep produced leads not only to an increase in the U.S. production of meat as depicted in figure 10 but also to an increased supply of wool shown in the left hand graph of figure 11 as a rightward shift of wool supply from SW_0^{us} to SW_1^{us}. The consequence is a leftward shift of the U.S. excess demand for wool from ED_0^{us} to ED_1^{us} in the middle graph of figure 11.

As shown in figure 10, the U.S. lamb promotion program has a tendency to increase the number of sheep produced in both Australia and New Zealand leading to additional lamb meat production and, consequently, additional wool production by those two countries. The additional wool produced in those two countries as a result of the lamb checkoff program is shown in figure 11 as a rightward shift in their domestic wool supply curve from SW_0^{ANZ} to SW_1^{ANZ} in the right hand graph in that figure. As a consequence, the excess supply of wool from those two countries shifts to the right from ES_0^{ANZ} to ES_1^{ANZ} in the middle graph of figure 11. As a result, the price of wool in all markets unambiguously declines. The decline in the price of wool will have a moderating effect on the increase in sheep and lamb production as a result of the increase in demand for lamb from the checkoff promotion.

The impact of the checkoff promotion on world wool trade is ambiguous and depends on not only the elasticities the supply and demand for wool in all countries but also the elasticity of sheep production in all countries to changes in sheep and wool prices. If the excess supply of wool from Australia and New Zealand increases by more than the U.S. excess demand for wool declines, then wool trade will increase. In the same way if the excess supply of wool from Australia and New Zealand increases by less than the U.S. excess demand for wool declines, then wool trade will decrease.

Figure 11 shows the case of no change in wool trade as a result of the lamb checkoff program.

Mathematical Representation of the World Sheep, Lamb, and Wool Model

The preceding graphical analysis provides an explanation of the potential effects of the lamb checkoff program on the domestic and foreign markets for lamb and wool. Although helpful for analyzing the expected direction of the effects of the checkoff-financed promotion and advertising in both the domestic and foreign markets, the graphical representation fails to capture the likely magnitude of the effects. A more in-depth analysis of the effects of a checkoff-induced increase in the U.S. demand for lamb and a check of the hypotheses of the direction of the effects presented in figure 10 require a quantitative analysis of the checkoff program. A mathematical representation of the global sheep, lamb, and wool supply chain is presented in table 1.

The mathematical representation includes: (table 1) the domestic U.S., Australia, and New Zealand live sheep supplies and demands (from breeding inventories through slaughter in each country); (2) the domestic U.S., Australia, and New Zealand production and consumer demand of lamb; (3) world lamb trade and price linkages; (4) the domestic wool supplies and demands in the U.S., Australia, New Zealand, Argentina, and Uruguay; and (5) world wool trade and price linkages. Table 2 provides a definition of the variables used in the model.

Equations (1) through (15) in table 1 represent the U.S. live sheep and lamb supply chain. Equation (1) in table 1, representing the ending inventory of the U.S. sheep breeding herd, is an identity defining the ending breeding inventories each year (totalbreedingsheep_US) as the sum of mature ewe inventories (matureewes_US), mature ram inventories (mature_rams_US), and replacement lamb inventories (replacement_lambs_US).

Equation (2) in table 1 represents mature ewe inventories which are a function of the real price of live sheep (newprice_sheep_live_us), the lagged dependent variable (matureewes_USlag), the real US farm price of wool (US_farm_pricenew), and exogenous shift variables (wme). The lagged dependent variable indicates the dynamic adjustment of inventories from one period to the other. Mature ewe inventories are expected to be positively related to the current price of live sheep and also to the current farm price of wool. The U.S. lamb crop (lambcrop_us in equation (3) in table 1) is specified as a function of mature ewe inventories (matureewes_US), the real slaughter sheep price (newsl_us), and some shift variables (wlc). The lamb crop is expected to increase with number of mature ewes and also with the slaughter price which acts as an incentive to increase the lambing rate and, thus, the lamb crop, over time. Replacement lamb numbers (replacement_lambs_us in equation (4) in table 1) are specified as a function of the the real price of sheep (newprice_sheep_live_us) the lagged lamb crop, death loss (death_loss_us), and other exogenous shift variables (wrl). When the real sheep price increases, producers retain ewes which are one year old to build their herds implying a positive relationship between price and the number of replacement lambs (replacement_lambs_us).

Table 1. Mathematical Model of World Sheep, Lamb, and Wool Markets[1,2]

U.S. Live Sheep Market:

(1) totalbreedingsheep_US = matureewes_US+mature_rams_US+replacement_lambs_US

(2) matureewes_US = f(matureewes_uslag, newprice_sheep_live_us, US_farm_pricenew, w_{me})

(3) lambcrop_us = f(matureewes_us, newsl_us, w_{lc})

(4) replacement_lambs_us = f(lambcrop_uslag, death_loss_us, newprice_sheep_live_us, w_{rl})

(5) death_loss_US = death_rate*totalbreedingsheep_US

(6) total_feed_US = f(total_feed_USLag ,newprice_sheep_live_us, newsl_us, w_f)

(7) total_slaughter_us = f(total_feed_USlag ,newretail_price_lamb_us, newsl_US, lambcrop_uslag ,total_slaughter_uslag, w_{ts})

(8) total_slaughter_US = totalbreedingsheep_USlag+total_feed_USLag-NetExportsheads_US-death_loss_US+lambcrop_US-totalbreedingsheep_US-total_feed_us

(9) newprice_sheep_live_us = f(newsl_US, w_{pl})

U.S. Lamb Meat Market:

(10) Production_US = averagewt_us*total_slaughter_us

(11) retailproduction = converretail*Production_US

(12) percapitacons_us = f(newexp_us ,newexp_uslag ,newretail_price_lamb_us, AdjNNIcapita_US, newreprice_beef_US, newporkrp, w_{pc})

(13) percapitacons_us = cons_retail_us/population_US

(14) cons_retail_us = Mlambpound_US+retailproduction

(15) Mlambpound_US = Mlambtonnes_US/Conversionlamb

Australian Live Sheep market:

(16) Totalstock_A= Breeding_ewesA+ Othersheep_A+Total_feed_A

(17) Breeding_ewesA = f(Breeding_ewesAlag, Aus_px_wnewreal, time, PP_LSnewreal, w_{bea})

(18) Lamb_crop_A = f(Breeding_ewesA, time, w_{lca})

(19) Othersheep_A = f(Othersheep_Alag, Aus_px_wnewreal, PP_LSnewreal, time, w_{ota})

(20) Total_feed_A= f(Total_feed_Alag, PP_LSnewreal, Lamb_RP_Anew, w_{fa})

(21) TotalSL_A = f(Lamb_RP_Anew , PP_LSnewreal, TotalSL_Alag, Lamb_crop_Alag, w_{sla})

(22) DL_A = deathrate_A*Totalstock_A

(23) NETExports_A = f(NETExports_Alag, ME_EUgdp, PP_LSnewreal, ME_EU_Exrate, w_{nxml})

(24) TotalSL_A = Totalstock_Alag-NETExports_A-DL_A+Lamb_crop_A-TotalstockS_A

Australian Lamb Meat Market:

(25) production_A = Conversionfactor_A*TotalSL_A

(26) TotalconsA = f(lamb_rp_anew, Beef_RP_Anew, Aus_disc_income, newChicken_RP_A, w_{tca})

(27) Exportmeat_A = production_A-TotalconsA

New Zealand Live Sheep Market:

(28) Totalstock_NZ = Breeding__ewesNZ+ othersheep + Total_feed_NZ

(29) Breeding__ewesNZ = f(Breeding__ewesNZlag, time, sheeplivepp_NZnewreal, NZ_px_wnewreal, w_{bnz})

(30) lamb_crop_NZ = f(time, Breeding__ewesNZ, w_{lcnz})

(31) othersheep_NZ = f(othersheeplag, time, sheeplivepp_NZnewreal, NZ_px_wnewreal, w_{otnz})

(32) Total_feed_NZ= f(Total_feed_NZlag, sheeplivepp_NZnewreal, NZ_px_mnewreal, w_{fnz})

(33) totalSL_NZ = f(NZ_px_mnewreal, sheeplivepp_NZnewreal, totalSL_NZlag, lamb_crop_NZlag, w_{snz})

(34) DL_NZ = death_rate_NZ*Totalstock_NZ

(35) NETExports_NZ = f(NETExports_NZlag, ME_EUgdp, sheeplivepp_NZnewreal, ME_EU_Exrate, w_{nxnz})

Table 1. Continued

(36) TotalSL_NZ = Totalstock_NZlag-NETExports_NZ-DL_NZ+lamb_crop_NZ-Totalstock_NZ

New Zealand Lamb Meat Market:

(37) production_NZ = conversion_NZ*TotalSL_NZ

(38) NZ_ConsTonnes = f(NZ_px_mnewreal, NZGDP, Beef_NZpxnewreal, , Chicken_NZpxnewreal, w_{tcnz})

(39) exporttonnes_NZ = production_NZ- NZ_ConsTonnes

International Lamb Meat Trade and Price Linkages:

(40) ROW_M = f(ROW_Mlag, importingworldgdp, perunitLPM, EU_ME_EXC, w_{rm})

(41) Mlambtonnes_US = Exportmeat_A+exporttonnes_NZ+ROW_X-ROW_M

(42) NZ_px_mnewreal = f(perunitLPM*NZ_exrate, w_{pxnz})

(43) Lamb_RP_Anew = f(perunitLPM*Aus_exrate, w_{pla})

(44) perunitLPM=f(newretail_price_lamb_us, w_{lpm})

U.S. Wool Market:

(45) Sheep_shorn_USml_lbs = Conwool_US*totalbreedingsheep_US

(46) Prod_greasy_wool = fleece_yield*Sheep_shorn_USml_lbs

(47) Productionwool = conwool1*Prod_greasy_wool

(48) End_stocks = f(End_stockslag, US_farm_pricenew, w_{wus})

(49) Mill_use = f(US_farm_pricenew, Mill_uselag, polyester_usnew, time, usgdp, retail_wool_real, wmus)

(50) Netimport=1*conwool21*NeMTonnes_US;

(51) Mill_use = End_stockslag+Productionwool+Netimport-End_stocks

Australian Wool Market:

(52) Aus_wool_prod = Aus_fl_y*Totalstock_A

(53) Aus_con = f(Aus_conlag, Aus_px_wnewreal, newaus_raw_c, Aus_disc_income, time, w_{Acon})

(54) Aus_X = Aus_wool_prod+Aus_M-Aus_con

New Zealand Wool Market:

(55) NZ_wool_prod = NZ_fl_y*Totalstock_NZ

(56) NZ_con = f(NZ_conlag, NZ_px_wnewreal, newnz_raw_c , NZGDP, time, w_{cnz})

(57) NZ_X = NZ_wool_prod+NZ_M-NZ_con

Argentina Wool Market:

(58) arg_wool_prod = arg_fl_yield*Arg_total_stock

(59) Arg_total_stock = f(arg_px_wnewreal, Arg_total_stocklag, w_{ats})

(60) arg_con = f(arg_conlag, arg_px_wnewreal, arg_px_cnewreal ,newarg_gdp, w_{acw})

(61) Arg_X_tonnes = arg_wool_prod+arg_M-arg_con

Uruguay Wool Market:

(62) Uruguay_wool_prod = U_fl_y*U_ts

(63) U_ts = f(U_px_wnewreal ,U_tslag , w_{uts})

(64) U_con = f(U_conlag, U_px_wnewreal, newu_raw_c newU_GDP, w_{ucon})

(65) U_X = Uruguay_wool_prod+U_M-U_con;

International Wool Trade and Price Linkages:

(66) ROW_W_M = f(perunitWP,realgdp_china,ex_rate_china,time)

(67) NeMTonnes_US = U_X+Arg_X_tonnes+NZ_X+Aus_X+ROW_W_X-ROW_W_M

Table 1. Continued

(68) Aus_px_wnewreal = f(perunitWP*Aus_exrate, w_{wa})
(69) arg_px_wnewreal = f(perunitWP*arg_exrate, w_{arg})
(70) U_px_wnewreal = f(perunitWP*U_exrate, w_{upx})
(71) NZ_px_wnewreal = f(perunitWP*NZ_exrate, w_{nzpx})
(72) Retail_wool_real=f(US_farm_pricenew, w_{rpw})
(73) perunitWP = f(Retail_wool_real, w_{wp});

[1] All prices are assumed to be in real terms, deflated by an appropriate price deflator, except those in price transmission or linkage equations.
[2] For simulation purposes, the model will be re-normalized to ensure that each endogenous variable appears on the left-hand side of one and only one equation.

Replacement lamb numbers, however, are constrained by the size of the lamb crop in the previous year (the lagged lamb crop). A low lamb crop in the previous year tends to constrain the number of replacement ewes. Death loss (death_loss_us) and replacement lamb numbers are expected to be positively related because an increase in death loss leads to the need to build up a depleting herd. Death loss (death_loss_us in equation (5) in table 1) is an identity equal to the death rate. times the number of total breeding sheep. Death rate is the average annual number deaths over a year The number of sheep on feed (total_feed_us in equation (6) in table 1) is specified as a function of its own lagged value (total_feed_uslag), the real price of live sheep, and the real slaughter price (newsl_us). Not all of the sheep and lambs in feedlots during a given year are from the lamb crop in the current year, hence the inclusion of the variable total_feed_uslag. Feedlot demand is expected to be negatively related to the real price of sheep because feeder lambs are an input to lamb feeding. Feedlot demand is expected to be positively related to the real slaughter price because slaughter sheep are the output of feedlots.

The demand for slaughter sheep (total_slaughter_us in equation (7) in table 1) is specified as a function of the real price of slaughter sheep (newsl_us), the real retail price of lamb (newretail_price_lamb_us), the lagged number of sheep on feed (total_feed_USlag), the lagged lamb crop (lambcrop_uslag), and lagged total slaughter (total_slaughter_uslag). The real slaughter price is expected to be negatively related to slaughter demand as it is the input price in the slaughter market while the real retail price is expected to be positively related as it is the output price for the slaughter market.

The lagged number of sheep on feed and the lagged lamb crop represent the availability of lambs to be slaughtered in a given year. The lagged dependent variable represents the changes in slaughter capacity which constrains the growth of slaughter from year to year.

Equation (8) in table 1 is the market clearing identity for the live sheep market. The total number of sheep slaughtered in a given year is equal to the sum of beginning sheep inventories (lagged total breeding sheep) plus the number of animals ready for slaughter (lagged number of sheep on feed) plus the lamb crop minus death loss minus net exports of live sheep (NetExportheads_US) minus the number of sheep on feed minus ending breeding sheep inventories.

Equation (9) in table 1 is the producer live sheep price to the slaughter sheep price transmission equation.

Table 2. Variable Definitions of the World Sheep, Lamb, and Wool Model

Variable Names	Variable Definitions
U.S. Live Sheep Market:	
totalbreedingsheep_US	Total ending breeding sheep inventories in U.S.*
matureewes_US	Ending mature ewe inventories within breeding herd *
mature rams_US	Ending mature ram inventories within the breeding herd
replacement_lambs_US	Replacement lamb inventories*
newprice_sheep_live_us	Real price of live sheep*
total_slaughter_us	Sheep slaughtered in US*
newsl_US	Real slaughter sheep price*
total_feed_U.S	Feedlot demand for feeder lambs*
NetExportsheads_US	Net exports of live sheep
death_loss_US	Death loss of sheep in feedlots*
lambcrop_US	Lamb crop (number of lambs produced)*
w_{me}, w_{rl}, w_f, w_{lc}, w_{pl}, w_{ts}	Other exogenous (shift) variables in the respective equations
U.S. Lamb Market:	
Production_US	Lamb production in million pounds*
averagewt_us	Average slaughter sheep carcass weight
retailproduction	Lamb production, retail weight*
converretail	Conversion from carcass weight to retail cuts of lamb
percapitacons_us	Per capita lamb consumption*
newexp_us	Square root transformation of expenditure
newretail_price_lamb_us	Real retail price per lb of lamb*
AdjNNIcapita_US	Real U.S. per capita income
newreprice_beef_US	Real retail price per lb of beef
time	Time trend
newporkrp	Real retail price per lb of pork
cons_retail_us	Total consumption of lamb, retail weight*
Mlambpound_US	U.S. lamb imports in pounds*
Mlambtonnes_US	U.S. lamb imports in metric tonnes*
Conversionlamb	Conversion parameter from pounds to metric tonnes
w_{pc}	Other exogenous shift variables
Australian Live Sheep Market:	
Totalstock_A	Total stock of sheep*
Breeding_ewesA	Breeding ewes in Australia*
Othersheep_A	Other merino and non-merino sheep in Australia*
TotalSL_A	Sheep slaughtered*
NETExports_A	Net export of live animals from Australia*
DL_A	Death loss of live sheep in feedlots*
Lamb_crop_A	Lamb crop*
Total_feed_A	Number of sheep and lambs on feed*
PP_LSnewreal	Real price of live sheep in Australia*
ME_EUgdp	Real Middle East and European Union-27 GDP
ME_exrate	Middle East exchange rate
ME_EU_Exrate	Weighted average of EU and Middle East exchange rates
w_{bea}, w_{ota}, w_{sla}, w_{nxml}, w_{lca}	Other exogenous shift variables in respective equations

Table 2. Continued

Variable Names	Variable Definitions
Australia Lamb Meat Market:	
production_A	Production of lamb meat*
Conversionfactor_A	Conversion of total slaughter to lamb production
TotalconsA	Total consumption of lamb meat*
lamb_rp_anew	Real retail price of lamb meat*
Beef_RP_Anew	Real retail price of beef
Aus_disc_income,	Australian disposable income
newChicken_RP_A	Real retail price of chicken
Exportmeat_A	Australian exports of lamb meat*
w_{ca}	Other exogenous shift variables in lamb consumption equation
New Zealand Live Sheep Market:	
Totalstock_NZ	Total stock of sheep*
Breeding_EwesNZ	Stock of breeding Ewes*
Othersheep_NZ	Stock of other merino and non- merino sheep*
Total_feed_NZ	Number of sheep and lambs on feed in NZ*
TotalSL_NZ	Sheep slaughter*
NETExports_NZ	Net export of live sheep*
DL_NZ	Death loss of live animals*
lamb_crop_NZ	Lamb crop*
sheeplivepp_NZnewreal	Real price of live sheep*
w_{otnz}, w_{bnz}, w_{snz}, w_{nxnz}, w_{lcnz}	Other exogenous shift variables
New Zealand Lamb Meat Market:	
production_NZ	Production of lamb meat*
Conversion_NZ	Conversion of total slaughter of animals to lamb meat production
NZ_ConsTonnes	Lamb meat consumption*
NZ_px_mnewreal	Real retail price of lamb meat *
Beef_NZpxnewreal	Real retail price of beef
Chicken_NZpxnewreal	Real retail price of chicken
NZGDP	New Zealand total GDP
exporttonnes_NZ	Exports of lamb meat*
w_{cnz}	Other exogenous shift variables in NZ lamb consumption
International Trade in Lamb Meat:	
ROW_M	Rest-of-the-World imports*
Importingworldgdp	Importing world GDP (mainly Middle East and European Union)
perunitLPM,	World import price of lamb meat*
Aus_exrate, NZ_exrate	Australia and New Zealand exchange rates
w_{rm}, w_{pxnz}, w_{pla}, w_{lpm}	Other exogenous shift variables in price linkage equations
Wool Market:	
Unites States Wool Markets:	
Sheep_shorn_USml_lbs	Total number of sheep shorn in U.S.*
Conwool_US	Conversion factor from total breeding sheep to sheep shorn

Table 2. Continued

Variable Names	Variable Definitions
Conwool1	Conversion factor from greasy wool to clean wool
Prod_greasy_wool	Production of greasy wool in U.S.*
fleece_yield	Fleece yield in U.S
Mill_use	Mill demand for greasy wool in U.S.*
Productionwool	Production of clean wool in U.S.*
Netimport	Net import of clean wool in U.S in million lbs.*
End_stocks	Ending stock of wool after use.*
US_farm_pricenew,	Real U.S. farm price of wool*
Retail_wool_real	Real U.S. retail price of wool*
polyester_usnew	U.S. price of polyester deflated by PPI
Usgdp	Real U.S. GDP
NeMTonnes_US	Net imports of clean wool converted to metric tonnes.*
Conversion121	Conversion from lbs to metric tonnes
w_{nm}, w_{mus}	Other exogenous shift variables
Australia Wool Market:	
Aus_X	Exports of raw wool*
Aus_wool_prod	Production of raw wool*
Aus_M	Imports of raw wool
Aus_con	Domestic consumption of raw wool *
Aus_fl_y	Fleece yield
Aus_px_wnewreal	Real price of raw wool*
newaus_raw_c,	Real price of raw cotton
w_{acon}	Exogenous shift variables for Australian wool consumption
New Zealand Wool Market:	
NZ_X	Exports of raw wool*
NZ_wool_prod	Production of raw wool*
NZ_M	Imports of raw wool
NZ_con	Domestic consumption of raw wool*
NZ_fl_y	Fleece yield
NZ_px_wnewreal	Real price of raw wool*
newnz_raw_c	Real price of raw cotton
w_{cnz}	Exogenous shift variables for New Zealand consumption
Argentina Wool Market:	
Arg_X_tonnes	Exports of raw wool*
Arg_wool_prod	Production of raw wool*
Arg_M	Imports of raw wool
Arg_con	Domestic consumption of raw wool*
Arg_total_stock	Total stock of sheep*
Arg_fl_y	Fleece yield
Arg_px_wnewreal	Real price of raw wool*
arg_px_cnewreal	Real price of raw cotton
newarg_gdp	Real GDP
wa_{ts}, w_{acw}	Exogenous shift variables for respective equations

Table 2. Continued

Variable Names	Variable Definitions
Uruguay Wool Market:	
U_X	Exports of raw wool*
U_wool_prod	Domestic production of raw wool*
U_M	Imports of raw wool
U_con	Domestic consumption of raw wool*
U_ts	Total stock of sheep*
U_fl_y	Fleece yield
U_px_wnewreal	Real price of raw wool*
newaus_raw_c	Real price of raw cotton
newU_gdp	Real GDP
w_{ts}, w_{ucon}	Other exogenous shift for respective equations
International Trade in Wool:	
World_X_Wool	Total world exports of wool *
ROW_W_X	Rest-of-the-World exports of wool
ROW_W_M	Rest-of-the-World imports (other than U.S.)*
realgdp_china	Real GDP of China
perunitWP	ROW per unit import price of wool*
Arg_exrate, U_exrate , ex_rate_China	Argentina, Uruguay, and China exchange rates
w_{wa}, w_{arg}, w_{upx}, w_{wp}	Other exogenous shift variables for respective equations

[1] Endogenous variables are marked with an asterisk (*)

Equation (10) in table 1 is the production of lamb (production_us) specified as the average carcass weight (averagewt_us) multiplied by the number of sheep slaughtered from equation (7). The average carcass weight is assumed to be determined by breeding research, choice of breeds, and other exogenous variables. Equation (11) converts the carcass weight lamb production to retail weight.

The domestic U.S. per capita demand for lamb (percapitacons_us in equation (12) in table 1) is specified as a function of the real retail price of lamb meat (newretail_price_lamb_us), the real retail price of beef (newreprice_beef_us), the retail price of pork (newporkrp), per capita income (AdjNNIcapita_US), and some transformation of real lamb checkoff expenditures to account for diminishing returns to promotion and the lagged effect of promotion on demand (newexp_us). Equation (13) in table 1 converts per capita consumption to total consumption (cons_retail_us). Equation (14) is the lamb market clearing identity in which total lamb consumption is set equal to the domestic production of lamb (retailproduction) plus the import of lamb (Mlambpound_US) from Australia and New Zealand. Equation (15) simply converts the units of lamb meat imports from metric tons (tonnes) to pounds.

The Australian and New Zealand live sheep and meat supply chain is represented by equations (16) through (39) of table 1. Equations (16) and (28) in table 1 are identities representing Australian and New Zealand ending sheep inventories (Totalstock_A and Totalstock_NZ, respectively) in which sheep inventories in the respective country are set equal to the sum of breeding ewe inventories (Breeding_ewesA and Breeding_ewesNZ, respectively), other sheep inventories (othersheep_A and othersheep_NZ, respectively) in each country and also the total animals on feed for both Australia (Total_feed_A) and New Zealand (Total_feed_NZ).

Equations (17) and (29) in table 1 specify the breeding ewe inventories in Australia (Breeding_ewesA) and New Zealand (Breeding_ewesNZ) as functions of lagged breeding ewes in each country (Breeding_ewesAlag and Breeding_ewesNZlag, respectively), the real prices of wool in each country (Aus_px_wnewreal and NZ_px_wnewreal, respectively), and the real prices of live sheep in each country (PP_LSnewreal and sheeplivepp_NZnewreal, respctively) in their respective local currencies, and exogenous shift variables (w_{bea} and w_{bnz}, respectively) representing technological change and other exogenous forces. The real price of wool and the real price of live sheep are expected to be positively related to breeding ewe inventories in each country. An increase in the real prices of wool and of live sheep sends signals to producers to build herd for possible future gains. The lagged breeding ewe variable accounts for the dynamic adjustment of inventories to their long-run equilibrium.

Equations (18) and (30) in table 1 specify the annual lamb crop in each country (Lamb_crop_A and Lamb_crop_NZ, respectively) as a function of breeding ewes and time. Time represents the effects of technological change that has impacted the lambing rate in those countries.

Equations (19) and (31) in table 1 represent the behavior of inventories of other (non-breeding) sheep in Australia and New Zealand (Othersheep_A and othersheep_NZ, respectively). These two equations are specified as functions of the same variables with the same expected economic effects as for the breeding ewe inventory equations in their respective countries (equations (17) and (29)).

Lamb feeding in Oceania is represented by equations (20) (Total_feed_A) for Australia and (32) (Total_feed_NZ) for New Zealand. These two equations (one for Australia and the other for New Zealand) are specified as functions of lagged feed variables (Total_feed_Alag and Total_feed_NZlag, respectively), live sheep prices (PP_LSnewreal and sheeplivepp_NZnewreal, respectively), retail lamb prices (Lamb_RP_Anew and NZ_px_mnewreal, respectively) and some exogenous variables. The lagged dependent variables are expected to have a positive sign with a coefficient less than one. The lagged dependent variables are included because not all feeder lambs gain the required weight within a given year. Live sheep prices are expected to be negatively related to the dependent variables because live sheep are inputs into feeding and positively related to the retail lamb prices. The retail lamb price rather than the slaughter price is used in these equations to represent the value of the output of lamb feeding because slaughter lamb prices for those two countries are not available.

Equations (21) and (33) in table 1 are the slaughter demand equations for Australia (TotalSL_A) and New Zealand (totalSL_NZ). Both the equations hypothesize that the slaughter demand in their respective countries are functions of the real prices of live sheep in each country, the real retail price of lamb meat in each country, the lagged lamb crop in each country, the lagged dependent variable, and other exogenous variables (w_{sla} and w_{snz}, respectively). Slaughter sheep are an input to lamb packing so that their price is negatively related to slaughter demand. On the other hand, lamb meat is the output of lamb packing so the lamb price is expected to be positively related to slaughter demand. The lagged slaughter is a proxy for processing capacity and ispositively related to slaughter demand in each country. The lagged lamb crop represents the annual availability of lambs to be slaughtered and is expected to be positively related to slaughter demand.

Equations (22) and (34) in table 1 represent the death loss of live sheep in Australia and New Zealand (DA_A and DA_NZ, respectively). Death loss is assumed to be four percent of the total stock of sheep for both the countries making it more compatible with the U.S. sheep industry.

Equations (23) and (35) in table 1 are the export demand for live sheep equations for Australia (NETExports_A) and New Zealand (NETExports_NZ). The equations are specified as functions of the weighted average of real Middle East gross domestic product and the EU-27 real gross domestic product (ME_EUgdp) since those two regions are the primary market for Australian and New Zealand live sheep exports, the real price of live sheep in the two respective exporting countries, the weighted average of the exchange rates of the Middle East (Saudi Arabia and United Arab Emirates) and EU-27 countries (ME_EU_Exrate), lagged export demand, and other exogenous shift variables (w_{nxml} and w_{nxnz}). The real price of live sheep reflects the per head cost of live sheep imports to Middle Eastern and EU-27 live sheep importing countries. The real prices of live sheep are expected to be negatively related to the net export demand. Higher purchasing power in the Middle East, EU, represented by the real GDP of countries UAE, Saudi Arabia and EU, is expected to increase the demand for imports of live sheep. The Middle East-EU-27 weighted exchange rates are also expected to be negatively related to net export demand for live sheep. A rise in the exchange rate makes imports more expensive to the importing countries, so that exports from Australia and New Zealand fall. The net export lag variable accounts for dynamic adjustment f exports from year to year.

Equations (24) and (36) in table 1 are the market clearing conditions for the live sheep markets in Australia and New Zealand.,. These two identities require that the sum of the beginning inventory of live sheep (breeding and other) and the lamb crop in each country equal the net exports of live sheep, death loss, and ending inventories of all live sheep.

Equations (25) and (37) in table 1 hypothesize that the domestic production of lamb meat in Australia and New Zealand (production_A and production_NZ, respectively) is the number of live sheep slaughtered (TotalSL_A and totalSL_NZ, respectively) multiplied by the average carcass weight (Conversionfactor_A and conversion_NZ, respectively).

The demands for lamb in Australia and New Zealand are specified in equations (26) and (38) in table 1. For Australia (equation (26)), domestic lamb demand (TotalconsA)is specified as a function of the real retail price of lamb (lamb_rp_anew), the real retail price of beef (Beef_RP_Anew), the real retail price of chicken (newChicken_RP_A), and Australian real disposable income (Aus_disc_income). Lamb demand is expected to be inversely related to its own real price and positively related to the real prices of beef and chicken. Changes in Australian disposable income are expected to be positively related to changes in lamb demand. Equation (38) represents New Zealand lamb meat consumption (NZ_ConsTonnes) which is assumed to be negatively related to its own price, and positively related to the price of beef (Beef_NZpxnewreal), the price of chicken (Chicken_NZpxnewreal), and real income (NZGDP).

Equations (27) and (39) in table 1 are the lamb market clearing conditions for Australia and New Zealand, respectively, in which exports of lamb meat must equal the difference between lamb production and lamb demand in each country.

The international trade and price linkages for lamb are specified in equations (40) to (44) in table 1. The import demand for lamb by all countries other than the U.S. (Rest-of-the-World or ROW) is specified in equation (40) to be a function of the lagged dependent variable (ROW_Mlag), the weighted average of the real GDPs of the Middle East and the European Union-27 (importingworldgdp), the trade-weighted average of the exchange rates of the Middle East and the EU-27 (EU_ME_EXC), the real import price (perunitLPM), and other exogenous variables (w_{rm}). The lagged dependent variable accounts for dynamic adjustment in the ROW import demand. The real import price is the U.S. import price of lamb meat in the U.S. The trade weighted GDP and exchange rates for Middle East and EU-27 are considered because they are the major lamb meat importers other than U.S from Australia and New Zealand. The ROW import demand for lamb is expected to be negatively related to the real import price, positively related to the weighted real GDP, and negatively related to the weighted average of the exchange rates.

Equation (41) in table 1 is the international lamb market clearing condition which requires that U.S. lamb imports (Mlambtonnes_US) must equal the sum of lamb exports from Australia (Exportmeat_A), New Zealand (exporttonnes_NZ), and other countries (ROW_X) minus what is exported to countries other than the United States (ROW_M) at each time period.

The U.S. and world prices of lamb are linked through price transmission equations (equations (42) through (44) in table 1). Equations (42) and (43) specify the prices of lamb in New Zealand and in Australia to be functions of the U.S. import price of lamb (which includes transportation costs) times the respective exchange rates for each country. Equation (44) links the U.S. retail price of lamb to the U.S. import price of lamb.

The world greasy wool market is represented by equations (45) through (73) in table 1. Equations (45) through (51) represent the U.S. wool market. Equation (45) is the number of U.S. sheep shorn (Sheep_shorn_USml_lbs). Almost all U.S. breeding sheep (totalbreedingsheep_US) are shorn for wool production so the number of sheep shorn is the breeding inventory times the proportion of those sheep which are shorn (Conwool_US) which is around 98% of the total breeding sheep. The total U.S. production of greasy wool in equation (46) in table 1 is defined as fleece yield per head (fleece_yield) multiplied by the number of sheep shorn. U.S. clean wool production (Productionwool) is derived as the loss rate due to shearing multiplied by the production of greasy wool (Prod_greasy_wool) (equation (47) in table 1).

Equation (48) in table 1 specifies that changes in U.S. wool ending stocks (End_stocks) are a function of changes in lagged ending stocks (beginning wool stocks), the current real U.S. farm price of wool (US_farm_pricenew), and some exogenous shift variables (w_{wus}). The ending stock of wool is assumed to be positively related to the current price of wool and lagged ending stocks.

Equation (49) in table 1 specifies U.S. wool mill demand (Mill_use) as a function of the real U.S. wool farm price (US_farm_pricenew) which is expected to be negatively related to wool mill demand because raw wool is an input to wool milling. The real retail wool price (Retail_wool_real) is expected to be positively related to wool mill demand as it is the output price. The real U.S. polyester price is expected to be positively related to mill demand along with the domestic real income (usgdp). A time trend captures the downward trend in wool mill processing capacity over time. The lagged dependent variable accounts for period to period dynamic adjustment of wool mill demand.

Equation (50) in table 1 converts U.S. wool from million pounds to tonnes. Equation (51) in table 1 is the U.S. wool market clearing identity which requires U.S. wool mill use to be equal to U.S. beginning wool inventories plus the U.S. production of wool and wool imports minus U.S wool ending stocks.

The major exporters of wool include Australia, New Zealand, Argentina, and Uruguay. Their wool markets are captured in equations (52) through (73). Equations 52, 55, 58, and 62 specify greasy wool production in each country (Aus_wool_prod, NZ_wool_prod, arg_wool_prod, Uruguay_wool_prod) as the fleece yield per head in each country (Aus_fl_y, NZ_fl_y, arg_fl_y, U_fl_y, respectively) times the total stock of sheep in each country.

The total stock of sheep in Australia and New Zealand were explained elsewhere in the model (equations (16) and (28)). For Argentina and Uruguay, equations (57) and (61) explain the total stock of sheep (Arg_total_stock and U_ts, respectively) in each country as functions of their domestic real prices of wool (arg_px_wnewreal and u_px_wnewreal, respectively), the lagged dependent variables (Arg_total_stocklag and U_tslag, respectively), and other exogenous variables (w_{ats}, w_{uts}). The wool prices are expected to be positively related to the stock of sheep for each country. The lagged dependent variables specify the change in stock of sheep from one period to another.

Equation (53), (56), (60), and (64) in table 1 specify the domestic demands for wool in Australia, New Zealand, Argentina, and Uruguay, respectively. The Australian domestic wool demand (Aus_con) in equation (53) is specified as a function of the real price of wool in Australia, the real price of cotton (newaus_raw_c) in Australia, Australian disposable income, and the lagged dependent variable (Aus_conlag). The demand for wool is expected to be negatively related to price of wool, positively related to price of cotton and positively related to real disposable income in Australia. The New Zealand wool demand (NZ_con in equation (56) in table 1), Argentina wool demand (Arg_con in equation(60) in table 1), and Uruguay wool demand (U_con in equation (64) in table 1) are also specified as functions of their domestic real prices of wool , real prices of raw cotton, the lagged dependent variables, income, and other exogenous variables.

Equations (54), (57), (61), and (65) in table 1 are the wool market clearing condition for Australia, New Zealand, Argentina, and Uruguay which require that their wool exports (Aus_X, NZ_X, Arg_X, and U_X, respectively) equal the sum of their domestic wool production and any imports of greasy wool (Aus_M, NZ_M, arg_M, and U_M, respectively) minus their domestic wool consumption (Aus_con, NX_con, arg_con, and U_con, respectively).

Equations (66) through (73) in table 1 represent the international trade flow and price linkages for greasy wool. Equation (66) defines the Rest-of-the-World wool imports (ROW_W_M) as a behavioral equation and is a function of the per unit import price of wool (perunitWP) which is expected to be negatively related to imports, positively related to China's GDP (realgdp_china), and negatively related to the Chinese exchange rate (ex_rate_china) as China is the major greasy wool importing country from Oceania.

Equation (67) in table 1 is the international wool market clearing identity which requires that U.S. wool imports equal the difference between the sum of wool exports by Australia, new Zealand, Argentina, and Uruguay minus wool imports by the rest-of-the-world (ROW).

Equations (68) – (73) in table 1 are the international wool price linkage equations. They are the price transmission equations connecting the U.S. price of wool with those of the major wool exporting countries. Equations (68) – (71) connect the Australian, New Zealand, Argentina and Uruguay wool prices, respectively, with the world import price of wool (perunitWP). Equation (72) in table 1 is the price linkage equation from between the real retail price of U.S. wool to the U.S. farm price of wool. The last equation (equation (73) in table 1) connects the world wool import price to the U.S. wool price to close the system of equations.

Data

Two general types of data will be required for this analysis: (1) data to support the modeling of the supply, demand, trade, prices, etc. in the world sheep, lamb, and wool model as outlined above and (2) the promotion expenditures of the American Lamb Board over time. The first set of data is available from numerous public sources. The U.S. main data sources for sheep and lamb are databases of various USDA agencies, including the National Agricultural Statistics Service (USDA 2013a and 2013d), the

Economic Research Service (USDA 2013b), and the Grains Inspection Packers and Stockyards Adminsitration (USDA 2013c). The main source of data for the wool market prices and quantities, will be the Cotton and Wool Yearbook of the Economic Research Service (USDA 2012). The data for Australia and New Zealand will be taken from databases available from their respective statistical services. Australian data for slaughter sheep numbers, lamb meat production, and lamb meat consumption are available from the Australian Bureau of Statistics (ABS 2012) which is Australia's official statistical organization. The retail prices of meat products are available from the Australian Department of Agriculture, Fisheries, and Forestry year book publication (DAFF 2012). The data for breeding ewes for Australia are not available for public use. The breeding ewes were calculated based on New Zealand's proportion of breeding ewes to total stock of sheep. The New Zealand data for breeding ewes, sheep slaughtered, and lamb meat production data are available from Infoshare-Statistics New Zealand (2012), a government organization. Due to the lack of data for domestic prices in New Zealand, the per unit export prices of lamb and substitute meats will be used instead.

The total stock of live sheep, per unit export prices, total sheep exported and total sheep imported for consumption of both meat and wool for Australia, New Zealand, Argentina and Uruguay are available from FAOSTAT (FAO 2012). Many exogenous variables like gross domestic product, exchange rates, price indices (such as producer price indices and consumer price indices) are available from the International Financial Statistics (IFS) of the International Monetary Fund (IMF 2012).

CHAPTER IV

THE STRUCTURAL MODEL OF THE WORLD SHEEP, LAMB, AND WOOL MARKETS

This chapter lays out the world sheep, lamb, and wool model (referred to subsequently as LamMod) based on the conceptual model discussed in Chapter III. First, the structural model to be used to estimate the model parameters is presented and then the statistical model is presented which includes the econometric estimates of the model parameters and various regression statistics. The chapter ends with s discussion of the model validation results and statistics

Structural Representation of LamMod

The structural representation of LamMod is similar to the conceptual model presented both graphically and mathematically in the previous chapter (tables 3 and 4). Due to the unavailability of some data, however, the specification of some equations has been altered accordingly. Data availability was not much of a problem for the U.S. portions of the model. Such was not the case for several key relationships in the Australia and New Zealand portions of the model, however, where the unavailability of data on lamb feeding in both countries forced some restructuring of the model to breeding ewe inventories in those countries to act as a pool of sheep for both breeding and feeding. The producer prices of sheep in each country were used as proxies for unavailable data on slaughter sheep prices in those countries. The Australian live animal market clearing

Table 3. Mathematical Representation of the LamMod[1]

U.S. Live Sheep Market:

(1) totalbreedingsheep_US = matureewes_US+mature_rams_US+replacement_lambs_US

(2) matureewes_US = f(matureewes_uslag, newprice_sheep_live_us, US_farm_pricenew, w_{me})

(3) lambcrop_us = f(matureewes_us, newsl_us)

(4) replacement_lambs_us = f(lambcrop_uslag, death_loss_us, newprice_sheep_live_us)

(5) death_loss_US = death_rate*totalbreedingsheep_US

(6) total_feed_US = f(total_feed_USLag ,newprice_sheep_live_us, newsl_us, w_f)

(7) total_slaughter_us = f(total_feed_USlag ,newretail_price_lamb_us, newsl_US, lambcrop_uslag, ,total_slaughter_uslag, w_{ts})

(8) total_slaughter_US = totalbreedingsheep_USlag+total_feed_USLag-NetExportsheads_US-death_loss_US+lambcrop_US-totalbreedingsheep_US-total_feed_us

(9) newprice_sheep_live_us = f(newsl_US, w_{pl})

U.S. Lamb Meat Market:

(10) Production_US = averagewt_us*total_slaughter_us

(11) retailproduction = converretail*Production_US

(12) percapitacons_us = f(newexp_us ,newexp_uslag ,newretail_price_lamb_us, AdjNNIcapita_US, newreprice_beef_US, newporkrp,w_{pc})

(13) percapitacons_us = cons_retail_us/population_US

(14) cons_retail_us = Mlambpound_US+retailproduction

(15) Mlambpound_US = Mlambtonnes_US/Conversionlamb

Australian Live Sheep market:

(16) Totalstock_A= Breeding_ewesA+ Othersheep_A

(17) Breeding_ewesA = f(Breeding_ewesAlag, Aus_px_wnewreal, time, PP_LSnewreal, w_{bea})

(18) Lamb_crop_A = f(Breeding_ewesA, time, w_{lca})

(19) Othersheep_A = f(Othersheep_Alag, Aus_px_wnewreal, PP_LSnewreal, time, w_{ota})

(20) TotalSL_A = f(Lamb_RP_Anew , PP_LSnewreal, TotalSL_Alag, Lamb_crop_Alag, w_{sla})

(21) DL_A = deathrate_A*Totalstock_A

(22) NETExports_A = f(NETExports_Alag, importingworldgdp, PP_LSnewreal, EU_ME_EXC, w_{nxml})

(23) TotalSL_A = Totalstock_Alag-NETExports_A-DL_A+Lamb_crop_A-TotalstockS_A-Unacc_A

Australian Lamb Meat Market:

(24) production_A = Conversionfactor_A*TotalSL_A

(25) TotalconsA = f(lamb_rp_anew, Beef_RP_Anew, Aus_disc_income, newChicken_RP_A, w_{tca})

(26) Exportmeat_A = production_A-TotalconsA

New Zealand Live Sheep Market:

(27) Totalstock_NZ = Breeding__ewesNZ+ othersheep

(28) Breeding__ewesNZ = f(Breeding__ewesNZlag, time, sheeplivepp_NZnewreal, NZ_px_wnewreal, w_{bnz})

(29) lamb_crop_NZ = f(time, Breeding__ewesNZ, w_{lcnz})

(30) othersheep = f(othersheeplag, time, sheeplivepp_NZnewreal, NZ_px_wnewreal, w_{otnz})

(31) totalSL_NZ = f(NZ_px_mnewreal ,sheeplivepp_NZnewreal, totalSL_NZlag, ttime ,lamb_crop_NZlag, w_{snz})

(32) DL_NZ = death_rate_NZ*Totalstock_NZ

(33) NETExports_NZ = f(NETExports_NZlag, importingworldgdp, sheeplivepp_NZnewreal, EU_ME_EXC, w_{nxnz})

(34) TotalSL_NZ = Totalstock_NZlag-NETExports_NZ-DL_NZ+lamb_crop_NZ-Totalstock_NZ

New Zealand Lamb Meat Market:

(35) production_NZ = conversion_NZ*TotalSL_NZ

Table 3. Continued

(36) NZ_ConsTonnes = f(NZ_px_mnewreal, NZGDP, Beef_NZpxnewreal,time w_{tcnz})
(37) exporttonnes_NZ = production_NZ- NZ_ConsTonnes

International Lamb Meat Trade and Price Linkages:
(38) ROW_M = f(ROW_Mlag, importingworldgdp, perunitLPM,EU_ME_EXC, w_{rm})
(39) Mlambtonnes_US = Exportmeat_A+exporttonnes_NZ+ROW_X-ROW_M
(40) NZ_px_mnewreal = f(perunitLPM*NZ_exrate, w_{pxnz})
(41) Lamb_RP_Anew = f(perunitLPM*Aus_exrate, w_{pla})
(42) perunitLPM=f(newretail_price_lamb_us, w_{lpm})

U.S. Wool Market:
(43) Sheep_shorn_USml_lbs = Conwool_US*totalbreedingsheep_US
(44) Prod_greasy_wool = fleece_yield*Sheep_shorn_USml_lbs
(45) Productionwool = conwool1*Prod_greasy_wool
(46) End_stocks = f(End_stockslag, US_farm_pricenew, time , w_{wus})
(47) Mill_use = US_farm_pricenew, Mill_uselag, polyester_usnew, time, usgdp, w_{mus})
(48) Netimport=1*conwool21*NeMTonnes_US;
(49) Mill_use = End_stockslag+Productionwool+Netimport-End_stocks+Unaccounted

Australian Wool Market:
(50) Aus_wool_prod = Aus_fl_y*Totalstock_A
(51) Aus_con = f(Aus_conlag, Aus_px_wnewreal, newaus_raw_c, Aus_disc_income, time, w_{Acon})
(52) Aus_X = Aus_wool_prod+Aus_M-Aus_con

New Zealand Wool Market:
(53) NZ_wool_prod = NZ_fl_y*Totalstock_NZ
(54) NZ_con = f(NZ_conlag, NZ_px_wnewreal, NZGDP, time, w_{cnz})
(55) NZ_X = NZ_wool_prod+NZ_M-NZ_con

Argentina Wool Market:
(56) arg_wool_prod = arg_fl_yield*Arg_total_stock
(57) Arg_total_stock = f(arg_px_wnewreal, Arg_total_stocklag, time, w_{ats})
(58) arg_con = f(arg_conlag, arg_px_wnewreal, arg_px_cnewreal, newarg_gdp, w_{acw})
(59) Arg_X_tonnes = arg_wool_prod+arg_M-arg_con

Uruguay Wool Market:
(60) Uruguay_wool_prod = U_fl_y*U_ts
(61) U_ts = f(U_px_wnewreal ,U_tslag , w_{uts})
(62) U_con = f(U_conlag, U_px_wnewreal, newU_GDP, w_{ucon})
(63) U_X = Uruguay_wool_prod+U_M-U_con;

International Wool Trade and Price Linkages:
(64) ROW_W_M = f(perunitWP,realgdp_china,ex_rate_china,time)
(65) NeMTonnes_US = U_X+Arg_X_tonnes+NZ_X+Aus_X+ROW_W_X-ROW_W_M
(66) Aus_px_wnewreal = f(perunitWP*Aus_exrate, w_{wa})
(67) arg_px_wnewreal = f(perunitWP*arg_exrate, w_{arg})
(68) U_px_wnewreal = f(perunitWP*U_exrate, w_{upx})
(69) NZ_px_wnewreal = f(perunitWP*NZ_exrate, w_{nzpx})
(70) perunitWP = f(US_farm_pricenew, w_{wp});

[1] All prices are assumed to be in real terms, deflated by an appropriate price deflator, except those in price transmission or linkage equations.

Table 4. LamMod Variable Definitions

Variable Names	Variable Definitions
U.S. Live Sheep Market:	
totalbreedingsheep_US	Total ending breeding sheep inventories in U.S. (heads)*
matureewes_US	Ending mature ewe inventories within breeding herd (heads) *
mature rams_US	Ending mature ram inventories within the breeding herd (heads)
replacement_lambs_US	Replacement lamb inventories (heads) *
newprice_sheep_live_us	Real price of live sheep (($/PPI)/head)*
total_slaughter_us	Sheep slaughtered in US (heads) *
newsl_US	Real slaughter sheep price (($/WPI)/head)*
total_feed_U.S	Feedlot demand for feeder lambs (heads)*
NetExportsheads_US	Net exports of live sheep (heads)
death_loss_US	Death loss of sheep in feedlots (heads)*
lambcrop_US	Lamb crop (number of lambs produced in heads)*
w_{me}	DE, DE1, DE2 – indicator variables for 1988, 1990, and 1991
w_f	DF, DF1-indicator variables for 1994, and 2001
w_{pl}	DLCUS, DLCUS1, DLCUS2- indicator variables for 1992, 1995, 2006
U.S. Lamb Market:	
Production_US	Lamb production in million pounds*
averagewt_us	Average slaughter sheep carcass weight (lbs)
retailproduction	Lamb production, retail weight (lbs)*
converretail	Conversion from carcass weight to retail cuts of lamb
percapitacons_us	Per capita lamb consumption (lb/person)*
newexp_us	Square root transformation of expenditure (thousand $)
newretail_price_lamb_us	Real retail price per lb of lamb(($/CPI)/lb)*
AdjNNIcapita_US	Real U.S. per capita income (($/CPI)/person)
newreprice_beef_US	Real retail price per lb of beef (($/CPI)/lb)
time	Time trend
newporkrp	Real retail price per lb of pork (($/CPI)/lb)
cons_retail_us	Total consumption of lamb, retail weight (lbs)*
Mlambpound_US	U.S. lamb imports in pounds*
Mlambtonnes_US	U.S. lamb imports in tonnes*
Conversionlamb	Conversion parameter from pounds to tonnes
w_{pc}	DUSALcon – indicator variable for 1987 and 1998
Australian Live Sheep Market:	
Totalstock_A	Total stock of sheep (heads)*
Breeding_ewesA	Breeding ewes in Australia (heads) *
Othersheep_A	Other merino and non-merino sheep in Australia (heads)*
TotalSL_A	Sheep slaughtered (heads)*
NETExports_A	Net export of live animals from Australia*
DL_A	Death loss of live sheep in feedlots*
Lamb_crop_A	Lamb crop (heads)*
Unacc_A	Unaccounted numbers of animals or statistical discrepancy
PP_LSnewreal	Real price of live sheep in Australia((Aus $/PPI)/animal))*
EU_ME_EXC	Wtd ave of EU and Middle East $US exchange rates
w_{bea}	Daussie – Indicator variable for the year 2000
w_{ota}	Daussieot, Daussieot2 - indicator variables for 1990 and 2000
w_{sla}	DAsl11, DAsl33 – indicator variables for the years 2000 and 2010

Table 4. Continued

Variable Names	Variable Definitions
w_{lca}	DALC – indicator variable for the year 1990
Australia Lamb Meat Market:	
production_A	Production of lamb meat (kilo tonnes)*
Conversionfactor_A	Conversion of total slaughter to lamb production
TotalconsA	Total consumption of lamb meat (kilo tonnes)*
lamb_rp_anew	Real retail price of lamb meat ((Aus $/CPI)/tonne))*
Beef_RP_Anew	Real retail price of beef (((Aus $/CPI)/tonne)))
Aus_disc_income	Australian disposable income (Aus $/CPI)
newChicken_RP_A	Real retail price of chicken (Aus $/CPI)/tonne)
Exportmeat_A	Australian exports of lamb meat*
w_{ca}	Dauslcon1 – indicator variable for the year 1987
New Zealand Live Sheep Market:	
Totalstock_NZ	Total stock of sheep (heads)*
Breeding_EwesNZ	Stock of breeding Ewes (heads)*
Othersheep	Other merino and non- merino sheep (heads) *
TotalSL_NZ	Sheep slaughter in NZ (heads)*
NETExports_NZ	Net export of live sheep (heads)*
DL_NZ	Death loss of live animals (heads)*
lamb_crop_NZ	Lamb crop (heads) *
sheeplivepp_NZnewreal	Real price of live sheep ((NZ $/PPI)/animal)))*
New Zealand Lamb Meat Market:	
production_NZ	Production of lamb meat (kilo tonnes)*
Conversion_NZ	Conversion of total slaughter of animals to lamb meat production
NZ_ConsTonnes	Lamb meat consumption (kilo tonnes)*
NZ_px_mnewreal	Real retail price of lamb meat ((NZ $/CPI)/tonne))*
Beef_NZpxnewreal	Real retail price of beef ((NZ $/CPI)/tonne))
NZGDP	New Zealand total real GDP ((NZ $/CPI))
exporttonnes_NZ	Exports of lamb meat (kilo tonnes)*
w_{cnz}	DNZCONL, DNZCONL1, DNZCONL2 – indicator variables for 1987, 1994, and 2011
International Trade in Lamb Meat:	
ROW_M	Rest-of-the-World imports (tonnes)*
Importingworldgdp	Importing world GDP (weighted average of Middle East and European Union-27 GDP in U.S. $)
perunitLPM	World import price of lamb meat ($/lb)*
Aus_exrate, NZ_exrate	Australia and New Zealand exchange rates (Aus. and NZ currencies to $US
w_{rm}	DRM0, DRM1, and DRM2 – indicator variables for 1987-95, 1996-01, and years >2001, respectively.
w_{pla}	DRPA – indicator variable for 2000
w_{lpm}	DMLPM – indicator variable for 2002

Table 4. Continued

Variable Names	Variable Definitions
Wool Market:	
Unites States Wool Market:	
Sheep_shorn_USml_lbs	Total number of sheep shorn in U.S. (heads)*
Conwool_US	Conversion factor from total breeding sheep to sheep shorn
Conwool1	Conversion factor from greasy wool to clean wool
Prod_greasy_wool	Production of greasy wool in U.S. (lbs)*
fleece_yield	Fleece yield in U.S (lb/head)
Mill_use	Mill demand for greasy wool in U.S. (ml.lbs)*
Productionwool	Production of clean wool in U.S. (ml.lbs)*
Netimport	Net import of clean wool in U.S in million lbs*
End_stocks	Ending stock of wool after use. (ml.lbs)*
US_farm_pricenew	Real U.S. farm price of wool ((cents/PPI)/lb)*
polyester_usnew	U.S. price of polyester deflated by PPI
Usgdp	Real U.S. GDP ($/CPI)
NeMTonnes_US	Net imports of clean wool converted to tonnes*
Conversion121	Conversion from lbs to tonnes
w_{mus}	DUSAstocks1, DUSAstocks2 indicator variable for 1989 and 1996
Australia Wool Market:	
Aus_X	Exports of raw wool (kilo tonnes)*
Aus_wool_prod	Production of raw wool (kilo tonnes)*
Aus_M	Imports of raw wool (kilo tonnes)
Aus_con	Domestic consumption of raw wool (kilo tonnes)*
Aus_fl_y	Fleece yield (kg/animal)
Aus_px_wnewreal	Real price of raw wool (Aus $/CPI)/tonne)*
newaus_raw_c	Real price of raw cotton (Aus $/CPI)/tonne)
w_{acon}	DAUSWOOL2 - indicator variable for years <1992)
New Zealand Wool Market:	
NZ_X	Exports of raw wool (1,000 tonnes)*
NZ_wool_prod	Production of raw wool (1,000 tonnes)*
NZ_M	Imports of raw wool (1,000 tonnes)
NZ_con	Domestic consumption of raw wool (1,000 tonnes)*
NZ_fl_y	Fleece yield (kg/head)
NZ_px_wnewreal	Real price of raw wool (NZ $/CPI)/tonne)*
w_{cnz}	DNZCONWool1 – indicator variable for 2011
Argentina Wool Market:	
Arg_X_tonnes	Exports of raw wool (tonnes) *
Arg_wool_prod	Production of raw wool (tonnes)*
Arg_M	Imports of raw wool (tonnes)
Arg_con	Domestic consumption of raw wool (tonnes)*
Arg_total_stock	Total stock of sheep (heads)*
Arg_fl_y	Fleece yield in Argentina (tonne/animal)
Arg_px_wnewreal	Real price of raw wool (Arg currency/CPI)/tonne)*
arg_px_cnewreal	Real price of raw cotton (Arg currency/CPI)/tonne)
newarg_gdp	Real GDP (Arg. Currency/CPI)

Table 4. Continued

Variable Names	Variable Definitions
wa_{ts}	Dargts – indicator variable for years <1993
w_{acw}	Dargwool, Dargwool1, Dargwool2 – indicator variables for 1988, 1989, and 1990, respectively
Uruguay Wool Market:	
U_X	Exports of raw wool (tonnes)*
U_wool_prod	Domestic production of raw wool (tonnes)*
U_M	Imports of raw wool (tonnes)
U_con	Domestic consumption of raw wool (tonnes)*
U_ts	Total stock of sheep (heads)*
U_fl_y	Fleece yield (tonne/head)
U_px_wnewreal	Real price of raw wool (U. currency/CPI)/tonne)*
newU_gdp	Real GDP (Local currency/CPI)
w_{ts}	Duwool2 – indicator variable for 1989
w_{ucon}	Duwool1 - indicator variable for 1988, Duwool2
International Trade in Wool:	
World_X_Wool	Total world exports of wool (tonnes)*
ROW_W_X	Rest-of-the-World exports of wool (other than Australia, New Zealand, Uruguay and Argentina) (tonnes)
ROW_W_M	Rest-of-the-World imports (other than U.S.)* (tonnes)
realgdp_china	Real GDP of China (Yuan/CPI)
perunitWP	ROW per unit import price of wool ($/tonne)*
Arg_exrate, U_exrate , ex_rate_China	Argentina, Uruguay, and China exchange rates (Argentina, Uruguay, and Chinese currencies to $ U.S.)
w_{wa}	DAzl – indicator variable for 1990

[1] Endogenous variables are marked with an asterisk (*)

condition (equation (23) in table 3) includes an exogenous variable (Unacc_A) representing statistical discrepancy because the supply and demand data are published by different sources so that they do not add to the same total in each year. Also, the export price of lamb was used as a proxy for unavailable retail lamb price data in New Zealand.

In the wool market portion of LamMod for New Zealand and Uruguay, no data for the prices of cotton or any other competing fiber prices were available. The raw wool demand equations for those two countries (equations (54) and (62) in table 3) do not include prices of substitutes as conceptualized in Chapter 3. The U.S. market clearing condition for wool stocks (equation (49) in table 3) also includes an exogenous variable capturing the statistical discrepancy between U.S. wool supply and demand.

Statistical Representation of LamMod

The parameter estimates and regression statistics of each equation of LamMod are presented in table 5. Again, the variable names can be found in table 4. The parameters of the model are estimated using the Ordinary Least Squares estimator with annual data for 1987 through 2011. Two- or Three-Stage Least Squares estimators are sometimes used to estimate the parameters of simultaneous equation models. In this case, the large number of equations in the model and the availability of limited data points resulted in a greater number of predetermined variables than the number of observations. The consistency and efficiency gained in parameter estimation with the use of such system estimators are large sample properties. Consequently, OLS was the estimator of choice. The SAS statistical software is used for this analysis.

The signs of all parameter estimates of the model are consistent with expectations as discussed in Chapter 3 and conform to economic theory. Also, the Durbin Watson statistics (DW) and Durbin-h statistics indicate the absence of autocorrelation in all behavioral equations. The adjusted R^2 in most equations suggest that each equation provides a good fit of the associated data. In table 4.3, the p-values in parentheses under each variable are provided as measures of the statistical significance of each variable in each equation.

As discussed in Chapter 3, U.S. mature ewe inventories (matureewes_US in equation (1) in table 5) are a function of the real price of live sheep (newprice_sheep_live_us), the lagged dependent variable (matureewes_USlag), real US farm price of wool (US_farm_pricenew) and exogenous shift variables. The coefficient of 0.93 of the the lagged dependent variable (matureewes_USlag), real US farm price of wool (US_farm_pricenew) and exogenous shift variables. The coefficient of 0.93 of the lagged dependent variable indicates a lengthy dynamic adjustment process of inventories to their long-run equilibrium. This is highly plausible since U.S. sheep inventories have been in almost a free fall since the end of World War II. Mature ewe inventories are positively related to the current price of live sheep with short-run and long-run price elasticities of 0.11 and 1.37 (table 6) which are consistent with the findings of Purcell et al. (1991) and Anderson (1994). Although estimated to be positive, the coefficient of the farm price of wool is not statistically significant suggesting that wool markets have little impact on the supply of sheep in the United States. The adjusted R^2 in the U.S. mature ewe inventory equation (1) in table 5 is 0.99 and the Durbin-h statistic is 0.59 indicating the absence of autocorrelation.

Replacement lamb inventories are determined primarily by the size of the lamb crop in the previous year (the lagged lamb crop). A low lamb crop in the previous year tends to constrain the number of replacement lambs in the next year even in periods of increasing price.

Table 5. LamMod Behavioral Equations and Parameter Estimates[1]

Meat market- U.S. live sheep and meat market:

1) matureewes_US = **-521660+.92737*matureewes_uslag+ 506098*newprice_sheep_live_us+ 439768*DE+ 804153*DE1**

(0.001) (0.001) (0.119) (0.021) (0.001)

+349189*DE2+98345*US_farm_pricenew

(0.028) (0.333)

Adjusted R^2=0.99, Durbin-h=0.59

2) replacement_lambs_us = **-3429920+.45567*lambcrop_uslag+0 .13772*death_loss_us+32135*time+265654*newretail_price_lamb_us**

(0.000) (0.000) (0.019) (0.011) (0.010)

Adjusted R^2=0.92, Durbin Watson=1.96

3) total_feed_US = **456706.1+0.773387*total_feed_USLag –251374*newprice_sheep_live_us+262289*newsl_us+672735.3*DF+173783.1*DF1**

(0.090) (0.000) (0.127) (0.120) (0.000) (0.100)

Adjusted-R^2=0.90, Durbin h=0.47

4) total_slaughter_us = **7109649+0.458935*total_feed_USlag +1019900*newretail_price_lamb_us-1012509*newsl_US+0.820278*lambcrop_uslag**

(0.000) (0.208) (0.001) (0.073) (0.000)

+0.357581*total_slaughter_uslag

(0.070)

Adjusted-R^2=0.96, Durbin h=0.90

Table 5. Continued

5) lambcrop_us **=** **-98146.3+0.921492*matureewes_us+836206*newsl_us**

(0.150) (0.000) (0.287)

Adjusted R^2 =0.98, Durbin Watson=1.90

6) newprice_sheep_live_us **=** **0.8270+0.3408*newsl_US-0.2870*DLCUS+0.2658*DLCUS1-0.2235*DLCUS2**

(0.000) (0.061) (0.0234) (0.047) (0.075)

Adjusted R^2=0.76, Durbin Watson=1.89

7) percapitacons_us **=** **0. 3401+ 0.010298 *newexp_us + .006865 *newexp_uslag+ .003433* newexp_uslag2 - 0.1301*newretail_price_lamb_us**

(0.246) (0.171) (0.171) (0.171) (0.066)

+0.0000104*AdjNNIcapita_US +0.1557*newreprice_beef_US +0.2117*newporkrp+0.0815*DUSALCon

(0.131) (0.026) (0.003) (0 .025)

Adjusted R^2=0.92, Durbin Watson=1.97

Australian live sheep and lamb market:

8) Breeding_ewesA **=** **30052952+ 0.546496* Breeding_ewesAlag +25693366*Aus_px_wnewreal + 7354691*Daussie2 +3337474*Daussie**

(0.022) (0.001) (0.478) (0.008) (0.172)

-850209*time +166113.3*PP_LSWtUSdollarston_Anewreal

(0.008) (0.137)

Adjusted R^2=0.97, Durbin h=0.56

Table 5. Continued

9) Othersheep_A	**=**	**36731387+ 0.546496*Othersheep_Alag+ 31402998*Aus_px_wnewreal+ 203027.4*PP_LSWtUSdollarston_Anewreal**
		(0.022) (0.001) (0.478) (0.138)
		- 1039144*time +8989067*Daussieot2 +4079135*Daussieot
		(0.172) (0.008) (0.172)
		Adjusted R^2=0.97, Durbin h=0.56
10) TotalSL_A	**=**	**12600000+6603276*DAsl33 +2156544*Lamb_RP_Anew -8371701*DAsl11 -628634*newPP_LSWtUSdollarston_A**
		(0.303) (0.041) (0.002) (0.014) (0.002)
		+0.59237*TotalSL_Alag+0.176182*lamb_crop_alag
		(0.014) (0.088)
		Adjusted R^2=0.88, Durbin h=0.42
11) NETExports_A	**=**	**20765785+0.221431*NETExports_Alag+176275*importingworldgdp-117143.1*PP_LSWtUSdollarston_Anewreal-**
		(0.001) (0.29) (0.003) (0.004)
		34935.37*EU_ME_EXC
		(0.004)
		Adjusted R^2=0.60, Durbin h=0.40

Table 5. Continued

12) Lamb_crop_a = **-20380551+1.3068*Breeding_ewesA +865444*time -7953522*DALC**

0.085) (0.001) (0.004) (0.007)

Adjusted R^2=0.97, Durbin Watson=1.90

13) TotalconsA = **243284.2-40101.5*lamb_rp_anew+9496.67*Beef_RP_Anew+26018.68*Aus_disc_income+24056.98*newChicken_RP_A**

(0.829) (0.003) (0.005) (0.004) (0.035)

+24826.5*Dauslcon1

(0.872)

Adjusted R^2=0.68, Durbin Watson=1.89

New Zealand live sheep and meat market:

14) Breeding__ewesNZ = **8180240+0.731185*Breeding__ewesNZlag -207766*time +127608*sheeplivepp_NZnewreal +6023846*NZ_px_wnewreal**

(0.015) (0.001) (0.096) (0.081) (0.583)

Adjusted R^2=0.97, Durbin h=0.78

15) othersheep = **8629164+0.457406*othersheeplag -222273*time +81337*sheeplivepp_NZnewreal+ 7767419*NZ_px_wnewreal**

(0.047) (0.052) (0.024) (0.25) (0.801)

Adjusted R^2=0.87, Durbin h=0.78

Table 5. Continued

16) totalSL_NZ	**=**	**13900779+311840000*NZ_px_mnewreal-688686*sheeplivepp_NZnewreal+7423614*DNZSL+.23*totalSL_NZlag-**
		(0.000) (0.012) (0.003) (0.006) (0.416)
		423681*time +5503224*DNZSL1+0.257633*lamb_crop_NZlag
		(0.004) (0.003) (0.006)
		Adjusted R^2=0.77, Durbin h=0.78
17) lamb_crop_NZ	**=**	**-16002895 -12295*time_2 +1.36008*Breeding__ewesNZ +894000*time**
		(0.200) (0.158) (0.000) (0.049)
		Adjusted R^2=0.94, Durbin Watson=2.04
18) NETExports_NZ	**=**	**-462995+0.818186*NETExports_NZlag +49281.4*importingworldgdp -90585*sheeplivepp_NZnewreal-**
		(0.519) (0.395) (0.880)
		-1026.523*EU_ME_EXC
		(0.796)
		Adjusted R^2=0.66, Durbin h=0.58

Table 5. Continued

19) NZ_ConsTonnes = -160809 -2885518*NZ_px_mnewreal -148154*DNZCONL2 +50511.16*DNZCONL -119208*DNZCONL1

(0.127) (c) (0.000) (0.148) (0.002)

+351886.6*NZGDP+4498.721*Beef_NZpxnewreal

(0.004) (0.008)

Adjusted R^2=0.74, Durbin Watson=1.96

International meat trade and price linkages:

20) ROW_M = -530654+0.571779*ROW_Mlag +6563.951*importingworldgdp -145414.9*perunitLPM-1543.75*EU_ME_EXC

(0.557) (0.008) (0.034) (c) (0.000)

+235544.6*DRMo+258451.7*DRM1+198096.5*DRM2

(0.000) (0.000) (0.000)

Adjusted R^2=0.72, Durbin h=0.80

21) NZ_px_mnewrel = 0.030525+0.00181*perunitLPM*NZ_exrate-0.00143*DRMo+.003745*DRM1+0.016849*DRM2

(0.074) (0.006) (0.152) (0.415) (0.049)

Adjusted R^2=0.87, Durbin Watson=1.80

22) Lamb_RP_Anew = 5.651122+0.72425*perunitLPM*Aus_exrate+-2.4307*DRPA

(0.000) (0.000) (0.029)

Adjusted R^2=0.62, Durbin Watson=1.78

Table 5. Continued

23) perunitLPM	**=**	**-14.1247+3.325514*newretail_price_lamb_us+-1.78867*DMLPM**
		(0.001) (0.001) (0.023)
		Adjusted R^2=0.76, Durbin Watson=1.90
Wool Market - U.S. wool market:		
24) End_stocks	**=**	**21.3592+0.5339*End_stockslag+ 0.7196*US_farm_pricenew-0.5204*time +26.3861*DUSAstocks1 +11.8566*DUSAstocks2**
		(0.003) (0.000) (0.395) (0.020) (0.000) (0.135)
		Adjusted R^2=0.82, Durbin h= 0.90
25) Mill_use	**=**	**-25.9769-1.9312*US_farm_pricenew +0.815318*Mill_uselag +39.45535*polyester_usnew-1.10102*time+0.19618*usgdp**
		(0.370) (c) (0.001) (0.024) (0.238) (0.135)
		Adjusted R^2=0.96, Durbin h=0.45
Australia wool market:		
26) Aus_con	**=**	**21161.78+ 0.262822*Aus_conlag+ 234280.8*DAUSWOOL2 -2128813*Aus_px_wnewreal+26844.05*newaus_raw_c**
		(0.865) (0.135) (0.001) (c) (0.460)
		+36677.38*Aus_disc_income-494.9*time_2
		(0.369) (0.000)
		Adjusted R^2=0.73, Durbin h=0.60

Table 5. Continued

New Zealand wool market:

27) NZ_con = **46080.24+ 0.513476*NZ_conlag+ 40227.4*DNZCONWool1 -2214080*NZ_px_wnewreal+258736.3*NZGDP-7039.79*time**

(0.700) (0.136) (0.128) (c) (0.008) (0.000)

Adjusted R^2=0.65, Durbin h=0.67

Argentina wool market:

28) Arg_total_stock = **5139865+4092877*arg_px_wnewreal +0.525521*Arg_total_stocklag +6392676*Dargts+78605.49*time**

(0.001) (0.041) (0.000) (0.000) (0.037)

Adjusted R^2=0.96, Durbin h=0.73

29) arg_con = **18271.48+ 0.707155*arg_conlag-429137*arg_px_wnewreal+596561.1*arg_px_cnewreal+3940.288*newarg_gdp**

(0.066) (0.001) (c) (0.003) (0.004)

+148534.7*Dargwool1+96943.13*Dargwool+55152.9*Dargwool2

(0.000) (0.000) (0.002)

Adjusted R^2=0.81, Durbin h=0.48

Uruguay wool market:

30) U_ts = **707289.3+88455.78*U_px_wnewreal +0.888*U_tslag +2655192*Duwool2**

(0.481) (0.004) (0.000) (0.638)

Adjusted R^2=0.98, Durbin h=0.91

Table 5. Continued

31) U_con = **17011.91+ 0.482155*U_conlag-7958.85*U_px_wnewreal +64646.27*newU_GDP +73478.78*Duwool1 +72925.71*Duwool2**

(0.061) (0.002) (c) (0.000) (0.000) (0.000)

Adjusted R^2=0.60, Durbin h=0.67

International wool trade and price linkages:

32) ROW_W_M = **867977.3-9.43705E-06*perunitWP+116.42*realgdp_china-8819*ex_rate_china+0.45*ROW_W_Mlag**

(0.001) (c) (0.001) (0.600) (0.230)

Adjusted R^2=0.84, Durbin h=0.92

33) Aus_px_wnewreal = **0.037946+0.003256*perunitWP*Aus_exrate**

(0.067) (0.028)

Adjusted R^2 =0.72, Durbin Watson=1.89

34) arg_px_wnewreal = **0.025851+0.0067*perunitWP*arg_exrate**

(0.554) (0.046)

Adjusted R^2 =0.78, Durbin Watson=1.68

35) U_px_wnewreal = **-8.79546+0.125573*perunitWP*U_exrate**

(0.058) (0.002)

Adjusted R^2 =0.81, Durbin Watson=2.05

Table 5. Continued

36) NZ_px_wnewreal	**=**	**0.052655+.00001*perunitWP*NZ_exrate+0.018059*DAzl**
		(0.000) (0.364) (0.134)
		Adjusted R^2=0.62, Durbin Watson=1.79
37) perunitWP	**=**	**4.016182+1.396018*US_farm_pricenew**
		(0.000) (0.055)
		Adjusted R^2 =0.68 , Durbin Watson=1.99

[1] Numbers in parentheses below the estimated parameters are the p-values. c = constrained coefficient.

In the replacement lamb inventory equation (replacement_lambs_us in equation (2) in table 5), the estimated coefficient of the lagged lamb crop indicates that if the previous year's lamb crop increases by one head, replacement lambs will increase by 0.46 head on average. The estimated positive coefficient of the price of lamb (newretail_price_lamb_us) indicates that an increase in that price is a signal to build the herd to take advantage of the increasing price. Death loss (death_loss_us) and replacement lambs are estimated to be positively related. The higher the death loss, the greater the number if replacement lambs will be needed. A one head increase in death loss is estimated to result in a 0.14 head increase in replacement lambs. A time variable has been added to the equation to capture the time trend of replacement lambs. The positive coefficient with respect to the time variable indicates an increase in the replacement lambs over time. The adjusted R^2 of equation (2) is 0.92 and the Durbin Watson statistic is 1.96.

The U.S. demand for feeder lambs (total_feed_US), equation (3) in table 5, is specified as a function of its own lagged value (total_feed_uslag), the real price of live sheep, and the real slaughter price (newsl_us). The coefficient of the lagged feedlot demand is 0.77 and statistically significant indicating some lag in the adjustment of feeder lamb inventories to their long-run equilibrium over time. Feedlot demand is negatively related to the real price of sheep as expected since feeder lambs represent an input to feedlot operations. The demand for lambs for feedingis derived from the demand by packers for slaughter lambs. As expected, feedlot demand is estimated to be positively related to the real slaughter price so that an increase in the price of slaughter sheep increases the demand by feeders for feeder lambs. The elasticities of feeder demand with respect to the U.S. live sheep price and the U.S. slaughter sheep price in the short-run are -0.15 and 0.15, respectively, and -0.65 and 0.66, respectively in the long-run (table 6). The adjusted R^2 is 0.90 and the Durbin-h is 0.46. These two statistics indicate good fit of the data and no autocorrelation. The U.S. demand for slaughter sheep by lamb packers (total_slaughter_us) (equation (4) in table 5) is estimated as a function of the real price of slaughter sheep (newsl_us), the real retail price of lamb (newretail_price_lamb_us), the lagged number of sheep on feed (total_feed_USlag), the lagged lamb crop (lambcrop_uslag), and lagged total slaughter (total_slaughter_uslag). Slaughter demand is estimated to be significantly and negatively related to the real slaughter price as expected with estimated short-run and long-run elasticities of -0.2 and -0.36, since slaughter sheep are inputs into the production of lamb by packers (table 6). On the other hand, slaughter demand is estimated to be significantly and positively related to the real retail price of lamb as expected with short-run and long-run elasticities of 0.77 and 1.42, given that lamb meat is the output price to lamb packers (table 6). The lagged (beginning) feeder inventories and lagged lamb crop together represent the availability of lambs to be slaughtered in the next year. Their coefficients are estimated to be positive and less than one as expected. A one head increase in feeder inventories and in the lamb crop in the previous year tends to increase lamb slaughter by 0.46 head and 0.82 head the following year. The coefficient of the lagged slaughter demand is also positive and less than one indicatingsome constraint in the adjustment of slaughter demand to its long run equilibrium. The adjusted R^2 for this equation is 0.96 and the Durbin h is 0.90 indicating good fit of the data and no autocorrelation respectively.

Table 6. Price Elasticities in Global Live Sheep Markets

Equations	Short-run Price Elasticities				Long-run Price Elasticities			
	Farm Price	Slaughter Price	Wool Mill Price	Lamb Retail Price	Farm Price	Slaughter Price	Wool Mill Price	Lamb Retail Price
U.S.								
Mature ewe inventory	0.11*				1.37*		0.01	
Replacement inventory				0.89***				
Lamb crop inventory		0.15						
Feeder demand	-0.15*	0.15*			-0.65*	0.65*		
Slaughter demand		-0.2**		0.77***		-0.36**		1.42***
Australia								
Breedingewe inventory	0.05*		0.03		0.11*		0.06	
Othersheep inventory	0.04*		0.05		0.09*		0.11	
Slaughter demand	-0.2***			0.68***	-0.49***			1.65***
New Zealand								
Breedingewe inventory	0.03**		0.14		0.11**		0.52	
Othersheep inventory	0.04		0.17		0.09		0.31	
Slaughter demand	-0.18***			0.56***	-0.23***			0.72***
Argentina								
TotalSheep inventory			0.03**				0.06**	
Uruguay								
TotalSheep inventory			0.04**				0.33**	

* fifteen percent significance level

** ten percent significance level

*** one percent significance level

c = constrained

The U.S. lamb crop (lambcrop_us) (equation (5) in table 5) is specified as a function of lagged (beginning) mature ewe inventories and the real slaughter sheep price (newsl_us). The positive coefficient of 0.92 with respect to mature ewe inventories indicates that a one head increase in those inventories leads to a 0.92 head increase in the lamb crop later in that year. Although not statistically significant at the usual levels, the coefficient of the slaughter price is positive as expected suggesting that the slaughter price may act as an incentive to increase the lambing rate and, thus, the lamb crop each year. The high adjusted R^2 of 0.98 indicates a good fit of the data. The Durbin W statistic of 1.90 suggests the absence of autocorrelation.

Equation (6) in table 5 is a price transmission equation linking the producer live sheep price (newprice_sheep_live_us) to the slaughter sheep price (newsl_US). An increase in the slaughter sheep price of one dollar per head is estimated to increase the live sheep price by $0.34 per head. The indicator variables in that equation account for a few data outliers. The adjusted R^2 is 0.76 and the Durbin Watson statistic is close to 2.0.

The domestic U.S. per capita demand for lamb (percapitacons_us in equation (7) in table 5) is specified as a function of the real retail price of lamb meat (newretail_price_lamb_us), the real retail price of beef (newreprice_beef_us), the retail price of pork (newporkrp), income per capita (AdjNNIcapita_US), and a lamb checkoff expenditure goodwill variable (newexp_us). To account for the time lag in the impact of checkoff expenditures on the per capita consumption of lamb, the Almon polynomial distributed lag (PDL) process is applied to estimate the expenditure parameter. The polynomial inverse lag (PIL) process has been used in some studies to account for the time lag between the expenditure of checkoff funds and the impact on demand (see, e.g., Capps, Seo, and Nichols (1997), Capps et al. (1997) , Davis et al. (2001), and Williams, Shumway and Love (2002)). Because the PIL implicitly imposes the assumption that advertising effects in one period have an infinite effect on consumption, the PDL process was deemed more appropriate for this study. The search for the degree of polynomial and the lag length in the PDL process involved a series of nested OLS regressions. Ultimately, a one degree polynomial with lag length two and endpoint restrictions was selected based on the Akaike Information Criteria (AIC) and Schwarz Information Criteria (SIC). To account for inflation, diminishing marginal returns, and zero expenditures in some years, a square root transformation of the inflation-adjusted expenditure variable is used in the demand model following Capps, Williams, and Dang (2010).

The real retail prices of lamb, beef, pork, and chicken were all originally included as regressor in the U.S. lamb demand equation. All except the price of chicken were found to be statistically significant with the expected signs. The estimated own-price elasticity of lamb demand is -0.62 while the cross price elasticities of beef and pork are somewhat lower at 0.46 and 0.47, respectively (table 7). Estimates of the beef cross price elasticities of lamb demand have ranged from about 0.50 to 0.60 (Schroeder et al. 2001; Shiflett et al. 2007; George and King 1971; and Williams, Capps and Dang 2010). As expected, the coefficient of the per capita income variable has a positive sign although the p-value is a little high indicating that income is not a highly significant driver of per capita lamb consumption, a result consistent with Williams, Capps and Dang (2010).

Table 7. Estimated LamMod Lamb Demand Elasticities

	Own-price	Cross-price			Income	Checkoff expendi-tures
		Beef	Pork	Chicken		
U.S	-0.62**	0.46**	0.47***	-	0.25*	0.037*
Australia	-0.89***	0.40***	-	0.43**	0.62***	
New Zealand	-0.79^{c}	0.47***	-	-	0.80***	

* fifteen percent significance level
** ten percent significance level
*** one percent significance level
c = constrained

The estimated income elasticity at the mean is 0.25 which is again consistent with previous research. The long-run lamb promotion expenditure elasticity is estimated to be 0.037 which is consistent with Williams, Capps, and Dang and in the range of those estimated for other checkoff commodities (Williams and Nichols 1998). The adjusted R^2 and the Durbin Watson statistic indicate a good fit of the data and the absence of autocorrelation. The expenditure elasticity p value can be said to be significant even at the fifteen percent (15%) level because of the less number of observations for expenditures in the dataset and due to the use of polynomial distributed lags, some observations are lost. Also it was tested as a one tailed testWhereas, if tested as a two tailed test, the test would indicate significance at ten percent (10%) levels.

Equations (8) through (13) and (14) through (19) in table 5 are the behavioral equations of LamMod for live sheep and meat markets of Australia and New Zealand, respectively. Equations (8) and (14) in table 5 specify breeding ewe inventories in Australia (Breeding_ewesA) and New Zealand (Breeding_ewesNZ), to be functions of lagged breeding ewes in each country (Breeding_ewesAlag and Breeding_ewesNZlag), the real prices of wool in each country (Aus_px_wnewreal and NZ_px_wnewreal), and the real prices of live sheep in each country (PP_LSnewreal and sheeplivepp_NZnewreal) in their respective local currencies, and a time trend which captures technological change over time. The short-run and long-run live sheep price elasticities of breeding ewe inventories in Australia are found to be 0.05 and 0.11, and 0.04 and 0.09, for New Zealand which are somewhat less than the live sheep price elasticity estimated for U.S. mature ewe inventories (table 6). The lagged breeding ewe inventory variable in each equation accounts for the speed of adjustment of breeding inventories to their long-run equilibrium. The estimated coefficients of those lagged dependent variables suggest that inventories in both New Zealand and Australia tend to adjust more rapidly towards the long-run equilibrium in a given year than is the case in the United States. The price of wool is estimated to have little statistically significant effect on changes breeding inventories in either Australia or New Zealand. The adjusted R^2 for equations (8) and (14) are both 0.97 each suggesting a good fit of the data. The Durbin-h statistic for both the countries indicate an absence of autocorrelation.

Equations (9) and (15) in table 5 represent inventories of other (non-breeding) sheep in Australia and New Zealand, respectively. These two equations are specified as functions of the similar variables and have the same coefficient signs for those variables as for the breeding ewe inventory equations in their respective countries (equations (8) and (14)). Equation (15) does not include a time trend variable. As with breeding sheep inventories, inventories of non-breeding sheep in each country are found to be statistically independent of changes in their respective prices of wool. The positive estimated coefficients of live sheep prices in both countries are close to being significant at the 10% level. The estimated short-run and long-run price elasticities of other sheep inventories in both Australia and New Zealand are 0.04 and 0.09, similar to what was found for their breeding sheep inventories (table 6). The high adjusted R^2s of 0.97 and 0.87 of equations (9) and (15) indicate good fits of their respective data. The Durbin-h statistics for the two equations are 0.56 and 0.78, indicating the absence of autocorrelation.

Equations (10) and (16) in table 5 are the slaughter demand equations for Australia (TotalSL_A) and New Zealand (totalSL_NZ), respectively. As expected, the slaughter demand in each country is found to be negatively and significantly related to the real prices of live sheep in each country (newPP_LSWtUSdollarston_A and sheeplivepp_NZnewreal, respectively) since sheep are an input to lamb packing. The short-run and long-run live sheep price elasticities of lamb slaughter in Australia are -0.20 and -0.49, respectively (table 6). For New Zealand, those elasticities are -0.18 and -0.23. Since lamb meat is the output of lamb packing, the estimated coefficients of retail lamb price in Australia and New Zealand (lamb_rp_anew and NZ_px_mnewreal, respectively) in their slaughter demand equations are positive as well as statistically significant with short-run elasticities of 0.68 and 0.56, rand long-run elasticities of 1.65 and 0.72 (table 6). These results are similar to those found for the U.S. slaughter demand (equation (4) in table 5). The lagged slaughter is a proxy for processing capacity and is, as expected, estimated to be positively related to slaughter demand in each country. The coefficients of 0.59 and 0.23 for lagged slaughter in each country suggest that lamb slaughter in Australia and New Zealand adjust quickly to their long-run equilibriums. The lagged lamb crop represents the annual availability of lambs to be slaughtered and, as expected, is estimated to be positively related to slaughter demand. The signs of the estimated coefficients in each slaughter demand equation are all consistent with expectations. The adjusted R^2s of 0.88 and 0.77 indicate good fits of their respective data for each equation. The Durbin-h statistic for both equations (0.42 and 0.78, respectively) indicate the absence of auto correlation.

Equations (12) and (17) in table 5 specify the annual lamb crop in Australia and New Zealand (Lamb_crop_A and Lamb_crop_NZ,) to be functions of breeding ewes and time. Time represents the effects of technological change that has positively impacted the lambing rate in those countries as represented by the signs of the respective estimated coefficients. The coefficients associated with the breeding ewes are positive as expected. The high adjusted R^2 of 0.97 for equation (12) and 0.94 for equation (17) indicate excellent fits of their respective data. The Durbin W statistic associated with each equation (1.90 and 2.04) indicate the absence of autocorrelation.

Equations (11) and (18) in table 5 are the export demand for live sheep equations for Australia (NETExports_A) and New Zealand (NETExports_NZ). The equations are specified as functions of the weighted average of real Middle East and EU-27 gross domestic products (importingworldgdp), the real price of live sheep in the respective countries, and the weighted average of the exchange rates of the Middle East (Saudi Arabia and United Arab Emirates) and EU-27 countries (EU_ME_EXC) and also lagged export demand. The real Australian price of live sheep is estimated to have a statistically significant, negative effect on the net export demand for live sheep from Australia. Although estimated to be negative as expected, the New Zealand coefficient of the live sheep price was small and not statistically significant, The elasticity of New Zealand's export coefficient for the live price was constrained to be equal to that of Australia because of its economic importance in linking New Zealand to foreign live sheep markets. Higher purchasing power in the Middle East and the EU, represented by the variable importingworldgdp, is estimated to have a positive impact on the net export demand for live sheep from Australia. The coefficient of the weighted GDP variable is positive as expected in the New Zealand live sheep export equation but is not statistically significant.

As expected, the Middle East-EU-27 weighted exchange rate is also found to be negatively and significantly related to net export demand for live sheep from Australia. A rise in the exchange rate makes sheep more expensive to the importing countries resulting in a drop in the demand for Australian live sheep exports. The coefficient of the exchange rate variable is found to be statistically insignificant in explaining live sheep exports from New Zealand, however. The adjusted R^2 for equations (11) and (18) are

0.60 and 0.66. The Durbin h statistic for both equations indicates the absence of autocorrelation.

The demand for lamb in Australia and New Zealand is specified in equations (13) and (19) in table 5. For Australia (equation (13)), domestic lamb demand (TotalconsA) is specified as a function of the real retail price of lamb (lamb_rp_anew), the real retail price of beef (Beef_RP_Anew), the real retail price of chicken (newChicken_RP_A), and Australian real disposable income (Aus_disc_income). The Australian lamb demand is found to be significantly but inversely related to its own real price (lamb_rp_anew) with a price elasticity of -0.89 which is consistent with what Australian reserachers have found (e.g., Hyde and Perloff 1998 and Cashin 1991) (table 7). Australian lamb demand is found to be significantly and positively related to the real prices of beef and chicken with cross-price elasticities of 0.40 and 0.43 (table 7). The cross price elasticities are again consistent with what Australian researchers have found (e.g., Hyde and Perloff 1998). Australian lamb demand is found to be income inelastic with an income elasticity of 0.62 which is more than double the estimated income elasticity of U.S. lamb demand. The higher income elasticity is highly plausible because lamb is consumed by a much larger proportion of the consuming population in Australia than in the U.S. and because per capita lamb consumption is also much higher.

Equation (19) is New Zealand lamb meat demand (NZ_ConsTonnes). The coefficient of the price of lamb has been constrained to a value consistent with an elasticity of -0.79 (table 7). The large sheep and lamb industry in New Zealand and its similar traits with Australian sheep and lamb led to the constraining of the elasticity at -

0.79. The estimated cross-price elasticity with respect to beef is estimated to be 0.47, similar to the beef cross-price elasticities of lamb demand in both the U.S. and Australia. At 0.80, the estimated income elasticity of New Zealand lamb demand is somewhat higher than the income elasticity of lamb demand in Australia and over 3 times higher than the income elasticity of U.S. lamb demand. The adjusted R^2 for both lamb demand equations ((13) and (19)) are 0.68 and 0.74 while their respective Durbin W statistics (1.89 and 1.96) indicate the absence of autocorrelation

The international trade and price linkages for lamb are specified in equations (20) through (23) in table 5. The import demand for lamb by all countries other than the U.S. (Rest-of-the-World or ROW) closes the world lamb market portion of LamMod and is specified in equation (20) as a function of the lagged dependent variable (ROW_Mlag), the weighted average of the real GDPs of the Middle East and the European Union-27 (importingworldgdp), the trade-weighted average of the exchange rates of the Middle East and the EU-27 (EU_ME_EXC), the real import price (perunitLPM), and other exogenous variables (indicator variables). As expected, the ROW import demand for lamb is negatively related to the real import price, positively related to the weighted real GDP, and negatively related to the weighted average of the exchange rates. The adjusted R^2 is 0.72 and Durbin-h is 0.80.

Equations 21 through 23 are the price transmission links between world lamb prices and the U.S. prices. Equations (21) and (22) specify the prices of lamb in New Zealand and in Australia to be functions of the U.S. import price of lamb (which includes transportation costs) times the respective exchange rates for each country. Equation (23) links the U.S. retail price of lamb to the U.S. import price of lamb. The positive and statistically significant estimated coefficients of the right-hand-side prices in each equation indicate a positive correlation of lamb prices among countries and within the United States. The somewhat low adjusted R^2 for each equation indicates that the price transmission is less than perfect in each case. The Durbin W statistics for each equation indicate the absence of autocorrelation.

The world wool market behavioral equations are represented in equations (24) through (37) in table 5. The U.S. ending stocks of wool (End_stocks) is specified as a function of the lagged dependent variable (End_stockslag), the current real U.S. farm price of wool (US_farm_pricenew), time, and some other exogenous variables. The ending stocks of wool (equation (24)) is positively related to the current price of wool with a price elasticity of only 0.01. The positive coefficient of 0.53 for the lagged dependent variable indicates some hindrance in the adjustment of stocks to their long-run equilibrium values. The negative coefficient associated with time indicates a consistent downward trend in U.S. wool stocks over the sample period. The high adjusted R^2 indicates a good fit of the data while the low Durbin-h statistic indicates the absence of autocorrelation.

Equation (25) in table 5 specifies the U.S. wool demand at the mill level (Mill_use) to be a function of the real U.S. wool farm price, the real U.S. polyester price, the domestic real U.S. GDP, and a time trend to capture the effect of the continuous decline in the number of wool mills in the United States over the last couple of decades. The own-price elasticity of U.S. wool demand is constrained to a value of -0.02 (table 8) based on the estimate of Clements and Lan (2001). Little research has been done at the mill level demand for wool in U.S. The only research which dealt with mill demand was that of Clements and Lan (date) To be consistent with that study, the elasticity was constrained at -0.02. The polyester cross price elasticity of U.S. wool mill demand is estimated to be positive and significant at 0.01 indicating a highly inelastic response of U.S. wool demand to changes in the price of polyester (table 8).

Table 8. Estimated LamMod Wool Demand Elasticities

	Own	Cross-price		
	Price	**Polyester**	**Cotton**	**Income**
U.S.	-0.02[c]	0.01**		0.23*
Australia	-0.55[c]		0.41	1.19
New Zealand	-0.60[c]			1.31***
Uruguay	-0.67[c]			0.82***
Argentina	-0.68[c]		0.002***	0.14***

* fifteen percent significance level

** ten percent significance level

*** one percent significance level

c = constrained

The income elasticity of wool demand is estimated to be 0.23 which is consistent with the estimate of Clements and Lan (2001) as well. The high adjusted R^2 indicates a good fit of the data and the low Durbin-h statistic the absence of autocorrelation.

The Australian domestic wool demand (Aus_con) in equation (26) is specified as a function of the real price of wool in Australia, the real price of cotton (newaus_raw_c) in Australia, Australian disposable income, and the lagged dependent variable (Aus_conlag). The own-price elasticity of the Australian demand for wool is constrained to a value of -0.55 based on the work of Donell (1992) (table 8). Again few studies at the mill level and the lack of proper data led to the constrained value. Australian wool demand is found to be positively related to price of cotton with a cross-price elasticity of 0.41 but at a low level of statistical significance. The income elasticity of Australian wool demand is estimated to be 1.19 which isat a low level of significance. The negative coefficient of the time trend variable is highly significant indicating a strong downward trend of wool demand in Australia, the same as was found for wool demand in the United States. The low Durbin-h indicates no autocorrelation.

Equation 27 in table 5 deals with the New Zealand consumption of wool (NZ_con). New Zealand wool consumption is specified as a function of the domestic real price of wool, the lagged dependent variable, income, and other exogenous variables. The estimated own-price elasticity of New Zealand wool demand is constrained to a value of -0.6, consistent with the price elasticity of Australian wool demand. The income elasticity of New Zealand is estimated to positive and statistically significant at 1.31, consistent with the income elasticity estimate for Australian wool demand. Wool may be considered to be something of a luxury good in both countries. The lack of data for the prices of substitute fibers for New Zealand precluded the estimation of any cross-price elasticities for New Zealand wool demand. The low Durbin-h statistic indicates the absence of autocorrelation.

The sheep inventories in Argentina and Uruguay (Arg_total_stock, U_ts, respectively) are specified in equations (28) and (30) in table 5 as functions of their respective domestic real prices of wool (arg_px_wnewreal, u_px_wnewreal, respectively), lagged dependent variables, time, and other exogenous variables (indicator variables). The wool price coefficients in each country are found to be positive and statistically significant in determining sheep inventories in those countries. The wool supply elasticities for each country are estimated at 0.03 and 0.04 respectively consistent with the wool supply elasticities estimated for the U.S., Australia, and New Zealand (see table 6). The lagged dependent variables in each equation are less than one and statistically significant. Time trend is also found to be statistically significant for the Argentina sheep inventories. Both equations have high adjusted R^2s and low Durbin-h statistics.

Equations (29) and (31) in table 5 are the wool demands in Argentina (Arg_con), and Uruguay (U_con), respectively. They are specified as functions of their respective domestic real prices of wool, real prices of raw cotton (Argentina), lagged dependent variables, income, and other exogenous variables. The own price elasticities of wool demand in Argentina and Uruguay are constrained to values of -0.68 and -0.67 based on the work of Witherell (1967) (table 8), resulting in similar price elasticities of wool demand in all four major wool producing regions in the model (Australia, New Zealand, Uruguay, and Argentina) (table 8). The lack of data for the prices of synthetic or other types of fiber for Uruguay precluded the estimation of cross-price elasticities of wool demand in that country. The estimated cotton cross-price elasticity of wool demand in Argentina, is statistically significant but quite low at 0.002 suggesting a highly inelastic response of wool demand in Argentina to changes in cotton price (table 8). Argentina and Uruguay wool demands are estimated to be income inelastic with income elasticities of 0.14 and 0.82. The low Durbin h for both equations indicates the absence of autocorrelation.

The Rest-of-the-World (ROW) wool import demand (ROW_W_M) in equation (32) is a behavioral relationship to close the global wool market portion of LamMod. ROW wool import demand is estimated to be negatively related to the import price of wool (perunitWP), positively related to China's GDP (realgdp_china), and negatively related to the Chinese exchange rate (ex_rate_china) given that China is the major destination for Australian and New Zealand greasy wool exports. The adjusted R^2 of 0.84 suggests a good fit of the data. The low Durbin-h statistic indicates the absence of autocorrelation. Equations (33) through (37) are the international price linkage equations. They are the price transmission equations connecting the U.S. wool import price to the wool price in the wool exporting countries. Equation (37) is the linkage between the U.S. wool import price and the U.S. farm price of wool.

Model Validation

Model validation through simulation is a check on the completeness, accuracy, and forecasting ability of a model. This process consists of two parts: (1) verification and (2) validation. Verification requires a careful check of the logic of the model to insure all equations are properly specified and the expected signs of the estimated parameters conform to theory. All equations of the model were checked carefully to insure that all signs of all variables were consistent with theory. After some adjustments to the model to constrain a few coefficients to insure theoretical validity of the model structure and simulation properties, the model was validated through a dynamic, within- sample simulation of the model. The simulation exercise was based on the period the data over which a common set of data were available (1987-2011). Theil inequality coefficients and Theil error decomposition proportions (bias, variance covariance) were generated to check the fit of the historical, dynamic simulation solution values to observed data.

Theil's inequality coefficient (U) test is formulated as (Pindyck and Rubinfeld 1998):

$$U = \frac{\sqrt{\frac{1}{T}\sum_{i=1}^{T}(Y_t^s - Y_t^a)^2}}{\sqrt{\frac{1}{T}\sum_{i=1}^{T}(Y_t^s)^2} + \sqrt{\frac{1}{T}\sum_{i=1}^{T}(Y_t^a)^2}}$$

where Y_t^a = actual value of the endogenous variable at time t, Y_t^s = simulated value of the endogenous variable at time t, and T = number of periods in the simulation.

The numerator of the U-statistic is defined as the Root-Mean-Squared Error (RMSE). The denominator is scaled in a way that U is always between 0 and 1. $U = 0$ indicates a perfect fit as $Y_t^s = Y_t^a$ for all t, while $U = 1$ suggests a poor fit of the model. It can be said that Theil's inequality coefficient measures the RMSE in relative terms.

The MSE measures the mean of the squared deviation between the simulated and the actual values and is expressed as:

$$MSE = \frac{1}{T}\sum_{i=1}^{T}(Y_t^s - Y_t^a)^2 \ .$$

The MSE depends upon the units in which the variable is expressed so that the relative magnitude of the error does not give any indication of how large the error is. This error can be compared only with the average size of the variable in question. The main advantage of MSE is that it can be decomposed into different components to evaluate the deviation between the simulated and the actual values. SAS provides two methods of decomposition - first, by Theil and second by Maddala.

The Theil decomposition of MSE is as follows:

$$\frac{1}{T}\sum(Y_t^s - Y_t^a)^2 = (\bar{Y}_t^s - \bar{Y}_t^a)^2 + (\sigma_s - \sigma_a)^2 + 2(1-\rho)\sigma_s\sigma_a,$$

where $\bar{Y}^s, \sigma_s$ are the mean and standard deviation of the series Y_t^s; and $\bar{Y}^a, \sigma_a$ are the mean and standard deviation of the actual series Y_t^a; ρ is the correlation coefficient of the two series. Rearranging the above equation we get the three components of MSE.

$$1 = \frac{(\bar{Y}_t^s - \bar{Y}_t^a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2} + \frac{(\sigma_s - \sigma_a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2} + \frac{2(1-\rho)\sigma_s\sigma_a}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2}$$

and

$$UM = \frac{(\bar{Y}_t^s - \bar{Y}_t^a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2}, \quad US = \frac{(\sigma_s - \sigma_a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2}, \text{ and } \quad UC = \frac{2(1-\rho)\sigma_s\sigma_a}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2} \ .$$

UM, US, UC, referred to as bias, variance and covariance proportion of U, respectively, sum to one. The UM represents the systematic error and its value is expected to be close to zero. A large value of US indicates a large variance proportion which implies that the actual series has more variability than the simulated series or vice versa. Finally, the covariance proportion UC shows the random, unsystematic error. The second MSE decomposition by Maddala, consists of bias (UM), regression (UR), and disturbance terms (UD):

$$\frac{1}{T}\sum(Y_t^s - Y_t^a)^2 = (\bar{Y}_t^s - \bar{Y}_t^a)^2 + (\sigma_s - \rho\sigma_a)^2 + (1-\rho^2)\sigma^2{}_a$$

After rearranging we get the following,

$$1 = \frac{(\bar{Y}_t^s - \bar{Y}_t^a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2} + \frac{(\sigma_s - \rho\sigma_a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2} + \frac{(1-\rho^2)\sigma^2{}_a}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2}$$

In this case:

$$UM = \frac{(\bar{Y}_t^s - \bar{Y}_t^a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2},\ UR = \frac{(\sigma_s - \rho\sigma_a)^2}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2},\ \text{and}\ UD = \frac{(1-\rho^2)\sigma^2{}_a}{\frac{1}{T}\sum(Y_t^s - Y_t^a)^2}\ .$$

UM, UR, UD are known here as the bias, regression and disturbance components of U. The UM and UR capture the systematic divergence of the model and so their values should be close to zero. The UD component captures the random divergence of the prediction from the actual values and its value should be close to one. The sum of UM, UR, and UD is equal to one.

After estimating all the equations, the model was solved simultaneously using the Newton method in SAS (Statistical Analysis System). An historical simulation of the model was done to validate the estimated model using the MSE and Theil inequality coefficient test statistics. Table 9 reports the validation statistics of the model. The MSE and its decomposition indicate that most UM values are close to zero while the disturbance terms are high suggesting that the errors of the simulated variables are random. The Theil U statistics are close to zero for almost all the endogenous variables of the model indicating an acceptable model performance. Since the bias and variance proportions are also close to zero, the ability of the structural equations to replicate the observed values of the endogenous variables over time is satisfactory. The proposed model tracks the historical changes in the key market variables properly. LamMod is used in the next Chapter to measure the effects of the lamb checkoff-program.

Table 9.LamMod Simulation Validation Statistics

Theil Forecast Error Statistics

Variable	MSE	MSE Decomposition Proportions					Inequality Coefficient	
		Bias (UM)	Reg (UR)	Dist (UD)	Var (US)	Covar (UC)	U1	U
totalbreedingsheep_US	3.79E+10	0.03	0	0.97	0.01	0.96	0.0297	0.0149
matureewes_US	1.73E+10	0.01	0.01	0.98	0	0.99	0.025	0.0125
replacement_lambs_US	1.17E+10	0.04	0	0.95	0.04	0.92	0.1013	0.0513
total_feed_US	1.44E+10	0.07	0.01	0.92	0.01	0.92	0.064	0.0323
total_slaughter_US	4.19E+10	0.01	0.19	0.8	0.14	0.85	0.0421	0.021
newsl_US	0.1526	0.05	0.87	0.08	0.53	0.42	0.4264	0.2139
lambcrop_US	4.09E+10	0.05	0	0.95	0	0.94	0.0369	0.0185
death_loss_US	5.01E+08	0.01	0.11	0.88	0.09	0.9	0.036	0.0179
newprice_sheep_live_us	0.0249	0	0.31	0.69	0	1	0.139	0.0696
Production_US	1.28E+14	0.01	0.16	0.84	0.1	0.89	0.0421	0.021
retailproduction	1.01E+14	0.01	0.16	0.84	0.1	0.89	0.0421	0.021
newretail_price_lamb_US	0.048	0.14	0.23	0.63	0.1	0.76	0.0393	0.0198
percapitacons_us	0.00258	0.1	0	0.9	0.1	0.8	0.0413	0.0208
cons_retail_us	1.90E+14	0.1	0.04	0.86	0.03	0.87	0.041	0.0207
Mlambpound_US	3.01E+14	0.15	0.11	0.74	0.04	0.81	0.1491	0.0759
TS_A	2.52E+13	0.03	0.04	0.94	0.01	0.96	0.0407	0.0204
BE_A	5.11E+12	0.03	0.04	0.94	0.01	0.96	0.0407	0.0204
OT_A	7.63E+12	0.03	0.04	0.94	0.01	0.96	0.0407	0.0204
SL_A	2.50E+12	0.01	0.07	0.91	0.01	0.97	0.05	0.0249
PP_LSWtUSdollarston_Anewreal	317.4	0.03	0.88	0.08	0.37	0.6	1.1894	0.519
NXML_A	4.07E+11	0	0.14	0.86	0.01	0.99	0.1256	0.0627
DL_A	3.41E+11	0.03	0.02	0.95	0	0.97	0.041	0.0206
LC_A	2.07E+13	0.02	0.11	0.86	0.02	0.96	0.0734	0.0369
production_A	9.76E+08	0.01	0.02	0.97	0.06	0.93	0.0497	0.0248
TotalconsA	1.36E+09	0.12	0.2	0.68	0	0.88	0.114	0.0559
Exportmeat_A	2.56E+09	0.03	0.16	0.81	0.02	0.95	0.1626	0.0827
Totalstock_NZ	1.95E+12	0.08	0	0.92	0	0.92	0.03	0.015
Othersheep	1.03E+12	0.1	0.02	0.88	0	0.9	0.0691	0.0349
Breeding__ewesNZ	6.75E+11	0.01	0	0.99	0	0.99	0.0257	0.0129
TotalSL_NZ	1.09E+12	0.04	0	0.96	0.03	0.93	0.0321	0.016
sheeplivepp_NZnewreal	4.3181	0.15	0.16	0.68	0	0.84	0.1464	0.0753
lamb_crop_NZ	1.74E+12	0.02	0	0.98	0.02	0.96	0.0368	0.0185
DL_NZ	1.34E+10	0.04	0.12	0.84	0.1	0.86	0.0261	0.013
NETExports_NZ	7.04E+10	0.01	0	0.99	0.05	0.94	0.3776	0.1925

Table 9. Continued

Variable	MSE	MSE Decomposition Proportions					Inequality Coefficient	
		Bias (UM)	Reg (UR)	Dist (UD)	Var (US)	Covar (UC)	U1	U
NZ_ConsTonnes	6.85E+08	0.01	0.19	0.8	0.01	0.98	0.1502	0.0746
production_NZ	3.01E+08	0.04	0	0.95	0.05	0.91	0.0319	0.0159
exporttonnes_NZ	6.89E+08	0	0.33	0.67	0.04	0.96	0.0706	0.0352
Mlambtonnes_US	61966315	0.15	0.11	0.74	0.04	0.81	0.1491	0.0759
ROW_M	2.25E+09	0.01	0.21	0.78	0.08	0.9	0.0733	0.0368
lamb_RP_Anew	0.2777	0.07	0.02	0.91	0.08	0.85	0.0539	0.0272
NZ_px_mnewreal	0.000028	0.11	0	0.89	0.05	0.85	0.1004	0.0511
perunitLPM	0.5671	0.12	0.19	0.69	0.05	0.83	0.1712	0.0875
US_farm_price	1954.4	0.06	0.75	0.19	0.45	0.49	0.5622	0.2715
Sheep_shorn_USml_lbs	0.0516	0.03	0	0.97	0	0.97	0.0296	0.0148
Prod_greasy_wool	3.0196	0.03	0	0.97	0	0.97	0.0292	0.0146
Productionwool	0.8503	0.03	0	0.97	0	0.97	0.0291	0.0146
Mill_use	67.1824	0.01	0.01	0.98	0	0.99	0.0771	0.0384
End_stocks	35.3471	0.02	0.04	0.94	0	0.98	0.1205	0.0608
US_farm_pricenew	0.3457	0.03	0.75	0.21	0.5	0.46	0.5776	0.2672
Netimport	67.3185	0	0.03	0.97	0.01	0.99	0.1337	0.0667
NeMTonnes_US	13850991	0	0.03	0.97	0.01	0.99	0.1337	0.0667
Aus_X	3.61E+09	0.02	0.09	0.89	0	0.98	0.1281	0.0646
Aus_wool_prod	8.59E+08	0.02	0.05	0.93	0.02	0.96	0.0401	0.0201
Aus_con	3.04E+09	0.01	0.02	0.98	0.13	0.87	0.198	0.0997
NZ_X	3.09E+08	0.04	0.16	0.81	0	0.96	0.2831	0.145
NZ_wool_prod	60041852	0.08	0.02	0.91	0	0.92	0.0295	0.0148
NZ_con	2.15E+08	0.01	0.08	0.92	0	0.99	0.0724	0.0361
Arg_X_tonnes	2.04E+09	0.06	0.92	0.02	0.68	0.26	2.2303	0.6134
Arg_total_stock	4.79E+11	0.02	0	0.98	0.01	0.97	0.0374	0.0187
Arg_con	2.02E+09	0.06	0.6	0.33	0.13	0.8	0.6304	0.3185
U_X	8.06E+08	0	0.94	0.06	0.5	0.5	2.086	0.6542
U_con	4.86E+08	0	0.61	0.39	0.17	0.83	0.3393	0.1677
U_ts	1.37E+12	0	0	0.99	0	1	0.0659	0.033
Uruguay_wool_prod	3.45E+08	0	0.02	0.97	0.56	0.44	0.2698	0.1384
ROW_W_M	2.70E+09	0	0.01	0.99	0.02	0.98	0.0906	0.0454
Aus_px_wnewreal	0.000067	0.12	0.02	0.86	0.01	0.87	0.1262	0.0646
NZ_px_wnewreal	0.000061	0.01	0.01	0.98	0.12	0.87	0.1395	0.0705
arg_px_wnewreal	0.00558	0.06	0.03	0.91	0.02	0.92	0.4618	0.2461
U_px_wnewreal	27.0612	0.05	0.33	0.62	0.15	0.8	0.49	0.2298

CHAPTER V

SIMULATION ANALYSIS OF THE LAMB CHECKOFF PROGRAM

The primary objectives of this study are to analyze the impact of the lamb checkoff program over time on U.S. and world sheep, lamb, and wool markets in the context global supply chains and to measure the returns to lamb industry stakeholders from their contributions to the lamb checkoff program. The first step in evaluating the benefit of the lamb checkoff program to those who pay for the program was to isolate the effects of the checkoff investments on U.S. and world sheep, lamb, and wool markets from those of all other events that may have affected those markets over the years. This was accomplished by simulating the econometric model of U.S. and world sheep, lamb, and wool markets (referred to as LamMod) over the 1987 to 2011 period *with* and *without* the checkoff expenditures and comparing the results. The baseline simulation used to validate LamMod as discussed in Chapter 3 represents the "with checkoff" expenditures scenario.

For the "without checkoff" expenditures scenario, the level of lamb checkoff expenditures in the U.S. lamb demand equation were set to zero in the model in each year from 1987 through 2011. LamMod was then simulated over the historical period to generate changes in the levels of U.S. and world sheep, lamb, and wool production, consumption, trade, and prices that would have existed over time in the absence of any checkoff expenditures. With no exogenous variable in LamMod other than lamb checkoff promotion expenditures was allowed to change as the two simulation scenarios were conducted, this process effectively isolated the impacts of lamb promotion expenditures on the many endogenous variables in the model. The simulated differences between the values of the endogenous variables in the baseline solution ("with checkoff" expenditures) and in the zero expenditure scenario ("without checkoff" expenditures) provide direct measures of the historical effects of the lamb checkoff expenditures on U.S. and world sheep, lamb, and wool markets.

Although the simulation analysis demonstrates the magnitude of the effects of the lamb checkoff promotion program on world sheep, lamb, and wool markets, the important question for lamb industry stakeholders who pay the costs of the program with their checkoff assessments is whether the market effects have generated sufficiently large additional net revenues to them to justify their respective contributions to the cost of the program. The standard method to address the question of stakeholder returns from a commodity checkoff program is to calculate the benefit-to-cost ratio (BCR) (i.e., the *average* return per dollar spent on the checkoff program) for each contributing group. After reviewing the simulated global impacts of the lamb checkoff program, the simulation results will be used to calculate the returns to stakeholders. Recall from Chapter 2 that 3 groups in the U.S. sheep industry are required to pay checkoff assessments: (1) sheep producers on the sale of their sheep, (2) feeders on the sale of their slaughter sheep to lamb packers, and (3) lamb packers on the purchase of slaughter sheep. Following the discussion of the global markets effects of the program, in addition to an overall BCR to the lamb checkoff program, BCRs at the producer, feeder, and packer level are also calculated and discussed. The chapter concludes with a summary of the main findings of the simulation analysis.

Global Sheep, Lamb, and Wool Market Effects of the U.S. Lamb Checkoff Program

A comparison of the changes in the endogenous variables in LamMod under the *with checkoff* and *without checkoff* scenarios indicates clearly that the lamb promotion expenditure has been effective in increasing the U.S. supply of live sheep, the U.S. lamb crop, the number of feeder lambs and slaughter sheep, lamb production , lamb consumption, and sheep and lamb prices. The results indicate that, on average between 1987-2011, breeding sheep inventories were 2.4% higher in each year than would have been the case in the absence of the U.S. lamb promotion expenditures (table 10). The lamb crop was higher by 3.8%, lambs on feed by 2.8%, lambs slaughtered by 4.5%, lamb production by 4.6%, lamb imports by 0.17%, consumption by 3.6%, and per capita lamb consumption by 3.5%, the producer price of live sheep by 3.3%, and the retail price of lamb by 0.9% on average in each year as a result of the checkoff program. Note that while both domestic lamb consumption and imports increase, lamb consumption increases by more than imports implying that that the lamb checkoff program has effectively worked to reduce the lamb import share of domestic consumption, a result consistent with the findings of Williams, Capps and Dang (2010).

With respect to world sheep, lamb, and wool markets, the impacts of the U.S. lamb checkoff program operate primarily through the changes registered in U.S. lamb and wool prices and imports. The 1.38 million pound increase in U.S. lamb imports generated by the checkoff program lead to increased sheep and lamb meat production and higher sheep and lamb prices in both Australia and New Zealand as well as lower domestic lamb consumption from the higher prices (table 11). The percentage impacts on Australia's and New Zealand's sheep and wool industry are quite small because the absolute changes generated by the U.S. checkoff program are small and the size of their industries are so much larger than that of the United States. The results demonstrate that the U.S. lamb checkoff program provides benefits to the Australian and New Zealand sheep industries in terms of larger live sheep inventories, slaughter, lamb exports, and sheep and lamb prices. The higher U.S. demand for lamb imports from Australia and New Zealand as a result of the U.S. lamb checkoff program stimulated an increase in sheep slaughter in the two countries of 11,584 head (0.03%) and 22,014 head (0.07%), on average in each year over the 1987-2011 period of analysis. Lamb production in the two countries was consequently higher by 248 and 263 metric tons, respectively, over the same period. The increase in slaughter demand led to larger average annual Australian breeding sheep inventories and lamb crop by about 12,102 head (0.05%) and 17,782 head (0.02%), respectively, than would have been the case without the U.S. lamb checkoff program. In New Zealand, sheep inventories and the lamb crop were higher by 16,825 head (0.06%) and 19,560 head (0.06%), in each year on average than would have been the case. The higher demand for lamb for export to the U.S. also raised the Australian and New Zealand prices of live sheep by 0.25 Australian dollars/mt (2.7%) and 0.15 New Zealand dollars/mt (3.2%), respectively.

Table 10. Effects of Lamb Checkoff Expenditures on U.S. Sheep Market

	1987-2002		**2003-2011**		**1987-2011**	
Average Annual Change in:	**head**	**%**	**head**	**%**	**head**	**%**
Breeding Sheep Inventories	120,571	1.7	135,834	3.2	**126,294**	**2.4**
Mature Ewe Inventories	61,020	1.1	86,585	2.5	**706,077**	**1.8**
Replacement Ewe Numbers	27,684	2.5	28,670	4.2	**28,054**	**3.4**
Feeder Lamb Numbers	44,946	2.8	54,777	3.1	**51,091**	**2.9**
Lamb Crop	160,265	3	189,431	4.6	**171,202**	**3.8**
Sheep/Lamb Slaughter	203,555	4	210,941	5	**206,325**	**4.5**
	mil.lbs		**mil.lbs**		**mil.lbs**	
Lamb Production	10.1	4.1	11.1	5.5	**10.5**	**4.6**
Lamb Consumption	11.5	3.5	11.9	3.7	**11.6**	**3.6**
Lamb Imports	1.39	0.18	1.37	0.16	**1.38**	**0.17**
Wool Production	0.93	1.7	1.01	3.1	**0.96**	**2.1**
Wool Consumption	1.25	0.01	1.3	0.01	**1.27**	**0.01**
Wool Imports	0.32	0.08	0.29	0.05	**0.31**	**0.06**
	lb/person		**lb/person**		**lb/person**	
Lamb Per Capita Consumption	0.38	3.4	0.4	3.6	**0.39**	**3.5**
Prices	**$/unit**		**$/unit**		**$/unit**	
Live Sheep ($/head)	2.65	3.2	4.59	3.4	**3.38**	**3.3**
Lamb Meat ($/lb)	0.05	1	0.03	0.9	**0.4**	**0.9**

Table 11. Effects of Lamb Checkoff Expenditures on World Sheep Market

	1987-2002		2003-2011		1987-2011	
Annual Average Change in	**head**	**%**	**head**	**%**	**head**	**%**
Australia Breeding Sheep	11,009	0.02	13,922	0.04	**12,102**	**0.5**
New Zealand Breeding Sheep	16,553	0.05	17,277	0.07	**16,825**	**0.06**
Australia Lamb Crop	17,369	0.02	18,469	0.03	**17,782**	**0.02**
New Zealand Lamb Crop	18,714	0.05	20,970	0.07	**19,560**	**0.06**
Australian Slaughter	11,467	0.03	11,780	0.04	**11,584**	**0.03**
New Zealand Slaughter	20,918	0.06	23,842	0.08	**22,014**	**0.07**
	tonnes	**%**	**tonnes**	**%**	**tonnes**	**%**
Australia Lamb Production	247	0.04	249	0.05	**248**	**0.04**
New Zealand Lamb Production	257	0.06	277	0.09	**263**	**0.07**
Australia Lamb Consumption	-73	-0.02	-68	-0.02	**-71**	**-0.02**
N Z Lamb Consumption	-106	0	-68	-0.04	**-93**	**-0.05**
Prices	**Local Currency /mt**	**%**	**Local Currency /mt**	**%**	**Local Currency /mt**	**%**
Australia Sheep Price	0.26	2.9	0.24	2.6	**0.25**	**2.7**
New Zealand Sheep Price	0.02	2.7	0.01	1.7	**0.15**	**3.2**
U.S. Lamb Import Price ($/mt)	0.28	2.4	0.26	2.3	**0.27**	**2.3**
Trade	**tonnes**	**%**	**tonnes**	**%**	**tonnes**	**%**
Australia Lamb Exports	320	0.01	317	0.01	**319**	**0.01**
New Zealand Lamb Exports	363	0.1	345	0.09	**356**	**0.09**
U.S. Lamb Imports	630	0.18	621	0.16	**626**	**0.17**

To contrast the market and trade effects before and after the implementation of the mandatory checkoff program in 2003, tables 10 and 11 also decompose the effects of the lamb checkoff program into two time periods: (1) 1987-2002 prior to the implementation of the mandatory checkoff program and (2) 2003-2011 since the mandatory program was initiated. The results indicate that the mandatory program had a somewhat more positive effect each year on U.S. sheep inventories and slaughter, lamb production and consumption, and wool production and consumption as well as on the live sheep and lamb prices than was the case for the voluntary checkoff program in previous years. The import-increasing effect of the checkoff was somewhat smaller during the mandatory period, however, than during the voluntary program period. Williams, Capps and Dang (2010) also found that the mandatory checkoff program had a somewhat larger effect on lamb consumption than was the case for the voluntary program in preceding years.

Benefit-Cost Analysis

The preceding simulation analysis clearly demonstrates that the lamb checkoff program has had a significant and positive effect on the U.S. sheep, lamb, and wool industries. The more critical question that must be answered about the U.S. lamb checkoff program is whether any gains in profit realized by industry stakeholders as a result of the program have been sufficient to more than pay for their costs in financing the program. That is, has the program run at a loss or a profit over time from the perspective of those who have paid for the program? Have the market effects induced by the checkoff program been substantial enough to generate sufficient additional profits to stakeholders over time to more than cover their cost in financing the checkoff program? If not, then the conclusion would be that the program should be discontinued because the program costs stakeholders more than it returns to them. On the other hand, if the profits generated more than cover the costs, the program would be deemed a successful investment opportunity for stakeholders in the sheep and lamb industry.

This section, then, provides a benefit-cost analysis of the lamb checkoff program to answer these questions based on the results of the scenario analysis discussed in the previous section of this chapter. First, the formulas for calculating the benefit cost ratio for the lamb checkoff program across all contributors and by individual contributors are discussed. Then the results of those calculations are presented and discussed.

Benefit-Cost Formulas

A checkoff Benefit Cost Ratio (BCR) is calculated as the additional industry profits (additional revenues net of additional production costs and checkoff assessments) earned by stakeholders as a consequence of the checkoff expenditures as measured through the scenario analysis divided by the historical level of checkoff expenditures made to generate those additional profits. The general formulation for a Benefit-Cost Ratio is:

(1) $$\text{BCR} = \frac{\sum_{t=1}^{T}(R_t - C_t - E_t)}{\sum_{t=1}^{T} E_t}$$

where R is the additional revenues generated by the checkoff program, C is the additional costs required to generate the additional revenue (such as cost of production), and E is the checkoff program expenditures.

Simplifying equation (1) gives:

(2) $\text{BCR} = \frac{\sum_{t=1}^{T}(R_t - C_t)}{\sum_{t=1}^{T} E_t} - 1.$

For the lamb checkoff program, there are 3 sets of stakeholders who pay the costs of the checkoff program through the assessments they pay to the American Lamb Board: (1) sheep producers, (2) lamb feeders, and (3) lamb packers (see Chapter 2 for a discussion of the lamb checkoff program funding). Consequently, the checkoff-induced revenue that has accrued to each of the three groups of stakeholders (net of production costs and checkoff expenditures) must be calculated from the simulation results, summed, and then divided by total lamb checkoff expenditures to calculate an industry-wide BCR.

The additional net revenue to <u>sheep and lamb producers</u> as a result of the lamb checkoff program in a given time period (RP) is the sum of the additional revenue they earn from additional sales of lambs and sheep and the additional sale of wool produced minus the additional costs of production related to additional inventories of sheep and lambs and the cost of shearing additional sheep in a given time period. RP can be calculated as follows (assuming all variables are subscripted by t for a given time period):

(3) $RP = \left(P_f^b Q_f^b + P_w^b Q_h^b - C_f Q_f^b - C_w Q_h^b\right) - (P_f^s Q_f^s + P_w^s Q_h^s - C_f Q_f^s - C_w Q_h^s)$

where P is price per unit or per head, Q is quantity sold or number of head, and C is cost of production per unit or per head; the subscripts f, w, and h refer to feeder lambs and sheep, wool, and sheep shorn, and the superscripts b and s refer to baseline simulation value (*"with expenditures"* scenario) and scenario simulation value *("without expenditures"* scenario), respectively.

The first parenthesis in equation (1) is calculated from the baseline simulation values (the *"with expenditure"* scenario) while the calculation in the second parenthesis uses the scenario simulation values (the *"without expenditures"* scenario). In both parenthesis in equation (1), $P_fQ_f + P_wQ_h$ is the sum of the revenue earned by producers from the sale of feeder lambs and the sale of wool while $C_fQ_f + C_wQ_h$ is sum of the cost of producing feeder lambs and shearing sheep for wool. Thus, the additional net returns to producers (RP) generated by the checkoff program over the period of analysis (1987-2011) is the difference between the net revenue earned by producers <u>with</u> and <u>without</u> the lamb checkoff program in place. Unfortunately, a time series of U.S. sheep production costs (C_f) is not available. An estimate of $61.65/head for the cost of sheep production for 2008 by Thomas (2008) was multiplied by the index of prices paid by producers published by (NASS,USDA, various years) (rebased to 2008) to generate a times series for the cost of sheep production over the simulation period. An estimate of $3.15/head was provided as the cost of shearing per head (C_w), for 2008 from the same study was likewise multiplied by the rebased index of prices paid by producers to generate a time series representing the cost of shearing sheep per head over the simulation period.

The additional net revenue to <u>lamb feeders</u> in a given time period as a result of the lamb checkoff program (RF) in a given time period is the additional revenue they earn from additional sales of slaughter lambs to packers minus the additional costs they accrue from purchasing additional feeder lambs from producers and the additional costs of production associated with feeding additional lambs to slaughter weights. RF can be calculated as follows (assuming all variables are subscripted by t for a given time period):

(4) $RF = \left(P_g^b Q_g^b - P_f^b Q_f^b - C_f Q_g^b\right) - (P_g^s Q_g^s - P_f^s Q_f^s - C_f Q_g^s)$

where P is price per head, Q is number of head, and C is cost per head of feeding lambs to slaughter weight; the subscripts g and f refer to slaughter sheep and feeder lambs, respectively; and the superscripts b and s refer to baseline simulation value *("with expenditures"* scenario) and scenario simulation value *("without expenditures"* scenario), respectively.

As with equation (1), the first parenthesis in equation (2) is calculated from the baseline simulation values (the *"with expenditure"* scenario) while the calculation in the second parenthesis uses the scenario simulation values (the *"without expenditures"* scenario). In both parenthesis in equation (2), P_gQ_g is the revenue earned by feeders from the sale of slaughter sheep to packers while $P_fQ_f + C_fQ_g$ is sum of the cost of the feeder lambs to the feeder and the cost of feeding lambs to slaughter weights. The additional net returns to feeders (RF) generated by the checkoff program over the period of analysis (1987-2011) is the difference between the net revenue earned by feeders with and without the lamb checkoff program in place. The cost per head of feeding lambs (C_f) was taken from information provided by Anderson(2013) and was monthly starting from April 1987 through October 1996. The yearly averages were taken and then forecasted till 2011.

The additional net revenue to lamb slaughterers (or packers) in a given time period as a result of the lamb checkoff program (RS) in a given time period is the additional revenue they earn from additional sales of lamb meat minus the additional costs they accrue from purchasing additional slaughter sheep and the additional costs of production associated with slaughtering additional slaughter sheep. RS can be calculated as follows (assuming all variables are subscripted by t for a given time period):

$$(5)\quad RS = \left(P_m^b Q_m^b - P_g^b Q_g^b - C_g Q_g^b\right) - \left(P_m^s Q_m^s - P_g^s Q_g^s - C_g Q_g^s\right)$$

where P is price per lb or per head, Q is number of head or number of pounds, and C is cost per head to packers of slaughtering sheep; the subscripts m and g refer to lamb meat and slaughter sheep, respectively; and the superscripts b and s refer to baseline simulation value (*"with expenditures"* scenario) and scenario simulation value (*"without expenditures"* scenario).

As with equations (1) and (2), the first parenthesis in equation (3) is calculated from the baseline simulation values (the *"with expenditure"* scenario) while the calculation in the second parenthesis uses the scenario simulation values (the *"without expenditures"* scenario). In both parenthesis in equation (5), P_mQ_m is the revenue earned by packers from the sale of lamb meat while $P_gQ_g + C_gQ_g$ is sum of the cost of the slaughter sheep to lamb packers and the cost of processing the slaughter sheep to packers. The additional net returns to packers (RS) generated by the checkoff program over the period of analysis (1987-2011) is the difference between the net revenue earned by lamb packers with and without the lamb checkoff program.

A time series for lamb processing costs per head (C_g) is also unavailable. A lamb processing cost of $31.50/head has been used by USDA in its Weekly National Lamb Market report since its inception. Assuming that the processing cost is correlated with the cost of labor, the employment cost index for all civilian workers for both farms and non-farms (employment cost index for total compensation, by ownership, occupational group, and industry rebased to the year 2005) (BLS 2013) was multiplied by the USDA lamb processing cost estimate to generate a lamb processing cost/head series for the entire simulation period of 1987-2011.

Using these measures of the returns to stake holders, several Benefit-Cost Ratios (BCRs) can be calculated. The Benefit-Cost Ratio that measures the return to the lamb checkoff program across all stake holders (producers, feeders, and packers), net of their contributions to the checkoff program expenditures, is referred to as the Total Benefit-Cost Ratio (TBCR) and is calculated as:

$$(6)\quad \text{TBCR} = \frac{\sum_{t=1}^{T}(RP_t + RF_t + RS_t)}{\sum_{t=1}^{T} ET_t} - 1$$

where ET is the sum of the checkoff expenditures from funds contributed by all three stakeholder groups.

In the same way, the BCR to each stakeholder group can be calculated as the sum of the returns to each group over the simulation period divided by the respective group's contribution to the checkoff expenditures. Thus, the producer BCR (PBCR) is calculated as:

(7) $\text{PBCR} = \frac{\sum_{t=1}^{T} RP_t}{\sum_{t=1}^{T} EP_t} - 1$

where EP is the share of the checkoff expenditures funded by contributions from sheep producers. The feeder BCR (FBCR) is calculated similarly as:

(8) $\text{FBCR} = \frac{\sum_{t=1}^{T} RF_t}{\sum_{t=1}^{T} EF_t} - 1$

where EF is the share of the checkoff expenditures funded by contributions from lamb feeders. Finally, the packer or slaughterer BCR is calculated as:

(9) $\text{SBCR} = \frac{\sum_{t=1}^{T} RS_t}{\sum_{t=1}^{T} ES_t} - 1$

where ES is the share of the checkoff expenditures funded by contributions from lamb packers.

Data for lamb advertising and promotion expenditures since July 2002 when the national lamb checkoff program began operations were provided by ALB (2013). Lamb promotion expenditures in the years before the national lamb checkoff program were provided by ASIA (2013). The checkoff expenditures attributable to each stakeholder group in each time period were calculated from total expenditures assuming that those expenditures were proportional to the number of animals on which each group were assessed a checkoff fee:

(10) $E_{it} = \frac{Q_{it}}{\sum_{t=1}^{T} Q_{it}}$

where E is checkoff expenditures, i = checkoff contributors (producers, feeders, and packers), and Q is the number of head on which a contributor group paid a checkoff assessment. As discussed earlier and in Chapter 2, producers are assessed a checkoff on feeder lambs (Q_f in equations (3) and (4) above), feeders are assessed a checkoff on slaughter lambs (Qg in equations (4) and (5) above), and packers also on slaughter lambs (aslo Qg in equations (4) and (5) above). As has been done by various studies of the return to commodity checkoff programs (Williams and Nichols 1998; Williams et.al. 2010), the lamb checkoff BCR and the BCRs for each stakeholder group can be discounted to account for the time value of money. A discounted BCR (DBCR) is calculated by discounting the net returns generated over time to present value before dividing by total promotion expenditures:

(11) $$\text{DBCR} = \frac{\sum_{t=1}^{T}(R_t - C_t - E_t)/(1+i)^t}{\sum_{t=1}^{T} E_t}$$

where i is the interest rate chosen to discount the net revenue to present value, R is the additional revenue generate by the checkoff program (total or for individual checkoff stakeholder groups). In this study, the 30-day Treasury bill interest rates over time were used to discount the net revenue. The Treasury Bill rate was used simply because it represents a realistic alternative investment rate for the period of analysis.

Benefit-Cost Analysis Results

The BCRs for the lamb checkoff program, calculated as discussed above, clearly indicate that the program has benefited the U.S. lamb industry as a whole and each contributor group as well (table 12). Over the period of analysis (1987-2011), the lamb checkoff program returned $27.74 per checkoff dollar spent on promotion. The results also indicate that returns per dollar spent on promotion were higher during the more recent period of the national checkoff program ($34.97) than was the case under the previous program funded by the wool subsidy ($24.14). The per dollar returns to each contributor were quite similar over the period of analysis at $27.52 to producers, $26.35 to feeders, and $27.78 to slaughterers. The returns to each contributor group were also higher in the more recent period of the national checkoff program ($34.57, $34.73, and $35.46) than in the period before the national program ($23.57, $22.76, and $24.38). The Discounted BCR (DBCR) across all programs was lower than the corresponding non-discounted BCR because the revenue stream over the years generated by the checkoff program is discounted to present value. Present value, also called "discounted value" is the current worth of a stream of cash flow (such as the stream of revenue generated by the lamb checkoff program) over time given a specified rate of return, referred to as the "discount rate". The higher the discount rate, the lower the present value of the cash flows. The present value of a cash flow, or stream of revenue in this case, is usually less than the actual or "future" value of those revenues because money has interest-earning potential, a characteristic referred to as the time value of money, described aptly by the well-known phrase that "a dollar today is worth more than a dollar tomorrow."

Table 12. Lamb Checkoff Program Benefit-Cost Analysis

	1987-2002	2003-2011	1987-2011
	$ net return/$spent	$ net return/$spent	$ net return/$spent
Benefit-Cost Ratios			
Total (BCR)	24.14	34.97	27.74
Producers (PBCR)	23.57	34.57	27.52
Feeders (FBCR)	22.76	34.73	26.35
Slaughterers (SBCR)	24.38	35.46	27.78
Discounted BCRs			
Total (DCBR)	14.14	14.16	14.15
Producers (PDBCR)	18.7	13.66	16.9
Feeders (FDBCR)	13.13	12.81	13.03
Slaughters (SDBCR)	13.4	15.89	14.17

Such is the case because each dollar could be invested and earn a day's worth of interest, making the total accumulate to a value more than a dollar by tomorrow. To calculate present value, the accumulated interest that might have been earned if those funds had been invested must be deducted from the revenue stream. The result is the return that was actually earned from the checkoff program since any income generated by the checkoff-earned revenue has been subtracted. In this sense the DBCR may be a more realistic measure of the return generated by the checkoff program per dollar of checkoff funds spent.

Summary of Findings

The simulation results presented in this chapter indicate that the lamb checkoff promotion program clearly enhanced the demand for lamb in the United States, a result consistent with those of Williams, Capps and Dang (2010). This study, however, provides the first measure ever of the impact of the lamb checkoff program beyond its effects on consumption. The study finds that the increase in lamb demand stimulated an increase in the price of lamb and transmitted enhanced value all along the U.S. sheep, lamb, and wool industry to packers, feeders, and producers.

This study also confirms that the lamb checkoff program has stimulated additional lamb imports and, therefore, provided "free rider" benefits to the Australian and New Zealand sheep and lamb industries. The "free rider" benefits, have been much smaller than those accruing to the U.S. sheep and lamb industry, resulting in growth of the U.S. sheep and lamb industry relative to that of Australia and New Zealand. The increase in lamb imports as a result of the checkoff program have been smaller than the increase in U.S. lamb consumption, leading to a checkoff-induced decline in the import share of U.S. lamb consumption. The results also show that the market effects and returns from the lamb promotion expenditures have been greater since the implementation of the national checkoff program. The lamb checkoff program has worked effectively against myriad factors that have combined to contract the U.S. sheep industry over the years. While the limited size of lamb checkoff expenditures has been insufficient to reverse the downward trend in inventories, production, and prices, the program has effectively slowed that trend. The program has worked to increase the share of lamb consumption from domestic production. In the process, the program has generated impressive returns to all stakeholders.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The U.S. sheep industry has suffered an almost constant decline in sheep and lamb inventories from a record of 56 million head in the early 1940s to only 5.54 million head in 2011. The steady decline of the industry can be attributed to a confluence of many factors, such as lower returns and higher production risks relative to other livestock and crop enterprises, a shift in consumer tastes and preferences toward other meats, the high cost and scarcity of qualified sheep shearers, and the discontinuation of the U.S. Wool Incentive payment program among many others (Williams et al. 2008). With the historical contraction of sheep inventories, U.S. sheep and lamb slaughter, lamb production, and lamb consumption have also steadily declined over the years. Lamb production declined by 48% over the period of analysis in this study (1987 to 2011). Lamb consumption has dropped by less over the same period (23%), however, as imports from Australia and New Zealand have gained a growing market share.

The decline in the production and the consequent rise in imports have prompted the sheep industry to undertake various actions over the years to grow its market and protect its market share. Domestic policies like the National Wool Act of 1954 were crafted to bolster the U.S. sheep industry and enhance the demand for sheep products. Section 708 of the National Wool Act of 1954 allowed for a portion of wool incentive payments to sheep producers to be directed towards promoting domestic lamb consumption.

Conducted under the direction of the American Sheep Producers Council (now known as the American Sheep Industry Association), lamb promotion activities came to a halt when the wool incentive program was phased out in 1996/97. A few years later, the U.S. lamb industry filed a section 201 complaint against Australia and New Zealand lamb imports which resulted in the imposition of a three-year tariff-rate quota (TRQ) in 1999 on lamb imports from Australia and New Zealand. The inside tariff was set at 9% in the first year and reduced to 6% in the second year and 3% in the third year. Outside tariff rates were set at 40% in the first year declining to 32% in the second year, and 24% in the third year. The revenue collected from the tariff was used to fund various projects benefitting the U.S. lamb industry including some lamb promotion programs during those three years. Then, in the year following the end of the lamb TRQ, the lamb industry approved a referendum to establish a U.S. lamb checkoff program which began in 2002/03.

From the implementation of the lamb checkoff program through 2011, the American Lamb Board spent a total of about $13 million on lamb advertising and promotion. The main objective of the program is to increase demand for "American" lamb rather than lamb in general which includes imported lamb (ALB 2013). The success of the lamb current checkoff program may be measured by determining whether the U.S. demand for lamb has increased as a result of the checkoff program and, if so, whether the increase has been of U.S. or foreign origin. Even if the program has successfully increased the demand for "American" lamb, whether or not the program could be deemed a success also depends on whether the cost required to increase the demand (in terms of expenditures of checkoff funds) has been greater or less than the additional net revenue to the industry that the program has generated. That is, if the program cost stakeholders more than they received in revenues as a result of the program (net of any additional costs), then the program could not be termed successful even if lamb demand increased as a result. This study focused on the answers to these questions with particular interest in the share of any benefits received by stakeholders up and down the U.S. sheep-lamb supply chain in the context of the global sheep-lamb-wool supply chain within which it operates.

Hypotheses

Before attempting an empirical analysis of the global effects of the U.S. lamb checkoff program, a conceptual model of world sheep and lamb markets was developed in Chapter 3 and used to derive hypotheses about the program's effects. The conceptual analysis concluded that a checkoff-induced increase in the U.S. demand for lamb would unambiguously increase U.S. imports of lamb but whether or not the U.S. price of lamb would increase depended on the magnitude of the sheep and lamb supply responses in both the U.S. and foreign countries. The conceptual analysis demonstrated that, theoretically, the lamb checkoff could result in a higher, lower, or unchanged price of lamb in U.S. and foreign markets.

The conceptual analysis also concluded that a checkoff-induced increase in the U.S. demand for lamb meat would lead to an increase in the number of U.S. sheep produced andin the U.S. production of lamb meat and wool. At the same time, the U.S. lamb promotion program would have a tendency to increase the number of sheep produced in both Australia and New Zealand leading to additional lamb meat and wool production in those countries. As a consequence, exports of both lamb and wool from Australia and New Zealand to the U.S. and elsewhere would increase. U.S. lamb and wool imports would increase as a result. The price of wool in all markets would unambiguously decline and have a moderating effect on the increase in Australian and New Zealand sheep and lamb production.

Procedures

Based on the conceptual model a 70-equation, non-spatial, price equilibrium global sheep and lamb model, referred to as LamMod, was developed in Chapter 4. The equation specifications were posited for LamMod, the structural and functional relationships were postulated, and the data necessary for econometrically deriving the model coefficients were identified and collected. The common set of usable data was determined to be 1987 through 2011. Using these data, the coefficients of LamMod were estimated econometrically using the Ordinary Least Squares estimator due to the large size of the structural model and limited data availability. The econometric results and related regression statistics were presented and discussed in Chapter 5. The SAS statistical software was used for the analysis.

After estimating the parameters, the model was simulated over the sample period (1987 through 2011) as a means of validating the model developed. Dynamic within-sample simulation statistics, including the mean squared error (MSE), root mean squared error (RMSE), and Theil inequality coefficients were calculated and discussed. The MSE and its decomposition indicated the absence of any systematic bias of the simulated model variables. Also, the Theil U statistics were close to zero. Taken together, the simulation statistics suggested that the ability of the LamMod to replicate the observed values of the endogenous variables over time is highly satisfactory. As a consequence, the model can be used with a high degree of confidence for simulation analyses, such as the effects of a change in the level of checkoff funding on the global sheep-lamb-wool supply chain.

Chapter 5 provided the results of using the validated LamMod to measure of the impact of lamb checkoff promotion expenditures on the global sheep-lamb-wool supply chain lamb and to calculate the returns to the stakeholders who pay for the checkoff program. The first step in the analysis was to use the model to generate a baseline historical simulation of the various endogenous variables in the model, such as sheep, lamb, and wool production, consumption, trade, and prices, over the sample data period. The results of this simulation were referred to as the "*with expenditures*" scenario or the baseline scenario because the simulation assumes that the checkoff expenditures to enhance U.S. lamb demand were made as actually occurred over time. The second step was to set lamb checkoff expenditures in the model to zero in every year and then simulate the model over time again to see how the model endogenous variables changed as a result of the removal of the checkoff expenditures from the model. The results of this simulation were referred to as the "*without expenditures*" scenario because the simulation assumes that the checkoff expenditures to enhance U.S. lamb demand were not made as actually occurred over time. In other words, this simulation assumed that the lamb checkoff program did not exist over the sample period (1987-2011). The differences between the simulated values of the corresponding endogenous variable in the two simulations provided a measure of the change not only in U.S. lamb demand but also in all other model variables that have occurred over time as a direct result of the lamb checkoff program.

The simulation allowed a measurement of the extent of the impact of the checkoff program on U.S. lamb demand, imports, and other activities along the global sheep-lamb-wool supply chain. A critical question to be answered to determine the successfulness of the lamb checkoff program is whether any gains in profit realized by industry stakeholders as a result of the program have been sufficient to more than pay for their costs in financing the program. That is, has the program run at a loss or a profit over time from the perspective of those who have paid for the program? Have the market effects induced by the checkoff program been substantial enough to generate sufficient additional profits to stakeholders over time to more than cover their cost in financing the checkoff program? If not, then the conclusion would be that the program should be discontinued because the program costs stakeholders more than it returns to them. On the other hand, if the profits generated more than cover the costs, the program would be deemed a successful investment opportunity for stakeholders in the sheep and lamb industry.

To determine the profitability or return from checkoff program to the program stakeholders (producers, feeders, and packers), the result of the two simulation scenarios in Chapter 5 were used to calculate benefit-cost ratios (BCRs) to the U.S. sheep and lamb industry as a whole and to each program stakeholder group. The relevant BCR formulas for each stakeholder along the U.S. supply chain (producers, feeders, and stakeholders) were first defined. The results of the two simulation scenarios were then used to calculate the BCRs as the increase in net revenues accruing to the U.S. sheep and lamb industry per dollar of expenditure as well as to each stakeholder group per dollar of expenditure attributable to the corresponding stakeholder group.

Results

The signs of all parameter estimates of LamMod were consistent with expectations and conformed to economic theory as discussed in Chapter 4. Also, the Durbin Watson statistics (DW) and Durbin-h statistics indicated the absence of autocorrelation in all behavioral equations. The adjusted R^2s indicated that most LamMod equations provide a good fit of the associated data. The p-values indicated statistical significance of most key endogenous variable in each equation of the model. The structural parameter estimates were used to calculate the elasticities of sheep, lamb, and wool supply and demand in the U.S., Australia, and New Zealand. The short-run and long-run price elasticities are particularly important because they provide insight into the responsiveness of the various segments of the global sheep-lamb-wool supply chain to shocks to the system over time, such as changes in the level of checkoff funding. Some key (short-run) elasticity findings included the following:

- The elasticity of the U.S. sheep breeding (mature ewe) inventory with respect to the live sheep price was estimated to be quite low (0.11) but more than double that of Australia (0.05) and New Zealand (0.03) and more than 5 times that of Argentina (0.02) and Uruguay (0.02);
- The wool price elasticity of the U.S. sheep breeding (mature ewe) inventory is also low (0.01) but comparable to that of Australia (0.03) and much lower than that of New Zealand (0.14);
- The elasticity of U.S. sheep slaughter demand to the price of live (slaughter) sheep (-0.20) and to the retail price of lamb (0.77) were highly similar to those same slaughter demand price elasticities in both Australia (-0.2 and 0.68) and New Zealand (-0.18 and 0.56);
- The U.S. demand for feeder lambs is inelastic with respect to both the live sheep price (-0.15) and to the slaughter sheep price (0.15);
- The U.S. demand for lamb is somewhat more inelastic with respect to the retail price of lamb (-0.62) than is the case in Australia (-0.89) and in New Zealand (-0.79).
- Beef is clearly considered a substitute for lamb in the U.S., Australia, and New Zealand and the beef cross-price elasticities in the three countries are remarkably similar (0.46, 0.40, and 0.47, respectively);
- Pork was found to be another substitute for lamb in the United States (cross-price elasticity of 0.47) while chicken was found to be an additional substitute for lamb in Australia (cross-price elasticity of 0.43);

- Income was found to be a highly significant determinant of lamb consumption in both Australia and New Zealand (income elasticities of 0.62 and 0.80.). Such was not the case for the United States, income was consistent with most existing empirical work on U.S. lamb demand;
- The estimated checkoff expenditure elasticity of lamb demand was 0.037, a value consistent with what has been found for most other checkoff commodity programs; and
- The own-price elasticity of the U.S. mill demand for wool is quite low (-0.02) compared to that in Australia (-0.55) and New Zealand (-0.60).

The results of simulating the effects of the lamb checkoff program on the global sheep-lamb-wool supply chain suggest that the program has effectively enhanced the U.S. consumption of lamb and has augmented the profits accruing to sheep and lamb producers, feedlot operators, and slaughterers. With respect to the two main objectives posed at the beginning of this dissertation, the key findings include the following:

Effects of U.S. Lamb Checkoff Program on the Global Sheep-Lamb-Wool Supply Chain

- In the U.S., the average annual lift[2] of the checkoff program was:
    - breeding sheep inventories by 2.2%;
    - lamb crop 4.8%;

[2] The "lift" is how much higher production, price or other variable was in each year on average over the sample period (1987-2011 in this study) than would have been the case in the absence of the program.

- lambs on feed by 2.9%;
- sheep slaughtered by 4.4%;
- lamb production by 4.5%;
- lamb imports by 0.9%;
- lamb consumption by 3.6%; and
- price of live sheep by 3.3% and retail price of lamb by 0.8%.

● U.S. lamb consumption increased by more than imports over the period of analysis implying that that the lamb checkoff program has effectively worked to reduce the lamb import share of domestic consumption, a result consistent with the findings of Williams, Capps and Dang (2010).

● Checkoff expenditures during the mandatory checkoff program years (2003-2011) created somewhat more lift along the U.S. sheep-lamb-wool chain than was the case in pre-mandatory years.

● The import-increasing effect of the checkoff program was somewhat smaller during the mandatory period than in preceding years, a result consistent with Williams, Capps and Dang (2010).

● The checkoff program also created some lift in Australia and New Zealand as well but to a lesser extent. The average annual lift in Australia and New Zealand was:

- breeding sheep inventories by 0.5% and 0.06%,;
- lamb crop by 0.2% and 0.06%,;
- sheep slaughter by 0.3% and 0.07%,;
- lamb production by 0.04% and 0.07%;

- lamb consumption by 0.02% and 0.05%;
- live sheep price by 0.1% and 3.2%, and
- retail price of lamb by 2.7% and 3.2%,.

Lamb Checkoff Program Returns to Stakeholders

- The BCR (dollars of net returns per dollar of expenditure) to the lamb industry as a whole (non-discounted) was $29.12 over the entire period of analysis (1987-2011), considerably lower than the $44.14 reported by Williams, Capps and Dang (2011) at the retail level.
- During the recent period of the mandatory checkoff program (2002-2011), the industry BCR was $36.57 compared to the BCR of $25.53 in preceding years when the promotion expenditures were funded by the wool incentive program.
- Returns to stakeholders (BCRs) were quite similar over the full period of analysis:
    - BCR to producers: $27.52 (non-discounted) and $16.90 (discounted);
    - BCR to feeders: $26.35 (non-discounted) and $13.03 (discounted); and
    - BCR to packers: $24.38 (non-discounted) and 13.40 (discounted).

The results of this study clearly indicate that not only did the lamb checkoff program increase the demand for lamb, the program tended to lift the entire supply chain in the process. The results also clearly indicate that the cost to generate that lift was much smaller than the additional industry profits generated as a result of the program. While the program generated additional imports over the years, the impact on consumption was larger than the import effect leading to a lower import share of consumption than would have been the case without the program in place. In addition, the returns to each stakeholder group were fairly even so that one group did not tend to gain at the expense of any other group.

The high BCRs calculated are not indicative of the impact of the program on the supply chain. The small amount of checkoff funds expended in each year generated a very small lift for the industry. The small positive benefit divided by an even smaller checkoff expenditure resulted in some relatively large BCRs. The implication is that the lamb industry is underinvesting in lamb promotion. The results of this study indicate that a substantial increase in the assessment rates paid by all stakeholders would generate a large return for every additional dollar of assessment paid by the industry. In other words, for every dollar in additional assessment NOT paid and spent on lamb promotion, the industry loses up to $29.12 in revenue. Increases in checkoff assessment rates and total spending on promotion are usually accompanied by a reduction in the BCR so that an increase in the lamb checkoff assessment would be expected to result in a lower return to promotion (Williams, Capps and Dang 2010). Given the high estimated BCR to the checkoff program, the industry could increase the assessment rate substantially and expect to generate a lower albeit still quite reasonable rate of return, more in line with the $2 to $10 earned by the larger commodity checkoff programs (Williams and Capps 2006). If assessment rates are changed, care should be taken not to change the relative assessments of the stakeholders to maintain the current balanced return to those stakeholders.

Limitations and Future Research Needs

The major limitation of this study was the unavailability of data for some variables. Although the data for all of the variables of interest for the U.S. were available at different domestic public sites, some of the same variables for Australia, New Zealand, and other trading partners of the U.S. were not available freely from public sources in the respective countries. Most of the data not available from in-country sources were collected from the World Bank, the International Monetary Fund (IMF), the Food and Agricultural Organization (FAO) of the United Nations, and the U.S. Department of Agriculture. Retail prices of lamb and wool for most of the countries other than U.S. and Australia were not available and were proxied in the model by the respective unit import and export values.

Livestock markets, especially those of sheep and lamb, tend to be quite seasonal in nature. The frequency of the data used in this analysis, however, was annual. Any considerations of intra-year seasonality could not be addressed as a result which may have had an effect on the properties of the model parameter estimates.

Another major limitation and, consequently, a future research need is related to the cost estimates used for livestock production, livestock feeding, and lamb slaughter in the calculation of the BCRs in this study. The lack of reliable cost data at all levels required assumptions regarding cost of production per head that may have affected the calculated BCRs. Research is needed to explore potential alternative cost assumptions and their impact on the BCR estimates.

Also, the BCRs calculated at all levels provide measures of *average* returns to sheep and lamb producers, feeders, and slaughterers from the lamb promotion expenditures, not the returns to individual stakeholders. In other words, not all producers earned $27.52 over the years from the promotion expenditures. Since the BCR is an average, some producers earned more and some less. The same follows for other stakeholders. Research is needed to explore the distribution of returns among stakeholders in each group.

Finally, the Australian and New Zealand sheep industries also promote the consumption of the lamb they produce in U.S. markets. Data relating to those expenditures were not available. Consequently, to the extent that lamb promotional expenditures by Australia and New Zealand tended to enhance U.S. lamb consumption, the estimate of the elasticity of U.S. lamb demand with respect to promotion could be biased upward.

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