Welfare changes in the Paraguayan Beef Supply Chain

by
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Abstract

The unprecedented beef export growth observed in Paraguay during recent years generated a new marketing environment in its livestock sector. While changes in beef marketed along the supply chain are well-known, no efforts have been undertaken to assess welfare changes of each economic agent of the Paraguayan Beef Supply Chain. Demand and supply systems are estimated for the fattening, slaughter and beef retail markets. A vertical multi-market approach accounting for the linkages among the three markets is used to measure welfare changes of all economic agents in the new marketing environment. The results suggest that consumers and slaughterhouses are worse off, feeder and calf producers are better off and overall society is better off.

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I am especially thankful to my husband, Eduardo, for his encouragement and understanding. Sincerest thanks to my lovely daughter Nicole and son Lucas. My heartfelt appreciation to my mother, father, my brother and my sister for their inspiration and support. And to my friends and family.

My special gratitude is to God who gave me the strength when I needed the most.

Dedication

To my dear husband and kids and my lovely parents

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Chapter 1

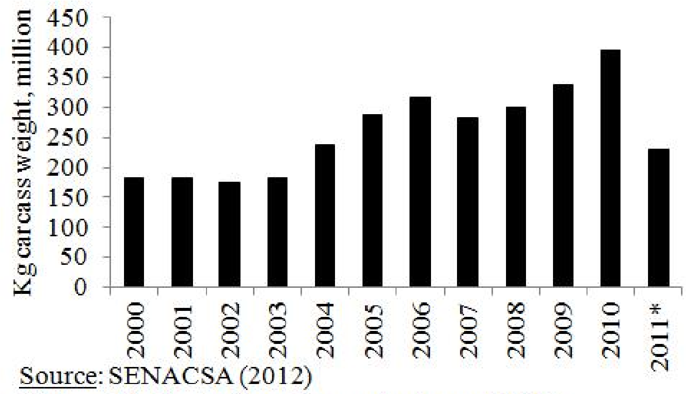
Introduction

For the last 20 years the livestock industry has been one of the major sectors in the Paraguayan economy. According to the Central Bank of Paraguay (Banco Central del Paraguay, 2011), the average share for livestock in the Gross Domestic Product (GDP) for this twenty year period is 5.53%. The livestock industry has a 23% share in the agricultural GDP and according to the Rural Association of Paraguay (Asociación Rural del Paraguay, 2012) employs 17.5% of the total economically active population. The herd reached 12,437,120 animals in the first semester of 2011 and experienced an accumulated herd growth of 61% in the last 20 years according to the Department of Animal Health (Servicio Nacional de Calidad y Salud Animal - SENACSA, 2012) statistics office. The herd population is distributed 62% and 38% in the Chaco Region and Occidental Region of Paraguay, respectively. In addition, beef production accounts for almost 81% of total Paraguayan meat production.

For a long time beef production was limited to the domestic market since Paraguayan consumers have high preference for beef among other meats and Paraguay only had access to the low-end tier international market (Ferreira and Vasconsellos, 2006). Figure 1.1a shows total Paraguayan beef production from January 2000 to August 2011 and Figure 1.1b shows the market distribution. Beef production was stable from 2000 to 2003 and 74% of the beef raised was consumed in the domestic market. Little beef was exported during that time. However, the scenario changed in 2004. Beef production and beef exports made an

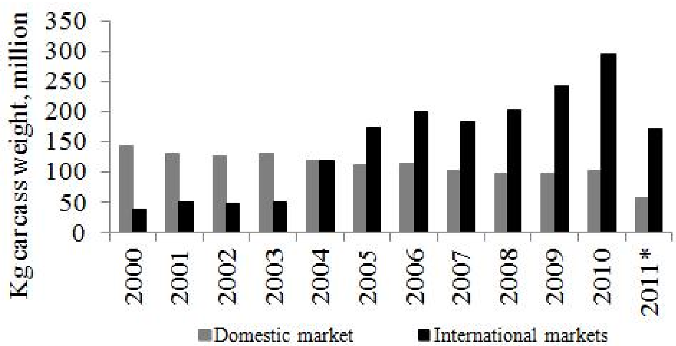
Figure 1.1: Total beef production and markets distribution

(a) **Total beef production**



Source: SENACSA (2012)
Note: * indicates from January to August, 2011

(b) **International and domestic markets**



Source: SENACSA (2012)
Note: * indicates from January to August, 2011

important leap in growth. Just in one year, from 2003 to 2004, beef production and beef exports experienced a growth rate of 30% and 126%, respectively. After 2004 beef exports began to increased further, mainly because international prices were higher than domestic prices (Ferreira and Vasconsellos, 2006). Figure 1.1b shows that meat processing plants started to sell more beef to international market rather than to the domestic market. International market has consumed more than 66% of Paraguayan beef and the domestic market has consumed remaining 34% on average for the period January 2004 to August 2011. Further, beef exports experienced an important accumulated growth of 246% from January 2003 to August 2011 (Banco Central del Paraguay, 2012). Beef exports represented more than US$ 600 million for the Paraguayan economy in 2011[1] and Paraguay provided 2% of total beef to the world (Banco Central del Paraguay, 2012 and United Nations Statistical Division, UN COMTRADE, 2012).

The most important factors that enable such growth in beef exports are improvements in sanitary conditions and cattle genetics that increase beef quality, and better practices in animal feeding and management, according to the Meat and Leather Commission of the Exports and Investments Network (Mesa de Carne y Cuero, Red de Inversiones y Exportaciones, 2011[2]). Private livestock investment[3] made these improvements possible and it increased 258% from 2005 to August 2011. Public sector has made efforts in order to support private sector investments by updating and improving its services, especially in the Department of Animal Health. The increase in beef exports made the livestock sector profitable and private investments improved the infrastructure of the farms, which in turn benefited the quality of the beef. Also, strong world demand and high export prices have contributed to Paraguay's beef export growth (United States Department of Agriculture - USDA, Foreign Agricultural Service - FAS, 2006). As a result Paraguay gained access to new and demanding international market[4]. In 2001 the European Union added Paraguay as a contributing supplier of the Hilton quota limited to 1,000 tons annually. Even though the 1,000 tons had a small impact on beef exports, it served as an international window to access other markets. Moreover, as a consequence of the outbreak of foot-and-mouth disease in Paraguay in 2002, the export beef sector sought markets with no restrictions on foot-and-mouth disease beef in order to avoid closing meat processing plants (Ferreira and Vasconsellos, 2006). At that time, Chile and Brazil were Paraguay's main beef customers which paid prices that encouraged the Paraguayan beef producers. Paraguayan beef was well accepted in their markets. Both countries together, on average, demanded 76% of

[1]From January to August, since the new outbreak of foot-and-mouth disease in September 2011.

[2]This information was provided by the Head of the Meat and Leather Comission of the Exports and Investments Network in Paraguay, Dr. José Laneri, phone number: (595) 616-3263.

[3]Livestock credit provided by the public sector is associated with many requirements hard to attained (the period to obtain a credit varies between 60 to 90 days)

[4]Beef markets are highly segmented due to sanitary regulations, and prices are higher in more demanding markets (Ferreira and Vasconsellos, 2006).

total beef exports. After 2003, Paraguayan beef gained new markets. Russia, Israel and Venezuela added Paraguayan beef to satisfy their domestic markets. Exports to these new markets increased opportunity for Paraguay to more than double its level of beef exports for 2004 from 47.6 million kilograms in 2003 to 107.6 million kilograms in 2004.

Paraguayan beef exports continued to grow with further demand from new markets. Currently, Paraguay's main beef markets are Chile, Russia, Israel, Brazil and Venezuela. These countries consume 87% of Paraguayan annual beef exports. As of August 2011, the sanitary status of Paraguay is free of foot-and-mouth-disease with vaccination and has an insignificant risk based on the World Organization of Animal Health assessment[5] (United States Department of Agriculture - USDA, Foreign Agricultural Service - FAS, 2011).

1.1 Paraguayan Beef Supply Chain

The growth of beef exports boosted the livestock sector as Paraguay became a world beef supplier (Asociación Rural del Paraguay, 2010). In order to assess how growth of beef exports affected the domestic market it is important to understand how the Paraguayan Beef Supply Chain works.

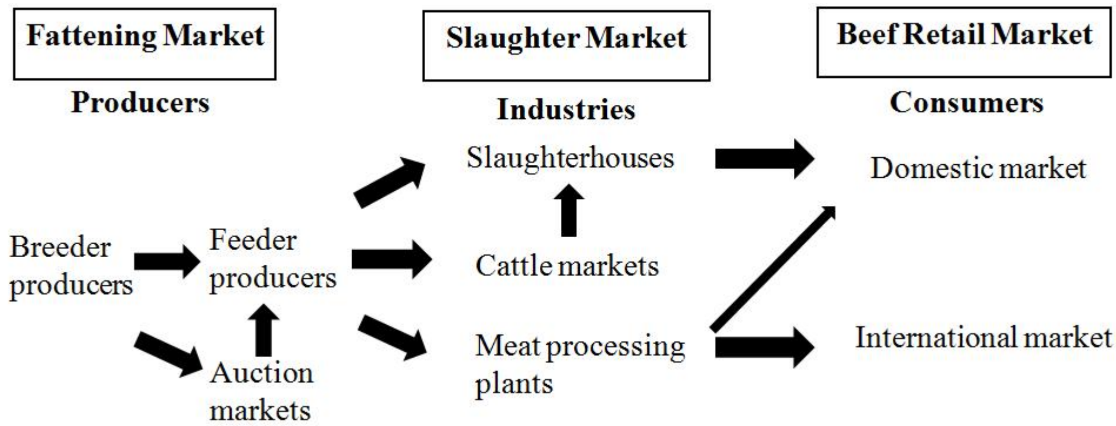
Figure 1.2 shows the Paraguayan Beef Supply Chain. The Fattening Market provides bull calves as main inputs to the Slaughter Market. In turn, the Slaughter Market provides carcass as the main input to the Beef Retail Market. Due to these relationships a change in prices in any of these markets will affect the quantities provided by the other markets.

The Fattening Market is composed of breeder producers and feeder producers. Cattle in Paraguay are mostly grass-fed[6] and it shows a strong concentration since only 9.3% of producers own 81.5% of cattle (large producers) and the remaining 90.7% of producers own only 18.5% of the cattle (small producers) (Ferreira and Vasconsellos, 2006). Figure 1.3 shows the length of the breeding and the fattening stages. Breeding can last 21 to 27

[5]Paraguay experienced a new outbreak of foot-and-mouth-disease in September 2011, which implied a suspension of its sanitary status. This thesis only considers the period before this outbreak, in August 2011.

[6]There are few producers who are implementing feed-lots and therefore, for the purpose of this research, it is assumed that cattle is only grass-fed.

Figure 1.2: Paraguayan Beef Supply Chain



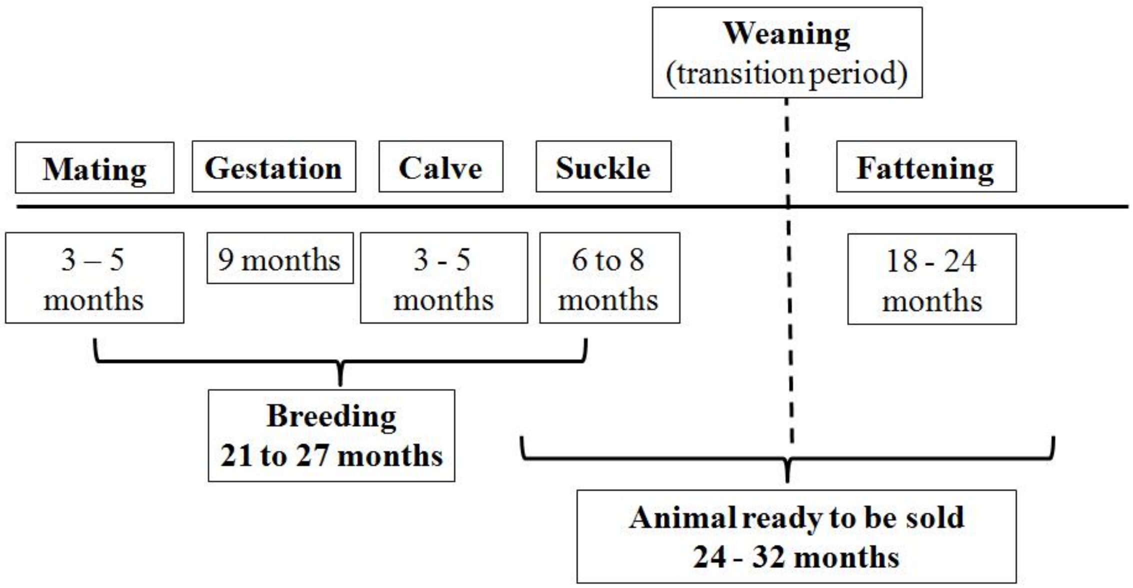
Source: Based on Ferreira and Vasconsellos (2006).

months on average[7] depending on the effectiveness of the reproduction stage (Ferreira and Vasconsellos, 2006). Suckle period ends when the animal is 6 to 8 months old on average. Then, weaning period is a transition when calves and cows are separated. Bull calves and a portion of heifers are sold for fattening purposes and cows start the matting process again. Fattening can last 18 to 24 months. In most cases an animal is ready to be sold after 24 - 32 months of its birth (Ferreira and Vasconsellos, 2006). Breeder producers are dedicated mostly to the production of bull calves. Also, these producers sell cows, cull cows, bulls and heifers that are not going to be used for breeding. Producers in the feeding business demand bull calves, heifers and cows. The transactions between these two producers can be done directly or through auction markets.

In the Slaughter Market, beef suppliers are classified according to the markets they provide: domestic or international. The domestic market is supplied by slaughterhouses and meat processing plants. Meat processing plants supply the domestic market with small amounts of processed beef and the leftover beef not accepted in international market. Slaughterhouses supply the domestic market only. There are many slaughtered animals not accounted for in the countryside since slaughter can occur in nonregistered slaughter-

[7]Open cows' reproductive life last 6 to 7 years. After that they are sold in cattle markets for domestic slaughter purposes.

Figure 1.3: Cattle cycle in Paraguay



Source: Based on Ferreira and Vasconsellos (2006).

houses. Slaughterhouses can stock up directly from producers and cattle markets that act as brokers. However, meat processing plants have to buy animals directly from producers. Since 2000, the Department of Animal Health passed a regulation that meat processing plants that are allowed to export cannot buy animals from cattle markets. This regulation is in place to achieve the sanitary conditions demanded by international markets. Therefore, meat processing plants have invested in infrastructure and in meeting export customers' standards and regulations in order to enter international market. This investment has increased production costs as meat processing plants have to meet legal, taxes, labor, sanitary and environmental regulations. Due to these increased costs, meat processing plants are not competitive in the domestic market.

The Beef Retail Market is composed of domestic and international consumers. Domestic consumers stock up from supermarkets and these supermarkets usually stock up from their own slaughterhouses because costs are lower. International consumers buy beef from meat processing plants.

1.2 Problem statement and objectives

The four economic agents in the Paraguayan domestic market that are affected by beef exports growth are breeder producers, feeder producers, slaughterhouses and domestic consumers. These four economic agents have experienced important changes in their business operations and consumption due to beef exports growth. Such growth implied a supply reduction for the domestic market because production is not enough to satisfy both domestic and international markets at the same time (Ferreira and Vasconsellos, 2006).

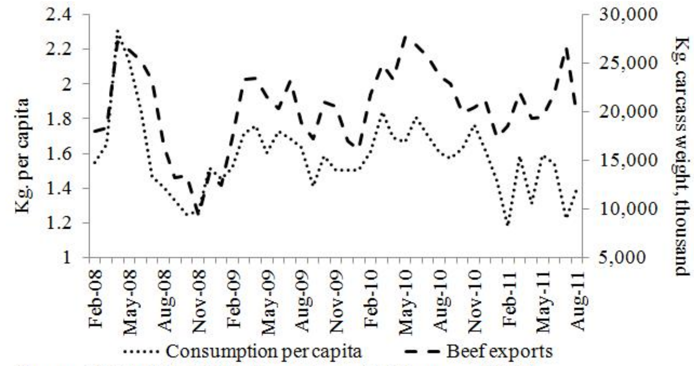
Producers and meat processing plants may have benefited from higher prices in the international market. Breeder producers and feeder producers experienced an increase in transactions buying and selling bull calves due to the increased demand from the meat processing plants. In fact, from January 2003 to August 2011, producers increased animals ready to be sold by 128%[8]. Meat processing plants increased the number of slaughtered animals for the international market by 337% in the same period. However, slaughterhouses may be worse off because they experienced a 51% decrease in the number of slaughtered animals available for the domestic market from January 2003 to August 2011 which implies a reduction in their profits. In turn, consumers in Paraguay argue the domestic market was left with only low quality and overpriced beef cuts (there is no consumption of imported beef in Paraguay). The domestic market stocks up only from domestic meat processing plants and slaughterhouses because Paraguayan beef is highly competitive due to low production costs that drive low domestic market prices, making it difficult for other countries to compete in the domestic market (Ferreira and Vasconsellos, 2006). Therefore, beef consumption per capita has dropped by 26% from January 2003 to August 2011. Figures 1.4a and 1.4b compare beef consumption per capita and beef prices with respect to beef exports from February 2008 to August 2011 (data for beef prices before February 2008 is not available and therefore, the beef exports growth is not observed). The figures show that the gap between beef consumption per capita and beef exports increases over time while beef

[8]The amount of steers have increased by 128% from January 2003 to August 2011. In other words, this percentage indicates the increase of bred and fed bull calves during that period.

prices with respect to beef exports decreased in 2009 and increased in the second half of 2010 until August 2011.

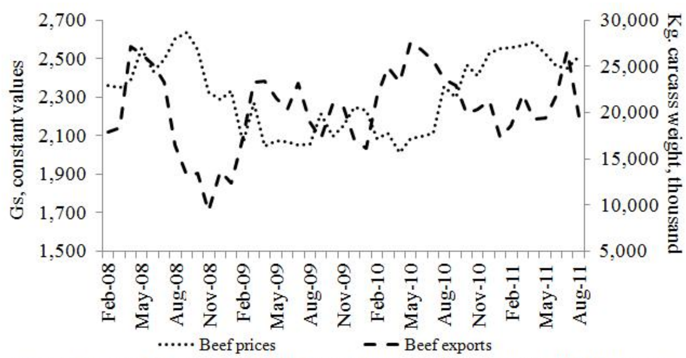
Figure 1.4: Beef consumption per capita and beef domestic prices vs beef exports. February 2008 - August 2011

(a) **Consumption per capita**



Source: SENACSA (2012); Banco Central del Paraguay (2012)

(b) **Domestic price**



Source: Investor Economia (2012); Vice-ministerio de Comercio (2011); Banco Central del Paraguay (2012)

The observed changes in the domestic market suggest that some economic agents in the Beef Supply Chain may be better off and others may be worse off due to beef exports growth. However, the overall effect on the Beef Supply Chain is not clear. Little research has been undertaken to assess the impact of the boom of beef exports on the Paraguayan Beef Supply Chain participants. Measures of welfare changes for consumers, slaughterhouses and producers may be helpful for policy makers to target economic agents' different needs and to understand how policy changes in one market may transmit to other markets. The purpose of this research is to estimate a system of equations for each of the markets in the Paraguayan Beef Supply Chain so as to measure welfare changes for each of the economic agents affected by the beef exports growth. Welfare is measured as the surplus of an economic agent and it is obtained by calculating areas behind the demand and above the supply curves. The curves have changed due to changes in prices and quantities as a consequence of the beef exports growth. Welfare changes are obtained by estimating a system of supply and demand equations for each market in the Paraguayan Beef Supply Chain.

The specific objectives of this thesis are:

- to estimate demand and supply equations for the following three markets: Fattening, Slaughter and Beef Retail;
- to obtain short-run own-price demand and own-price supply elasticities for each market;
- to measure welfare changes for each of the economic agents in the domestic market in the new environment of increased beef exports.

A system of demand and supply equations for each market is estimated using the Three Stage Least Squares (3SLS) method which accounts for endogeneity and corrects the correlation between the errors of the two equations in each system. Own-price demand and supply elasticities are calculated using estimates from the above system. Finally, welfare changes are measured by computing the areas behind the demand and above the supply estimated curves.

1.3 Thesis outline

This thesis is organized as follows: *Chapter II* presents an overview of previous research related to beef demand in Paraguay. Then, literature about demand and supply systems is reviewed, specifying the importance of both equations in a simultaneous analysis and the importance of taking into account the endogeneity problem. Besides, this chapter presents previous research on welfare measures, the relevance of identifying appropriate areas for the different affected economic agents and welfare analysis in vertical multi-market. *Chapter III* presents livestock data from Paraguay and the computation needed to build some of the data series. Also, it presents results of the unit root test for each variable. *Chapter IV* presents the model of the Paraguayan Beef Supply Chain which includes the Fattening, Slaughter and Beef Retail markets. Then, *Chapter IV* presents the theory of simultaneous equations and instrumental variables. The estimation method (3SLS) and the theory and computation of the definite integrals to measure welfare changes are also presented. *Chapter V* shows the estimated demand-supply system results, own-price-demand, own-price-supply and cross-price elasticities and welfare changes for each domestic economic agent. Finally, *Chapter VI* presents the conclusions. A comparison of the estimated coefficients via Ordinary Least Squares (OLS), Two Stage Least Squares (2SLS), 3SLS and Seemingly Unrelated Regression (SUR) methods is included in *Appendix 1*. The conditions for identification for each system are shown in *Appendices 2* and *3*. *Appendix 4* contains the autocorrelation and partial autocorrelation functions of the errors for each equation.

Chapter 2

Literature Review

Most of the literature about the livestock and beef market in Paraguay focuses on performance and international trade (Red de Inversiones y Exportaciones, 2012, Asociación Rural del Paraguay, 2010 and 2012). The USDA Foreign Agricultural Service (FAS) reports the growth of this sector (USDA, FAS, 2006 and 2011). Ferreira and Vasconsellos (2006) is the only study to summarize in detail the livestock business in Paraguay. Building on Ferreira and Vasconsellos (2006), Laíno and Reina (2008) conclude that the Paraguayan Livestock sector has strengthened its competitiveness during the last decades.

Only three studies have estimated beef demand elasticities for Paraguay; however, they provide mixed results. These studies were performed using consumption data only, for a single year, and prior to the observed market changes associated with the beef exports growth. Aguilera (2002) reported the first set of demand elasticities for Paraguay using the first Paraguayan Integrated Household Survey from 1997/1998. He estimated elasticities for six food groups, including meat. Using the Almost Ideal Demand System (AIDS) model and a Multinomial Linear Logit Model (MLLM) he found that own-price elasticities for beef, chicken, pork and fish ranged from negative values to approximately one. Also, he found that income elasticities for meat were less than one for both models, suggesting that meat is a necessary good for Paraguayan families. Alfonzo and Hanawa-Peterson (2006) used data from the same survey as Aguilera (2002), and estimated elasticities for 12 groups, including beef (fresh beef cuts). Using the same AIDS model as Aguilera (2002), Alfonzo and Hanawa-Peterson (2006) obtained own-price elasticities ranged from negative to approximately one. The cross-price elasticity of chicken with respect to beef is negative (-0.52), suggesting that chicken is a complement good of beef while the cross-price elasticity of other meats with respect to beef is positive (0.07), suggesting that other meats are substitute goods for beef. Lema et al. (2007) used data from the 2000 Paraguayan Integrated Household Survey and aggregated food data into 11 groups to estimate a Lin-Quad incomplete demand system for Argentina, Bolivia and Paraguay. For Paraguay, they found an unexpected positive own-price elasticity for high quality beef (4.98) and negative own-price elasticities for medium (-0.44) and low qualities beef (-0.003). Also, the cross-price elasticities between chicken and the high quality beef (0.18) and the low quality beef (0.002) are positive, and the cross-price elasticity between chicken and medium quality beef is negative (-0.07), suggesting that chicken is a substitute good for both high quality beef and low quality beef, and it is a complement good for the medium quality beef.

Besides these studies about beef demand, no research has been performed to study the supply side of the Beef Retail Market. Moreover, there is no research related to the Slaughter Market or the Fattening Market that estimates own-price demand and supply elasticities for bull calf or carcass. This thesis attempts to model the Paraguayan Beef Supply Chain using a vertical multi-market approach. The methods used in this research follow Jeong, Garcia, and Bullock (2003) for the Japanese beef market. This study will estimate own-price demand and supply elasticities for the main products of these markets (bull calf, carcass and beef) and provide measures of welfare changes for the domestic market in Paraguay after beef exports growth.

Section 2.1 focuses on the estimation of demand and supply systems for the beef market in different countries. Section 2.2 focuses on studies related to welfare changes following a multi-market approach.

2.1 Demand and supply systems

Research on meat markets focuses on estimating demand equations and calculating elasticities for the different types of meat, assuming a perfectly elastic supply curve (Wahl and Hayes, 1990). Capps et al. (1994) employed a Rotterdam model to find own-price and cross-price elasticities for meat in the Pacific Rim region (Japan, South Korea and Taiwan), using annual data from 1960 to 1991. They found that own-price demand elasticities for beef, chicken and pork were different among these three countries. For example, Taiwan has the largest own-price demand elasticity for beef and pork, while South Korea has the largest elasticity for chicken, suggesting that elasticity estimates are country-specific and using estimates from different countries may lead to misleading results. Leeming and Turner (2004) estimated inverse log-linear demand equations for beef, lamb and pork for the United Kingdom in order to measure the effects of the 1996 Bovine Spongiform Encephalopathy (BSE) crisis on these red meat prices, using quarterly data from 1985 to 2000. They estimated the inverse demand equations for beef, lamb and pork using OLS, 2SLS and 3SLS. They concluded that allowing for the joint endogeneity of the price variables by using 2SLS and 3SLS yield estimates that differ from using OLS which in some cases yielded estimates that were not significant or had the incorrect expected signs. Allowing for endogeneity by using 2SLS and 3SLS, estimates from these equations increase their magnitudes and/or increase their level of significance, specially for the substitution effects among equations. Henneberry and Hwang (2007) developed a demand system for imported meat (beef, pork and poultry) in South Korea using quarterly data from 1996 to 2003. The purpose of this paper was to study United States (U.S.) competitiveness in the South Korean meat import market and to obtain estimates of meat import demand elasticities for the South Korea meat market. Using a Restricted Source-Differentiated Almost Ideal Demand System (RSDAIDS), they found the U.S. had an important advantage in the South Korean beef market compared with Australia, in terms of beef exports. In addition, U.S. along with Thailand had an advantage in the South Korean poultry market, while South Korea had advantages in its domestic pork market.

Each of these three papers estimated different models for demand equations. There are differences among these studies and this thesis, such as comparing preferences for international consumers (Capps et al., 1994) while this thesis only focuses on the domestic market. Leeming and Turner (2004) consider prices as endogenous and quantities as exogenous while this thesis considers both quantities and prices as endogenous (Chapter 4 provides a discussion of prices endogeneity in the Paraguayan beef market). Another difference is that this thesis focuses only on domestic production and consumption since Paraguay has no imported beef (Banco Central del Paraguay, 2012). Henneberry and Hwang (2007) consider import meat markets in order to assess competitiveness of each supplier country. A similarity with Leeming and Turner (2004) is that they estimated a 3SLS method in order to allow for joint endogeneity of substitute prices. Findings in Henneberry and Hwang (2007) indicate that South Koreans have strong preferences for domestic beef since it is higher quality. Paraguayan consumers also have higher preferences for their domestic beef. Neither of these papers consider the meat supply side as estimated jointly with the meat demand side. Not considering the upward-sloping supply curve may underestimate the price responsiveness in the demand equation, because price elasticities increase when an upward-sloping supply curve is assumed (Wahl and Hayes, 1990). Therefore, a demand - supply system may yield better estimates for both own-price demand and supply elasticities. Equilibrium prices and quantities are determined by the intersection of the demand and supply curves (Griffths, Hill, and Judge, 1993). Prices and quantities are jointly determined, and therefore they are the endogenous variables in the system. Examples of studies accounting for this simultaneity are Lianos and Katranidis (1993) and Marsh (2003).

Lianos and Katranidis (1993) estimated a demand and supply system for the beef market of Greece for the period 1966 - 1981. In their model, the slaughter and producer agents are one agent, so changes in slaughtering and cattle inventory are reflections of the same decision making process. In this thesis producers and the slaughter industry are modeled separately. Another difference between the Greek and the Paraguayan markets is that in

Greece the consumer beef price is endogenous but the producer beef price is exogenous since it is administratively determined[1] while in Paraguay both prices are endogenous. They use 2SLS to estimate the beef demand and the beef consumer price and they use OLS to estimate the other equations in the model (supply of beef, supply of slaughterings, average weight and cattle inventory).

Marsh (2003) estimated a system of inverse demands and primary supplies for the slaughter and feeder cattle sectors to determine the effects of declining U.S. retail beef demand on farm-level beef prices and production for the period 1970-1999. He estimated two demand and supply systems for the slaughter and feeder cattle markets. In order to account for these effects on these two markets, he used equilibrium prices from each of these markets as explanatory variables, except for the beef price which is exogenous. Price of beef by products and feeder steer price are explanatory variables in the slaughter cattle market and, in turn, slaughter steer price is an explanatory variable for the feeder cattle market. Results of this study suggest that changes in the beef retail market in the U.S. affect farm demand prices and production. Marsh concludes that the increase of consumer beef demand would not affect only processors and retailers; instead, processors, retailers and producers of slaughter and feeder cattle would benefit from distribution of income gains. Marsh's work differs from previous studies since he uses prices that come from the interrelated markets as explanatory variables to account for the linkages among these markets. This thesis follows the same approach as Marsh as it uses information from interrelated markets to account for the linkages among them.

2.2 Measures of welfare changes

The theory underlying applied economic welfare analysis is explained in detail in Just, Hueth, and Schmitz (1982). Bullock (1993) argues that this theory sometimes is not appropiately used because researchers added up seemingly related geometric areas across

[1]During the period of study, in Greece producer beef prices were determined as a result of economic policy decisions rather than market forces in order to keep low levels of consumer beef prices.

markets, after some distortions in the markets, which then resulted in misleading results. Therefore, care should be put in identifying areas due to shifts or movements of the supply and demand curves. This is an important issue for welfare analysis as a multi-market approach since welfare changes must be decomposed by groups to capture within changes that otherwise would be treated as homogeneous (Paarlberg, Lee, and Seitzinger, 2003). Moreover, Paarlberg, Lee, and Seitzinger (2003) suggest that consumers and producers welfare measures must be decomposed for those who are affected by a particular event from those who are not. For example in analysing a potential outbreak of foot-and-mouth disease (FMD) in the U.S., they considered three different scenarios to assess welfare changes for consumers and producers. The first scenario are producers which have quarantine and slaughter animals, named as stamping out. The second scenario is described as stamping out and an export ban for the U.S beef. The third scenario is described as the first two scenarios plus adverse consumer reaction with respect to an FMD outbreak. They found that welfare changes for producers and consumers differ among the three scenarios, pointing out the importance of identifying agents who are affected by this potential outbreak.

The limited research using a multi-market approach to welfare estimation (Dadakas and Katranidis, 2010) has focused on analyzing the impacts of agricultural trade policies on consumers' and producers' welfare. Some of these studies include industries' welfare as well. Jeong, Garcia, and Bullock (2003) is one of the most relevant contributions in this area. They analyse welfare changes on different economic agents after beef imports partial liberalization in the Japanese beef market. The research employed a vertical multi-market economic model in a partial equilibium framework, including the three markets in the beef supply chain: fattening, slaughter and beef retail markets. Also, they included demand and supply of pork since the pork market is affected by beef policies through the substitution effect in consumer demand. They performed 3SLS method to account for endogeneity and with the estimated coefficients they computed welfare measures. They found that the tariffication of Japanese beef imports generated US$238.5 million of net social surplus, which in per capita terms represents US$1.93. This thesis employs the same approach for the Paraguayan beef market.

Katranidis, Nitsi, and Bullock (2005) present a horizontal multi-market welfare analysis for the European Union's Common Agricultural Policy corn, cotton and sugar beet regimes on farmers' practices in Greece after its 1981 entry into the European Union. The research modeled horizontal links among the three crops (corn, cotton and sugar beet) and vertical links between corn and meat markets since corn is the main input for livestock production. These horizontal and vertical links among the markets show that economic or political changes in any of these markets will affect "the income transfer" (it refers to the measure of change in producer welfare) of producers in the other markets. Parra and Gómez (2007) followed Jeong, Garcia and Bullock's (2003) methodology in order to study welfare changes for consumers and producers in the Colombian beef market after the introduction of a Free Trade Agreement with the U.S. and the Southern Common Market (Mercado Comun del Sur - MERCOSUR[2]). Their model combined a horizontal multi-market model for the poultry and beef markets and a vertical multi-market model for the slaughter market in Colombia. This work is relevant for the Paraguayan case because of the characteristics of the livestock sector in Colombia. Colombian livestock represents an important share in the agricultural GDP, consumers prefer beef and this sector faces similar challenges as Paraguayan livestock. For example, Colombia needs to improve statistical data, develop private and public policies to better organize this economic sector and improve access roads and technological development in rural areas. Their results suggest that consumers would be better off due to the trade opening; however, producers would be worst off if they do not take actions reducing their production costs and increasing their productivity in order to be more competitive in international market. This thesis identifies similar explanatory variables to estimate the systems as Parra and Gómez (2007).

[2]Countries that belong to the MERCOSUR are: Argentina, Brazil, Paraguay and Uruguay.

Chapter 3

Data

Most of the data for this research was provided by Investor Economia[1], which also provided useful insight about the livestock business in Paraguay. Data used in this research also came from governmental statistic offices, including the Department of Animal Health (SENACSA), the Department of Meteorology, the Central Bank of Paraguay (BCP) and the Department of Industry and Commerce (Vice-ministerio de Comercio).

Data was collected for the period February 2008 - August 2011. The starting point was determined by the Fattening Market series. The data for the Fattening Market is from CODEGA S.A., one of the three main auction markets in Paraguay, which had the most complete data series for the period February 2008 - August 2011[2]. The end research point is the outbreak of the foot-and-mouth disease in Paraguay in September 2011.

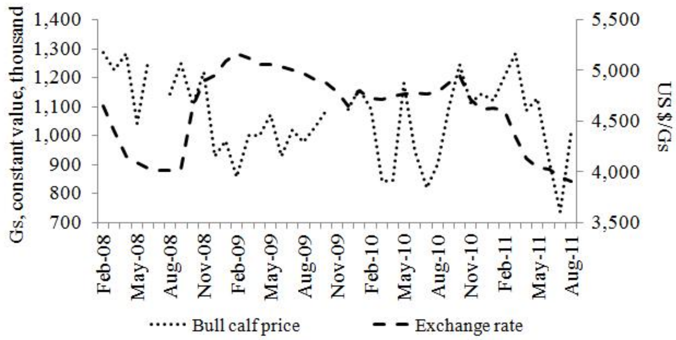
All prices used in the analysis are in Paraguayan currency, Guaranies (Gs). Prices in Gs yield better results than prices in U.S. dollar (US$) because the exchange rate has experienced strong variation in the period under study. Figure 3.1 compares beef, carcass and bull calf prices with the exchange rate for the same period of time. All prices are in constant values.

[1]Investor Economia is a Paraguayan private company which focuses on developing businesses related to Agribusiness, Real Estate and Economics. It operates in Paraguay and its website is www.investor.com.py

[2]There are two missing observations, July 2008 and November 2009. The data available for the other two auction markets, Ferusa and El Corral, was for a shorter period.

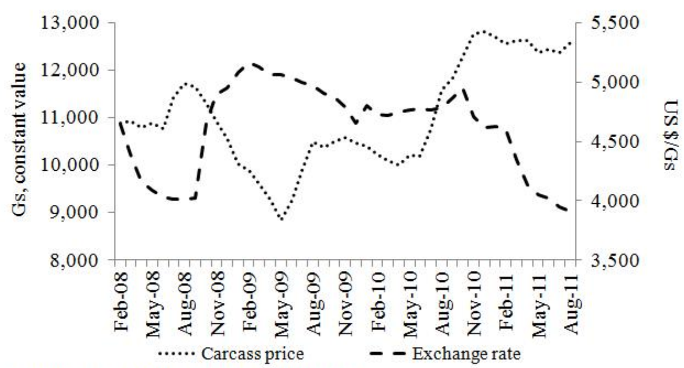
Figure 3.1: Prices in constant Gs vs exchange rate

(a) **Bull calf price vs exchange rate**



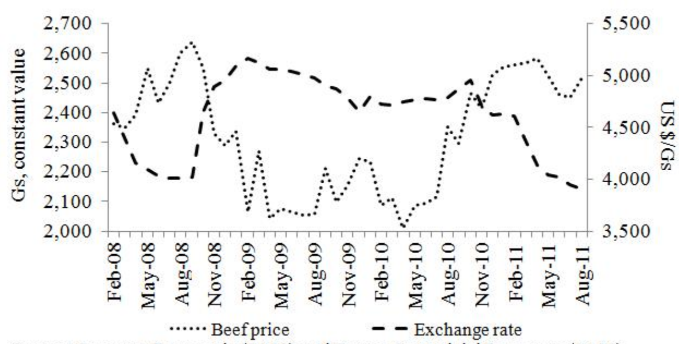
Source: Investor Economia (2012) and Banco Central del Paraguay (2012)

(b) **Carcass price vs exchange rate**



Source: Banco Central del Paraguay (2012)

(c) **Beef price vs exchange rate**



Source: Investor Economia (2012) and Banco Central del Paraguay (2012)

3.1 Description of data and sources

Tabla 3.1 provides the definition and sources of each of the twenty one variables used in the analysis.

Variable Y_t is an index which is calculated by the Central Bank of Paraguay as follows:

$$IMAEP_t = \sum_{j=1}^{n} \alpha_{j,0} IMAE_{j,t}$$

where IMAE is a weighted sum of volume index of each economic activity j (Agricultural, Livestock, Forest, etc.) during period t, α indicates the weight of each economic activity and 0 indicates base period. Prices P_t^{bc}, P_t^h, P_t^{cc}, P_t^b and variable I_t were deflated using the Consumer Price Index (CPI) from Paraguay with base period in December 2007. The CPI in Paraguay is calculated by the Central Bank of Paraguay using prices from a particular bundle of goods and services that a normal family consumes in the Metropolitan Area of Asuncion city. Variable I_t is a proxy to indicate private investments from private banks only. Variable K_t is an average lending rate from domestic banks and domestic finance companies. This is an effective active lending rate in Gs.

Quantity Q_t^{tc} is the total production of Paraguayan beef for both domestic and international markets[3]. It is calculated as follows,

$$Q_t^{tc} = Q_t^d Kg_t + Q_t^{xd} + Q_t^x$$

where Q_t^d represents beef quantity for the domestic market only and it is obtained by adding traded cattle (steers, bulls and cows) in cattle markets in 2008, slaughtered animals in slaughterhouses in 2009, 2010 and 2011 and slaughtered animals in meat processing plants in 2008, 2009, 2010 and 2011; Kg represents kilograms in carcass weight; Q_t^{xd} represents beef cuts that are not exportable and are sold in the domestic market; and Q_t^x represents beef exports. Monthly data was used for each of these variables. The details of the computation

[3]The Head from the Mesa de Carne y Cuero from the Red de Inversiones y Exportaciones, Dr. Laneri, provided useful insight for computing this variable.

Table 3.1: **Description of data and sources**

Variable	Definition	Source
	Endogenous variables	
Q_t^{bc}	Bull calf quantities, in heads	Investor Economia
Q_t^{c}	Carcass quantities for domestic market, in kilogram carcass weight	Investor Economia
Q_t^{bf}	Beef quantities, in kilogram carcass weight/per capita	SENACSA and IMF
P_t^{bc}	Bull calf price, in constant Gs/head	Investor Economia
P_t^{c}	Carcass price, in constant Gs/kilogram carcass weight	BCP
P_t^{bf}	Beef price, in constant Gs/kilogram	Investor Economia and Vice-ministerio de Comercio
	Exogenous variables	
P_t^{ck}	Chicken price, in constant Gs/kilogram	BCP
P_t^{pk}	Pork price, in constant Gs/kilogram	BCP
P_t^{h}	Heifer price, in constant Gs/head	Investor Economia
P_t^{cc}	Cull cow price, in constant Gs/kilogam	Investor Economia
P_t^{b}	Bull price, in constant Gs/kilogam	Investor Economia
Q_t^{h}	Heifer quantities, in heads	Investor Economia
Q_t^{x}	Beef exports, in kilogram carcass weight	BCP
Q_t^{tc}	Total slaughtered animals for domestic and international markets, in kilogram carcass weight	SENACSA
S_t	Ratio between total slaughtered animals and total herd	SENACSA
W	Dummy variable that indicates winter period in Paraguay (from May to September)	
I_t	Private livestock investments, in constant Gs	Investor Economia
E_t	Monthly average exchange rate (Gs vs US$)	BCP
Y_t	Monthly Index of the Paraguayan Economic Activity	BCP
K_t	Commercial lending rate, in percentage	BCP
R_t	Rain in livestock areas, in millimeter	Meteorology

of these variables are the following:

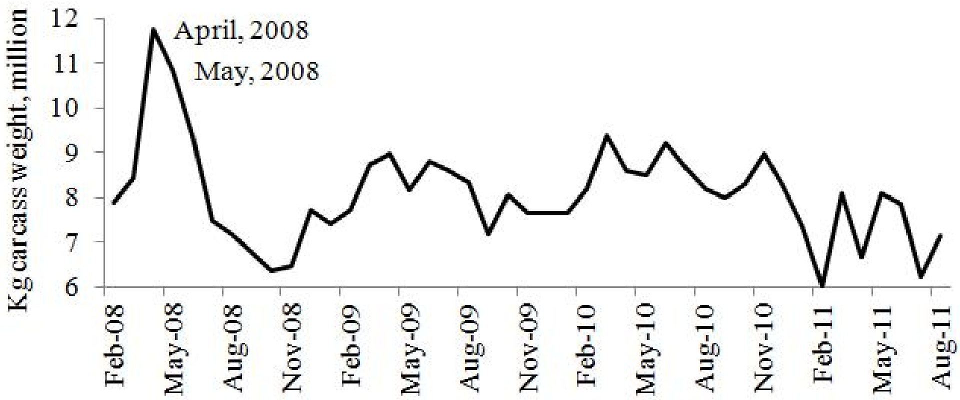
- Quantity Q_t^d in 2008 is traded cattle from all cattle markets[4] because the number of traded animals is higher than the number of slaughtered animals in slaughterhouses. Slaughtered animals in slaughterhouses for years 2009, 2010 and 2011 were higher than traded animals in cattle markets. Cattle sold in cattle markets appear to be less than slaughtered cattle in the slaughterhouses because producers sell animals directly to slaughterhouses and no record of these sales exists. Besides, meat processing plants slaughter approximately 4% of animals for the domestic market.

- Variable Kg_t represents average live kilogram for animals traded in cattle markets per month converted to kilogram carcass weight using 0.51 factor.

- Quantity Q_t^{xd} and quantity Q_t^x come from the number of slaughtered animals in meat processing plants for the international market multiplied by the average kilogram carcass weight in meat processing plants. Quantity Q_t^{xd} represents beef cuts that are not exportable but are sold into the domestic market by meat processing plants (each slaughtered animal provides cuts that are suitable for both domestic and international markets). Cuts with bones which are known as *ribs* are traded in the domestic market because of sanitary restrictions in international market related to foot-and-mouth disease and transportation difficulties. Cuts with bones represent, on average, 14% of total exportable beef. Quantity Q_t^x represents exportable cuts known as *forequarter* and *hindquarters*. These cuts are also differentiated as *chilled beef* and *frozen beef*. This amount of beef represents, on average, 86% of total amount of exportable beef. These percentages, 14% (cuts with bones) and 86% (exportable beef), were calculated by comparing the total amount of beef produced in meat processing plants for international market with beef exports registered by the Central Bank of Paraguay. The amount not registered as beef export was assumed to be sold in the domestic

[4]There are four cattle markets: El Rodeo, El Corral, Ferusa and CODEGA S.A. that are located mainly in the surroundings of Asuncion city.

Figure 3.2: Carcass quantities for domestic market



Source: SENACSA (2012)

market and represents the 14% of cuts which are not accepted by the international market.

Quantity Q_t^c is obtained by calculating the difference between Q_t^{tc} and Q_t^x. Figure 3.2 shows that Quantity Q_t^c presents two observations, in April 2008 and May 2008, which are considerably different from the rest of the observations and had remained in the residuals of preliminary models. The dummy variable D_t accounts for these observations which were identified by eyeballing the plot of the dependent variable and the errors in preliminary estimated models. Quantity Q_t^{bf} is obtained by dividing Q_t^c by population. Annual Paraguay population (from 2008, 2009, 2010 and 2011) comes from the International Monetary Fund (IMF). Finally, variable S_t is a ratio between Q_t^{tc} expressed in heads and total herd in hundreds.

Price P_t^c comes from the Producer Price Index (PPI) from Paraguay[5]. Price P_t^c has the same behavior as carcass price in trading operations[6]. However, the carcass price series was available starting in February 2008, and the carcass price from trading operations was

[5]The PPI in Paraguay is calculated using products that come from Agricultural, Livestock, Forest, Mine, Quarry, Industries and Imports Sectors. Product price is the final price for the Producer where it is included production costs and profits, and costs related to trading and taxes ad valorem are excluded. It is calculated by the Central Bank of Paraguay and uses information that comes from the entire country.

[6]Correlation between carcass price computed from PPI and carcass price from trading operations is 0.8252, which implies that both variables are close enough to assume that carcass price computed from PPI is a good proxy of carcass price from trading operations.

available starting in August 2008. In order to have data for all markets for the same period, carcass price computed from the PPI was used. This carcass price was deflated using the CPI.

Price P_t^{bf} was obtained as follows,

$$P_t^{bf} = \sum_{j=1}^{11} \alpha_j P_t^j$$

where P_t^j represents the beef cut j relative price for period t and α_j represents the share of beef cut j. In turn, relative price P_t^j is obtained as follows: for period t, reference prices for each beef cut from August 2011 (before the outbreak of foot-and-mouth disease) provided by the Department of Industry and Commerce were used. These reference prices from August 2011 were obtained by calculating the average price of each beef cut from weekly surveys the Department of Industry and Commerce conducted in ten different supermarkets (including the one which provides the price index). Then, in order to compute relative prices for period $t-1$, each reference price in period t (August 2011) was divided by a ratio between the corresponding index price $P_{j,t}^i$ in period t and the same index price $P_{j,t}^i$ in period $t-1$. This index price $P_{j,t}^i$ is calculated by a supermarket in Asuncion based on monthly sales. Resulted beef prices P_t^{bf} were deflated using the CPI.

Finally, price P_t^{ck} and price P_t^{pk} were computed using reference prices of chicken and pork, respectively, from August 2011. Price P_t^{ck} was calculated by dividing the reference price from August 2011 by a ratio between the index price of chicken from August 2011 and the previous month. Price P_t^{pk} was obtained in the same manner. Reference prices and index prices were provided by the Central Bank of Paraguay.

3.2 Stationarity test

A stationary test was performed for all variables. A series is said to be stationary if its mean and variance are constant over time, and the covariance between two values from the series depends only on the length of time separating the two values, and not on the actual times at which the variables are observed (Enders, 2004).

Let y_t represent a time series such as any of the series listed in Table 3.1 which can be modeled as follows,

$$y_t = \alpha + \rho y_{t-1} + v_t \tag{3.1}$$

where α indicates a constant, ρ is the lagged dependent variable coefficient, v_t is the error terms, y_{t-1} is the lagged dependent variable and $t = 1 \ldots T$. If $\rho = 1$, then y_t is a non-stationary series, i.e. it has a unit root. Econometric models using non-stationary variables may yield misleading results since the relation among the variables could be spurious. In order to test for stationarity, the Augmented Dickey-Fuller (ADF) test was performed because it allows for higher-order equations, i.e. ρth-order autoregressive process (Enders, 2004). This test assumes that ϵ_t is independent and has a constant variance (Enders, 2004). Equation 3.1 can be expressed in first differences as follows,

$$y_t - y_{t-1} = \rho y_{t-1} - y_{t-1} + \epsilon_t$$

$$\Delta y_t = (\rho - 1) y_{t-1} + \epsilon_t$$

$$\Delta y_t = \gamma y_{t-1} + \epsilon_t \tag{3.2}$$

The null hypothesis is that the process has a unit root and the alternative hypothesis is that the series is generated by a stationary process. That is,

- If H_0: $\gamma = 0$ is true, then y_t follows a random walk and therefore it is non-stationary since $\gamma = \rho - 1 = 0, \rho = 1$.

- If H_1: $\gamma < 0$ is true, then y_t is stationary since $\gamma = \rho - 1 < 0, \rho < 1$.

Series y_t is tested using three different models, with a constant and a trend, with a constant only or with no constant and no trend. These models are as follows,

- Constant and trend model:

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \alpha_2 trend + \sum_{i=1}^{m} \beta_i \Delta y_{t-i} + \epsilon_t \qquad (3.3)$$

where α_0 indicates the constant, α_2 is the estimated coefficient for $trend$ and β_i indicates the estimated coefficient for y_{t-i}.

- Constant model:

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \sum_{i=1}^{m} \beta_i \Delta y_{t-i} + \epsilon_t \qquad (3.4)$$

- No constant and no trend model:

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{m} \beta_i \Delta y_{t-i} + \epsilon_t \qquad (3.5)$$

In order to identify the appropiate lag structure for y_t, the Akaike Information Criteria (AIC) was employed[7]. First, the ADF test was performed using equation 3.3. All of the variables, except variable Q_t^{bf}, are non-stationary with trend and constant. The presence of trend and constant in each of these models was tested using the ϕ_3 and ϕ_1 test statistic[8]. All models present no trend and no constant, except for variable R_t which presents constant only. Equation 3.4 was performed to test for stationarity of R_t. The other variables were tested using equation 3.5 and the results indicate that all variables are non-stationary, without trend and without constant. The same procedure was applied for series in first differences. All of the series are stationary in the model without trend and without constant, except for variable I_t which is non-stationary in first differences in any of the three

[7] $AIC(k) = 2ln(L) + 2k$ where k indicates the number of parameters estimated and $ln(L)$ is the maximized log-likelihood of the model.

[8] An unrestrictive and a restrictive model are estimated to calculate ϕ_3 and ϕ_1. Then, sum of square residuals (SSR) is obtained for each model. Finally, ϕ_i is obtained as follows,

$$\phi_i = \frac{[SSR_{restrictive} - SSR_{unrestricted}]/r}{SSR_{unrestricted}/(T-k)}$$

where *r* represents number of restrictions, *T* represents number of observations and *k* represents number of parameters in the unrestricted model (Enders, 2004).

models. Results of the unit root test for all variables in levels and first differences are presented in Table 3.2. Table 3.3 shows the ϕ_i test statistic for variables in both levels and first differences.

Table 3.2: Results of Dickey-Fuller test

	In levels			In first differences		
Variables	**Lag(s)**	**$\hat{\tau}$ value**	**Model**	**Lag(s)**	**$\hat{\tau}$ value**	**Model**
Q_t^{bc}	6	0.18	NCNT	6	-2.52^{**}	NCNT
Q_t^{c}	6	-0.56	NCNT	6	-3.84^{**}	NCNT
Q_t^{bf}	3	-3.62^{*}	CT	5	-3.90^{**}	NCNT
P_t^{bc}	6	0.27	NCNT	6	-2.09^{**}	NCNT
P_t^{c}	6	0.39	NCNT	6	-2.67^{**}	NCNT
P_t^{bf}	6	-0.05	NCNT	6	-2.97^{**}	NCNT
P_t^{h}	6	-0.23	NCNT	6	-2.31^{**}	NCNT
P_t^{b}	6	0.60	NCNT	6	-2.50^{**}	NCNT
P_t^{cc}	6	0.33	NCNT	6	-2.37^{**}	NCNT
P_t^{ck}	6	-0.05	NCNT	6	-2.91^{**}	NCNT
P_t^{pk}	6	0.62	NCNT	6	-3.10^{**}	NCNT
S_t	1	-0.48	NCNT	1	-6.00^{**}	NCNT
R_t	6	-3.92^{*}	CNT	6	-3.61^{**}	NCNT
I_t	6	1.13	NCNT	6	-1.17	NCNT
E_t	6	-0.18	NCNT	6	-3.18^{**}	NCNT
Y_t	6	0.82	NCNT	6	-2.15^{**}	NCNT
K_t	6	0.10	NCNT	5	-1.84^{**}	NCNT

Note: * and ** indicates 1% and 5% level of level of significance.
CT: constant and trend;
CNT: constant and no trend;
NCNT: no constant and no trend

Table 3.3: Test statistic ϕ_i of the Dickey-Fuller test

	Level		First Differences	
Variables	ϕ_3	ϕ_1	ϕ_3	ϕ_1
Q_t^{bc}	0.18	0.93	< 0.01	< 0.01
Q_t^{c}	0.09	1.59	0.35	0.04
Q_t^{bf}	0.02	4.00	0.16	0.07
P_t^{bc}	0.01	0.64	< 0.01	< 0.01
P_t^{c}	2.79	0.08	1.77	0.07
P_t^{bf}	0.40	1.01	1.55	< 0.01
P_t^{h}	0.03	0.97	0.12	< 0.01
P_t^{b}	2.06	0.06	1.00	0.16
P_t^{cc}	1.75	0.37	0.96	0.05
P_t^{ck}	0.30	1.11	0.30	< 0.01
P_t^{pk}	1.22	0.36	0.76	0.16
S_t	< 0.01	3.40	0.04	< 0.01
R_t	0.29	5.07^{*}	0.02	< 0.01
I_t	1.05	0.84	0.51	0.67
E_t	1.82	0.94	2.33	< 0.01
Y_t	0.45	0.34	0.02	0.07
K_t	0.62	1.78	0.01	0.02
Note:	* indicates 5% of level of significance.			

Chapter 4

Methods

This Chapter includes structural equations of the Paraguayan Beef Supply Chain. A partial equilibrium framework is used to assess the welfare changes on consumers, slaughterhouses and producers during the beef export growth period, following the model proposed by Jeong, Garcia, and Bullock (2003). The estimation method is then described, including the identification of the system, the role of instrumental variables and the 3SLS method. Finally, the theory underlying welfare changes of the different economic agents is presented.

4.1 Paraguayan Beef Supply Chain model

Demand-supply systems for each market in the Paraguayan Beef Supply Chain are specified, based on the discussion in Chapter 1. Equations in the system are estimated in first differences (except the dummy variables) based on the results of the stationatity tests performed in Chapter 3 suggesting non-stationary variables in levels.

The first system represents the Fattening Market as follows,

$$\Delta Q_t^{bc,d} = \alpha_{11} + \alpha_{12}\Delta P_t^{bc} + \alpha_{13}\Delta P_t^{c} + \alpha_{14}\Delta S_t + \alpha_{15}\Delta P_{t-1}^{bc} + \epsilon_t^{bc,d} \tag{4.1}$$

$$\Delta Q_t^{bc,s} = \alpha_{21} + \alpha_{22}\Delta P_t^{bc} + \alpha_{23}\Delta P_t^{h} + \alpha_{24}\Delta Q_t^{h} + \alpha_{25}\Delta P_t^{cc} + \alpha_{26}\Delta P_t^{b} + \\ + \alpha_{27}\Delta R_t + \alpha_{28}\Delta I_t + \alpha_{29}\Delta P_{t-1}^{bc} + \epsilon_t^{bc,s} \tag{4.2}$$

$$\Delta Q_t^{bc,d} = \Delta Q_t^{bc,s} \tag{4.3}$$

where $Q_t^{bc,d}$ is the quantity of bull calves demanded, $Q_t^{bc,s}$ is the quantity of bull calves supplied in auction markets for feeding purposes, α_{ii} are estimated coefficients, ϵ_t^{bc} are random errors and the rest of the variables have been defined in Table 3.1. Equation 4.3 states the market clearing condition. These quantities, along with bull calf price P_t^{bc}, are the endogenous variables in this system. The explanatory variables in equation 4.1 are: the carcass price P_t^c, the ratio between total slaughtered animals and total herd S_t and the lagged bull calf price P_{t-1}^{bc}. The price P_t^c comes from the Slaughter Market. Because it represents income for the feeder producers it is expected to be positive. The ratio S_t indicates the needs of replacement for producers. The higher S_t, the higher the demand of replacement and, therefore, it is also expected to be positive. The lagged bull calf price P_{t-1}^{bc} captures the dynamics of the market. The explanatory variables in equation 4.2 are: the heifer price P_t^h, the heifer quantity Q_t^h, the cull cow price P_t^{cc}, the bull price P_t^b, rain R_t, private livestock investments I_t and the lagged bull calf price P_{t-1}^{bc}. The price P_t^h, the quantity Q_t^h and the price P_t^{cc} are by-products in this market and, therefore, they are all expected to be positive. The price P_t^b represents input cost and, therefore, it is expected to be negative. The variable R_t represents rain in livestock areas. Large amount of rain likely yields high quantity and quality of pasture and, therefore, it is expected to be positive. The variable I_t is private livestock investment and it is expected to be positive due to high investment levels observed in the livestock sector.

The second system represents the Slaughter Market as follows,

$$\Delta Q_t^{c,d} = \alpha_{31} + \alpha_{32}\Delta P_t^{c} + \alpha_{33}\Delta P_t^{bf} + \alpha_{34}\Delta E_t + \alpha_{35} D_t + \alpha_{36}\Delta Q_{t-1}^{c,d} + \\ + \alpha_{37}\Delta P_{t-2}^{c} + \epsilon_t^{c,d} \tag{4.4}$$

$$\Delta Q_t^{c,s} = \alpha_{41} + \alpha_{42}\Delta P_t^c + \alpha_{43}\Delta P_t^{bc} + \alpha_{44}\Delta P_t^h + \alpha_{45}\Delta P_t^{cc} + \alpha_{46}W_t + \\ + \alpha_{47}D_t + \alpha_{48}\Delta Q_{t-1}^{c,s} + \alpha_{49}\Delta P_{t-2}^c + \epsilon_t^{c,s} \quad (4.5)$$

$$\Delta Q_t^{c,d} = \Delta Q_t^{tc} - \Delta Q_t^x \quad (4.6)$$

where $Q_t^{c,d}$ and $Q_t^{c,s}$ are carcass quantities demanded and supplied for domestic consumption. These quantities, along with the carcass price P_t^c, are endogenous variables. The explanatory variables in equation 4.4 are: the beef price P_t^{bf}, the exchange rate E_t, the lagged dependent variable $Q_{t-1}^{c,d}$ and the lagged carcass price P_{t-2}^c. The price P_t^{bf} comes from the Beef Retail Market and it represents income for slaughterhouses and, therefore, it is expected to be positive. The exchange rate E_t is the exchange rate between the guarani and the U.S. dollar. Exchange rate represents a proxy for beef international prices, so if the exchange rate increases there will be more beef for international market, and less beef for domestic market. Thus, it is expected a negative sign for this variable. The lagged dependent variable $Q_{t-1}^{c,d}$ captures the dynamics of the market and serves as a good instrument for this system. The lagged carcass price P_{t-2}^c captures the dynamics of the market. The explanatory variables in equation 4.5 are: the bull calf price P_t^{bc}, the heifer price P_t^h, the cull cow price P_t^{cc}, winter W_t, lagged dependent variable $Q_{t-1}^{c,s}$, dummy variable D_t and the lagged carcass price P_{t-2}^c. The price P_t^{bc}, the price P_t^h and the price P_t^{cc} come from the Fattening Market and represent input costs for the feeder producers and, therefore, are all expected to be negative. The variable W_t is a dummy variable for winter months (May, June, July, August and September) when beef supply decreases, therefore, it is expected to be negative. Equation 4.6 states the market clearing condition, that is, the demand of carcass $Q_{c,t}^d$ is equal to the difference between total carcass quantities for domestic and international markets Q_t^{tc} and quantity of beef exports Q_t^x.

The third system represents the Beef Retail Market as follows,

$$\Delta Q_t^{bf,d} = \alpha_{51} + \alpha_{52}\Delta P_t^{bf} + \alpha_{53}\Delta P_t^{ck} + \alpha_{54}\Delta P_t^{pk} + \alpha_{55}\Delta Y_t + \alpha_{56} D_t + \\ + \alpha_{57}\Delta P_{t-1}^{bf} + \epsilon_t^{bf,d} \tag{4.7}$$

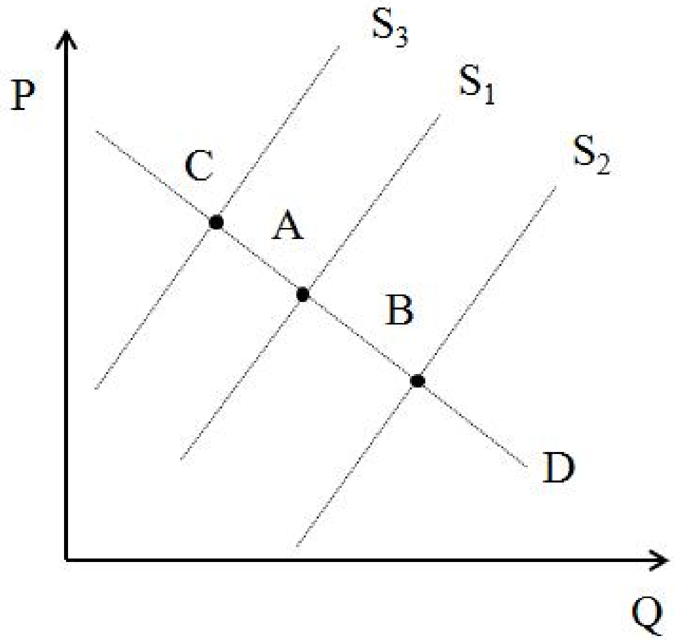
$$\Delta Q_t^{bf,s} = \alpha_{61} + \alpha_{62}\Delta P_t^{bf} + \alpha_{63}\Delta P_t^{c} + \alpha_{64}\Delta K_t + \alpha_{65}\Delta P_{t-1}^{bf} + \epsilon_t^{bf,s} \tag{4.8}$$

$$\Delta Q_t^{bf,d} = \Delta Q_t^{bf,s} \tag{4.9}$$

where $Q_t^{bf,d}$ and $Q_t^{bf,s}$ are per capita beef quantities demanded and supplied. These variables along with the beef price P_t^{bf} are the endogenous variables of this system. The explanatory variables in equation 4.7 are: the chicken price P_t^{ck}, the pork price P_t^{pk}, the income Y_t, the dummy variable D_t and the lagged beef price P_{t-1}^{bf}. The price P_t^{ck} and the price P_t^{pk} represent substitute goods. Both of them are expected to be positive. The income Y_t is a monthly index of Paraguayan economic activity which is a proxy for income and therefore it is expected to be positive. The lagged beef price P_{t-1}^{bf} captures the dynamics of the market. The explanatory variables in equation 4.8 are: the carcass price P_t^c, the interest rate K_t and the lagged beef price P_{t-1}^{bf}. The price P_t^c comes from the Slaughter Market and it represents input cost and, therefore, is expected to be negative. The interest rate K_t represents the cost of capital which is a commercial lending rate and, therefore, is expected to be negative. Equation 4.9 states the market clearing condition.

Diagnostic tests are performed for the residuals ϵ_t. First, the residuals are plotted to check for the presence of any pattern. Then, the autocorrelation (ACF) and the partial autocorrelation functions (PACF) are estimated. When there is significant presence of autocorrelation identified in the ACF and PACF the appropiate lag dependent structure is incorporated into the model. The ACF and PACF plots for the residuals ($\epsilon_t^{bc,d}$, $\epsilon_t^{bc,s}$, $\epsilon_t^{c,d}$, $\epsilon_t^{c,s}$, $\epsilon_t^{bf,d}$ and $\epsilon_t^{bf,s}$) are shown in Appendix A.4.

Figure 4.1: Tracing out a demand curve



4.2 Simultaneous equations and instrumental variable estimator

Equations 4.3, 4.6 and 4.9 state the market clearing condition in each market that represents equilibrium quantities and prices. A change in the explanatory variables in the demand and/or supply equation in any of these markets (equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8) will shift the demand and/or supply curve from the initial equilibrium to a new position. Therefore, both demand and supply equations are necessary to describe the data-generation process (Griffths, Hill, and Judge, 1993). Figure 4.1 shows an initial equilibrium position in point A. If the supply curve shifts from S_1 to S_2 to S_3 and the demand curve D does not shift, the equilibrium data points A, B and C trace out the D curve. However, the supply curve is not identified because there is no shift in the demand curve (Greene, 2008).

If the disturbances from the supply and/or demand equation change (because one or more omitted explanatory variables change), then the supply and/or demand curve shifts and the equilibrium quantity (Q) and price (P) change. The disturbances are assumed to be related across equations, that is,

$$Cov(\epsilon_t^{bc,d}, \epsilon_t^{bc,s}) = E[\epsilon_t^{bc,d}\epsilon_t^{bc,s}] = \sigma_{d,s}^{bc} \neq 0,$$

$$Cov(\epsilon_t^{c,d}, \epsilon_t^{c,s}) = E[\epsilon_t^{c,d}\epsilon_t^{c,s}] = \sigma_{d,s}^{c} \neq 0$$

$$Cov(\epsilon_t^{bf,d}, \epsilon_t^{bf,s}) = E[\epsilon_t^{bf,d}\epsilon_t^{bf,s}] = \sigma_{d,s}^{bf} \neq 0$$

which imply that the disturbances $\epsilon_t^{bc,d}$ and $\epsilon_t^{bc,s}$, $\epsilon_t^{c,d}$ and $\epsilon_t^{c,s}$, $\epsilon_t^{bf,d}$ and $\epsilon_t^{bf,s}$ are contemporaneously correlated due to the simultaneity in determining Q and P. The fact that P is an endogenous right-hand-side variable correlated with the disturbances violates one of the fundamental assumptions of the Classical Linear Regression Model which requires that the covariance between the explanatory variables, in this case P, and the disturbances is zero. In this case, the OLS estimator for P will be biased and inconsistent (Griffths, Hill, and Judge, 1993).

Due to the endogeneity problem (prices and quantity jointly determined) changes in Q are related to changes in P and ϵ_t and therefore it is difficult to measure the impact of P on Q only. In this scenario, the system needs exogenous or explanatory variables to be included in order to measure this impact. These variables are known as *instrumental variables*. Equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8 are estimated using instrumental variables. An instrumental variable Z has two important properties (Greene, 2008):

1. it is correlated with the endogenous variable P,

2. it is not correlated with the error terms ϵ_t.

The variable Z has the only source of correlation with Q only indirectly via P. This implies that Z allows the elimination of the effects of P on ϵ_t while considering only the effect on Q, thus making it possible to obtain a valid estimate (Stock and Watson, 2003).

To assess the above two properties, the tests are:

- Instrument relevance: is related to how well Z explains variations of P, i.e. $Cov(Z, P) \neq 0$. The test assumes there is a single endogenous variable, P. If Z does not explain clearly the variations of P, Z is considered a weak instrument. The test is performed using an F-test after regressing the instruments on P via OLS (Stock and Watson, 2003). Results of this test are presented in Table 4.1.

- Instrument exogeneity: implies that the instrument is not correlated with the disturbances, i.e. $Cov(Z, \epsilon_t) = 0$. To test this null hypothesis, the Wu test (Wu, 1973) is performed (Greene, 2008). This test works in two stages as follows,
  - the first stage consists of regressing $\mathbf{X}$ on P via OLS, where $\mathbf{X}$ is a matrix compounded by all variables from one equation of the system, namely $\mathbf{X_1}$, and by instruments which are the exogenous variables from the other equation of the system, namely $\mathbf{Z}$. Then, $\hat{P}$ is obtained by predicting P;
  - the second stage consists of regressing $\mathbf{X_1}$, P and $\hat{P}$ on Q via OLS. The t-test is used to assess the significance of $\hat{P}$.

Results of this test are presented in Tables 4.2 and 4.3. The test suggests that P_t^{bc} and P_t^c from demand equations 4.1 and 4.4 and P_t^{bf} from supply equation 4.8 are endogenous; however, P_t^{bc} and P_t^c from supply equations 4.2 and 4.5 and P_t^{bf} from demand equation 4.7 appear to be exogenous. Thus, Wu test results show that some of these prices are endogenous and some of them are exogenous. The OLS and SUR methods will produce consistent estimators if $Cov(P, \epsilon) = 0$ only; and, 2SLS and 3SLS will produce consistent estimators under both cases ($Cov(P, \epsilon) = 0$ or $Cov(P, \epsilon) \neq 0$). Therefore, 3SLS is used for estimation to account for endogeneity due to high contemporaneous correlation between the disturbances of the equations in the systems[1]. Tables A.1.1, A.1.2, A.1.3, A.1.4, A.1.5 and A.1.6 in Appendix A.1 show the results of regressing individual equations 4.1, 4.2, 4.4, 4.5, 4.7 and the 4.8 via OLS[2] and 2SLS and the results of regressing systems equations (4.1 and 4.2, 4.4

[1]Contemporaneous correlation in the Fattening Market is 0.59, in the Slaughter Market is 0.63 and in the Beef Retail Market is 0.07.

[2]Results of autocorrelation and heteroscedasticity are shown in Appendinx A.1. White corrected standard errors are used in equations that show no constant variance. The Generalized Method of Moments (GMM) is used in equation 4.5 due to autocorrelation.

and 4.5, 4.7 and 4.8) via 3SLS and SUR. Results show that most of the estimated coefficients are similar in magnitudes; however, they are insignificant, except for few cases which are significant in at least one method.

Table 4.1: Instrument relevance

Bull calf price (P_t^{bc})			Carcass price (P_t^{c})			Beef price (P_t^{bf})		
Variable	**Coefficient**	**t-value**	**Variable**	**Coefficient**	**t-value**	**Variable**	**Coefficient**	**t-value**
ΔS_t	$371,100.80^{**}$	2.26	ΔP_t^{bf}	0.43	0.93	ΔP_t^{ck}	0.02	0.20
ΔP_t^{c}	-20.93	-0.21	ΔE_t	-0.49	-1.45	ΔP_t^{pk}	0.02	0.46
ΔP_t^{h}	0.11	1.00	ΔP_t^{bc}	< -0.01	-0.49	ΔY_t	0.29	0.21
ΔR_t	933.20^{**}	2.31	ΔP_t^{h}	< -0.01	-0.89	ΔD_t	25.75	0.34
ΔI_t	-1.03^{**}	-2.58	ΔP_t^{cc}	0.45^{**}	2.60	ΔP_t^{c}	0.11^{**}	2.09
ΔP_t^{b}	95.01	0.46	W_t	117.59	1.12	ΔK_t	-36.96	-1.46
ΔP_t^{cc}	-70.67	-0.37	D_t	-94.74	-0.30	ΔP_{t-1}^{bf}	-0.39^{**}	-2.35
ΔQ_t^{h}	-112.01	-1.05	ΔQ_{t-1}^{c}	< -0.01	-0.33			
ΔP_{t-1}^{bc}	-0.40^{**}	-2.36	ΔP_{t-2}^{c}	0.23	1.61			

Note: $*$, $**$ and $***$ indicate 1%, 5% and 10% level of significance. For P_t^{bc} F-value=2.42 and adj $R^2 = 0.27$; For P_t^{c} F-value=2.52 and adj $R^2 = 0.28$; For P_t^{bf} F-value=2.08 and adj $R^2 = 0.18$.

Table 4.2: Instrument exogeneity: Wu test for demand equations

Dependent variable: ΔQ_t^{bc}			*Dependent variable:* ΔQ_t^{c}			*Dependent variable:* ΔQ_t^{bf}		
Variable	**Coefficient**	**t-value**	**Variable**	**Coefficient**	**t-value**	**Variable**	**Coefficient**	**t-value**
$Constant$	-12.01	-0.36	$Constant$	-469.19	< -0.01	$Constant$	-0.01	-0.35
ΔP_t^{bc}	< 0.01	1.07	ΔP_t^{c}	745.69	1.32	ΔP_t^{bf}	< -0.01	-0.76
$\Delta \hat{P}_t^{bc}$	$< -0.01^{***}$	-1.98	$\Delta \hat{P}_t^{c}$	$-2,451.77^{**}$	-2.36	$\Delta \hat{P}_t^{bf}$	< -0.01	-0.81
ΔS_t	451.42^{**}	2.37	ΔP_t^{bf}	607.45	0.43	ΔP_t^{ck}	< 0.01	0.11
ΔP_t^{c}	0.18^{***}	1.84	ΔE_t	$-1,780.10$	-1.60	ΔP_t^{pk}	< 0.01	0.28
ΔP_{t-1}^{bc}	< 0.01	0.84	D_t	$2,861,874.00^{*}$	3.19	ΔY_t	0.01^{***}	1.93
			ΔQ_{t-1}^{c}	-0.38^{**}	-2.64	D_t	0.16	1.06
			ΔP_{t-2}^{c}	-104.08	-0.23	ΔP_{t-1}^{bf}	< -0.01	-0.58

Note: $*$, $**$ and $***$ indicate 1%, 5% and 10% level of significance.

Table 4.3: Instrument exogeneity: Wu test for supply equations

Dependent variable: ΔQ_t^{bc}			*Dependent variable:* ΔQ_t^{c}			*Dependent variable:* ΔQ_t^{bf}		
Variable	**Coefficient**	**t-value**	**Variable**	**Coefficient**	**t-value**	**Variable**	**Coefficient**	**t-value**
$Constant$	11.11	0.31	$Constant$	$194,602.20$	0.91	$Constant$	< -0.01	-0.23
ΔP_t^{bc}	< 0.01	1.24	ΔP_t^{c}	745.69	1.42	ΔP_t^{bf}	< -0.01	-0.76
$\Delta \hat{P}_t^{bc}$	< 0.01	0.16	$\Delta \hat{P}_t^{c}$	294.24	0.19	$\Delta \hat{P}_t^{bf}$	0.01^{***}	1.87
ΔP_t^{h}	< -0.01	-1.67	ΔP_t^{bc}	-0.67	-0.68	ΔP_t^{c}	$< -0.01^{***}$	-1.90
ΔR_t	-0.72	-1.28	ΔP_t^{h}	-0.71	-0.92	ΔK_t	0.20^{***}	1.81
ΔI_t	< -0.01	-0.15	ΔP_t^{cc}	$-1,123.74$	-1.34	ΔP_{t-1}^{bf}	< 0.01	1.63
ΔP_t^{b}	-0.29	-1.29	ΔW_t	$-485,647.60$	-1.34			
ΔP_t^{cc}	0.19	0.81	D_t	$3,605,744.00^{*}$	4.45			
ΔQ_t^{h}	0.49^{*}	4.02	ΔQ_{t-1}^{c}	-0.46^{*}	-3.09			
ΔP_{t-1}^{bc}	$< 0.01^{**}$	2.14	ΔP_{t-2}^{c}	-626.84	-1.18			

Note: $*$, $**$ and $***$ indicate 1%, 5% and 10% level of significance.

A simultaneous equations system can be estimated if it is complete, that is, if the number of variables that are stochastic within the system is equal to the number of linear structural equations. If the system is complete, the explanatory variables are nonstochastic, i.e. they do not covary with the disturbances in the system. Each of the three systems in the Paraguayan model is complete since there are two stochastic variables (prices and quantities) and two structural equations (demand and supply) in each system. Besides this general rule, there are two conditions for identification: order condition and rank condition.

- *Order condition* is a necessary condition for identification to determine if the system is underidentified, just identified or overidentified. The number of exogenous variables excluded from the *i*th structural equation must be at least as great as the number of endogenous variables included less one. This ensures there are at least as many instruments as regressors (Cameron and Trivedi, 2009). A system will be just identified if the number of exogenous variables excluded from the *i*th structural equation equals the number of endogenous variables included less 1. A system will be underidentified if the number of exogenous variables excluded from the *i*th structural equation is lower than the number of endogenous variables included less one. It will be overidentified if the number of those variables is higher than the number of endogenous variables included less one (Johnston and DiNardo, 1996). The above condition implies that a system will be estimated if it is just identified or overidentified (Greene, 2008). This implies that each equation in the system has enough explanatory or exogenous variables to be identified (Griffths, Hill, and Judge, 1993). The three systems presented in Section 4.1 are overidentified, since they have more explanatory variables than endogenous variables (See Appendix A.2 for proof.).

- *Rank condition* is a necessary and sufficient condition for identification[3]. The rank condition states that in a model containing M equations in M endogenous variables, an equation is identified if and only if at least one nonzero determinant of order

[3]The term *rank* refers to the rank of a matrix which is the largest number of linearly independent rows or columns of that matrix (Gujarati, 2004)

$(M-1)(M-1)$ can be constructed from the coefficients of the variables (both endogenous and predetermined) excluded from that particular equation but included in the other equations of the model (Gujarati, 2004). Although the order condition can specify that the system is identified, the rank condition can show that it is not because columns and/or rows of a particular matrix are not linearly independent, which indicates that there is some relationship between some of the variables in the equation. Appendix A.3 provides proof of this condition. Following the rule, it shows that each of the three systems are identified.

Both the order and rank conditions indicate that the three systems are identified. Therefore, it is possible to estimate them. To do this, 3SLS is performed.

4.3 Three Stage Least Squares method

The estimation is performed using the 3SLS method. This method allows for the possibility of contemporaneous correlation between the disturbances in different structural equations, $Cov(\epsilon_1, \epsilon_2) \neq 0$ (Johnston and DiNardo, 1996). Equations 4.1 and 4.2, 4.4 and 4.5, 4.7 and 4.8 can be expressed separately as a system of equations as follows,

$$\begin{bmatrix} Q_t^d \\ Q_t^s \end{bmatrix} = \begin{bmatrix} C_{1,t} & 0 \\ 0 & C_{2,t} \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \begin{bmatrix} \epsilon_{1,t} \\ \epsilon_{2,t} \end{bmatrix} \tag{4.10}$$

where $\mathbf{C_{i,t}}$ $(i = 1, 2)$ includes all exogenous $(\mathbf{X})$ and endogenous variables $(\mathbf{P})$ in the right-hand-side of each equation from each system. In matrix form, 4.10 can be written as follows,

$$\mathbf{Q} = \mathbf{C}\alpha + \mathbf{\Sigma} \tag{4.11}$$

where

$$\Sigma = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \end{bmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{11} I_T & \sigma_{12} I_T \\ \sigma_{21} I_T & \sigma_{22} I_T \end{pmatrix} = W \right] \tag{4.12}$$

which recognizes that the contemporaneous correlation between the equation disturbances may not be zero, i.e. it may be $\mathbf{W}$.

The three different stages of the 3SLS method are the following (Greene, 2008, Johnston and DiNardo, 1996):

The *first stage* is to estimate the endogenous variable $\mathbf{P}$ in $\mathbf{C}$ in terms of the exogenous variables $\mathbf{X}$ in $\mathbf{C}$. This is performed via OLS using $\mathbf{P}$ as the dependent variable and all exogenous variables $\mathbf{X}$ as explanatory variables,

$$\mathbf{P} = \mathbf{X}\pi + \mathbf{\Sigma} \tag{4.13}$$

where π is estimated as follows,

$$\hat{\pi} = [\mathbf{X}'\mathbf{X}]^{-1}\mathbf{X}'\mathbf{C} \tag{4.14}$$

The predicted value for $\mathbf{C}$ is,

$$\hat{\mathbf{C}} = \mathbf{X}\hat{\pi} = \mathbf{X}[\mathbf{X}'\mathbf{X}]^{-1}\mathbf{X}'\mathbf{C} \tag{4.15}$$

The *second stage* uses $\hat{\mathbf{C}}$ to run an OLS in each equation in the system, i.e. in each equation in 4.10 as follows,

$$\begin{bmatrix} \hat{Q}_t^d \\ \hat{Q}_t^s \end{bmatrix} = \begin{bmatrix} \hat{C}_{1,t} & 0 \\ 0 & \hat{C}_{2,t} \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \begin{bmatrix} \epsilon_{1,t} \\ \epsilon_{2,t} \end{bmatrix} \tag{4.16}$$

since $\hat{\mathbf{C}} = [\hat{\mathbf{P}} \;\; \mathbf{X}]$. Then, the estimated coefficients can be expressed as follows,

$$\hat{\alpha}_{\mathbf{2SLS}} = [\hat{\mathbf{C}}'\mathbf{W}^{-1}\hat{\mathbf{C}}]^{-1}\hat{\mathbf{C}}'\mathbf{W}\hat{\mathbf{Q}} \tag{4.17}$$

where $\mathbf{W}$ is the covariance matrix defined in 4.12. Since $\mathbf{W}$ is unknown, it is estimated in the third stage.

The *third stage* estimates $\mathbf{W}$ by estimating σ_{ij} for the contemporaneous covariances for the equation 4.16. The predicted values that are used to estimate σ_{ij} (ϵ_1 and ϵ_2) are obtained as follows,

$$\hat{\epsilon}_{1t} = \hat{Q}_t^d - \hat{\mathbf{C}}_{\mathbf{1},\mathbf{t}}\hat{\alpha}_1$$

$$\hat{\epsilon}_{2t} = \hat{Q}_t^s - \hat{\mathbf{C}}_{\mathbf{2},\mathbf{t}}\hat{\alpha}_2$$

where $\hat{Q}_t^d$, $\hat{Q}_t^s$, $\hat{\mathbf{C}}_{\mathbf{1},\mathbf{t}}$ and $\hat{\mathbf{C}}_{\mathbf{2},\mathbf{t}}$ are predicted values and $\hat{\alpha}_1$ and $\hat{\alpha}_2$ are the estimated coefficients in the second-stage. Then, for $i \neq j$ $\hat{\sigma}_{ij}$ is defined as follows,

$$\hat{\sigma}_{ij} = \frac{\sum_{t-1}^{n} \hat{\epsilon_{it}}\hat{\epsilon}_{jt}}{n}$$

For $i = j$, $\hat{\sigma}_{ij}$ is defined as follows,

$$\hat{\sigma}_{ij} = \frac{\sum_{t-1}^{n} \hat{\epsilon}_{it}^2}{n}$$

The 3SLS estimator is,

$$\hat{\alpha}_{\mathbf{3SLS}} = [\hat{\mathbf{C}}'\hat{\mathbf{W}}^{-1}\hat{\mathbf{C}}]^{-1}\hat{\mathbf{C}}'\hat{\mathbf{W}}\hat{\mathbf{Q}} \tag{4.18}$$

4.4 Estimating demand and supply functions

To use 3SLS estimated coefficients to calculate elasticities and welfare changes, it is neccessary to transform predicted bull calf, carcass and beef quantities in first differences into predicted values in levels. The methodology in Epple and McCallum (2006) was used to transform each of the dependent quantities in equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8 from first differences into levels. The estimated model in differences can be written as,

$$\Delta\hat{Q}_t = \hat{\alpha} + \hat{\alpha}_P \Delta P_t + \Delta\mathbf{A}\hat{\alpha}_{\mathbf{A}} \tag{4.19}$$

where $\hat{Q}_t$ represents the predicted quantities, P_t is the observed own-price of Q_t, $\mathbf{A}$ is a $n \times k$ (n is the number of observations and k is the number of variables) matrix of observed values of the explanatory variables from equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8, $\hat{\alpha}$ is a constant, $\hat{\alpha}_P$ is the estimated coefficient of P_t and $\hat{\alpha}_{\mathbf{A}}$ is a $k \times 1$ vector matrix of estimated coefficients of $\mathbf{A}$.

Equation 4.19 can be expressed as follows,

$$Q_t - Q_{t-1} = \hat{\alpha} + \hat{\alpha}_P(P_t - P_{t-1}) + (\mathbf{A_t} - \mathbf{A_{t-1}})\hat{\alpha}_{\mathbf{A}} \tag{4.20}$$

The initial values are included in the constant $\alpha^{initial}$ as follows,

$$\alpha^{initial} = \hat{\alpha} + Q_0 - \hat{\alpha}_P P_0 - \mathbf{A_0}\hat{\alpha}_{\mathbf{A}} \tag{4.21}$$

where $\mathbf{A_0}$ is a $1 \times k$ matrix of initial observed values of the explanatory variables from equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8.

The predicted quantity $\hat{Q}_t$ is calculated as follows,

$$\hat{Q}_t = \hat{\alpha}^{initial} + \hat{\alpha}_P P_t + \mathbf{A_0}\hat{\alpha}_{\mathbf{A}} \tag{4.22}$$

Equation 4.22 represents the demand or supply function at the initial and final levels. A change in any function comes from $\mathbf{A_0}$ which shifts the demand or supply function when any explanatory variable changes its initial value to another value.

4.5 Elasticities

Own-price demand and own-price supply elasticities were computed for bull calf, carcass and beef as follows,

$$E_b^a = \frac{\partial Q_b^a}{\partial P_b^a}\frac{\overline{P}_b^a}{\overline{Q}_b^a} \tag{4.23}$$

where a indicates if the product is bull calf, carcass or beef, b indicates if it is a demand equation or a supply equation, and $\overline{P}_b^a$ and $\overline{Q}_b^a$ are average prices and quantities respectively.

The estimated coefficients from equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8 are used to compute E_b^a.

In addition, cross-price demand elasticities were computed for chicken and pork as follows,

$$E_c^{bf} = \frac{\partial Q^{bf}}{\partial P^c} \frac{\overline{P}^c}{\overline{Q}^{bf}} \tag{4.24}$$

where c indicates if the product is chicken or pork, and $\overline{P}^c$ and $\overline{Q}^{bf}$ are average chicken price or pork price and beef quantity demanded, respectively. Then, the estimated coefficient from equation 4.7 is used to compute E_c^{bf}.

4.6 Measuring welfare changes

Using the 3SLS estimates from the demand and supply systems 4.1 through 4.9, welfare changes are measured for each of the four agents of the beef supply chain which are consumers, slaughterhouses, feeder producers and breeder producers. Following the methodology proposed by Just, Hueth, and Schmitz (1982) the welfare measures are calculated by sequentially summing geometric areas behind the demand curves for consumer surplus and behind the derived input demand curves and above output supply functions for producers surplus. These demand and supply curves of beef, carcass and bull calf are plotted by using the regression estimates. Observed data was used to make scatterplots in the same figures (which may capture changes in more variables than those included in the model in Section 4.1). Figures 4.3 and 4.4 show the shift of the demand curves given by a change in relevant prices holding all other variables constant. Because these curves are a function of various prices that change at the same time (equations 4.1 to 4.9) the geometric areas are defined using line integrals. With a line integral, the function is integrated over a curve L of initial to final prices. For example, a change in consumer surplus (ΔCS) associated with a change in prices (holding income constant) from (P_1^0, ..., P_n^0, Y) to (P_1^1, ..., P_n^1, Y) is represented by the line integral:

$$\int_L -Q_1(P_1, ..., P_n, Y)dP_1, ..., -Q_n(P_1, ..., P_n, Y)dP_n \tag{4.25}$$

where Q_i is the quantity demanded of i, P_i is the price of product i, P_j ($i \neq j$) are prices of complements and substitutes of i, and Y is income. The line integral 4.25 can be represented as a definite integral using the following theorem (O'Neil, 2012):

$$\begin{aligned}\int_L -Q_1(P_1, ..., P_n, Y)dP_1, ..., -Q_n(P_1, ..., P_n, Y)dP_n = \\ \int_{P_1^0}^{P_1^1} -Q_1(P_1, P_2^0, ..., P_n^0, Y)dP_1 + ...+ \\ + \int_{P_n^0}^{P_n^1} -Q_n(P_1^1, P_2^1, ..., P_n^1, Y)dP_n\end{aligned} \tag{4.26}$$

The change in consumer surplus is not well defined when multiple prices and/or income change with prices (Just, Hueth, and Schmitz, 1982). In order to evaluate a change in consumer surplus the order in which prices or prices-income change matters. This is known as the path dependency problem, which is a path adjustment for these changes. It is important to point out that this methodology overcomes the path-dependency problem due to multiple price changes. The line integral 4.25 is independent of path L if

$$\frac{\partial Q_i(\mathbf{P}, Y)}{\partial P_j} = \frac{\partial Q_j(\mathbf{P}, Y)}{\partial P_i} \tag{4.27}$$

where $\mathbf{P} = (P_1, ..., P_n)$ (O'Neil, 2012, Just, Hueth, and Schmitz, 1982). That is, path independence of 4.25 requires symmetry. However, if Q_i is a Marshallian demand, i.e. derived from utility maximization subject to a budget constraint, symmetry can only be attained when the income effect of a price change is zero in the Slutzky decomposition[4].

[4]The Slutsky decomposition relates changes in the Marshallian demand to changes in the Hicksian demand and demostrates that changes in the demand of a good due to a price change is the result of a substitution

Therefore, this thesis assumes a low income effect due to changes in prices.

4.6.1 Consumer surplus

Consumer surplus (CS) is the area under the demand curve and above the price line. This demand curve for consumers in the Beef Retail Market is plotted using the estimates from equation 4.7 and converting the dependent beef quantity into levels using equation 4.22. Thus, the initial consumer surplus is represented by the area *abc* in Figure 4.2, with the initial equilibrium levels P_0^{bf} and Q_0^{bf}. A beef price increase from P_0^{bf} to P_1^{bf} implies a move along the demand curve, $Q^{bf,d}$. Consequently, from the initial equilibrium P_0^{bf} and Q_0^{bf} the beef price change implies a new equilibrium in P_1^{bf} and Q_1^{bf}, that is, an increase in beef price and a decrease in beef quantity demanded. Therefore, the new consumer surplus is represented by the area *ade* in Figure 4.2. Equations 4.28 and 4.29 are used to calculate the welfare change, which corresponds to area *dbce* in Figure 4.2.

$$\begin{aligned}\Delta CS =& Q^{bf,d}(P_1^{bf}, P_0^{ck}, P_0^{pk}, Y_0, D_0, P_{t-1,0}^{bf}) - \\ &- Q^{bf,d}(P_0^{bf}, P_0^{ck}, P_0^{pk}, Y_0, D_0, P_{t-1,0}^{bf})\end{aligned} \tag{4.28}$$

$$\Delta CS = -\int_{P_0^{bf}}^{P_1^{bf}} Q^{bf,d}(P^{bf}, P_0^{ck}, P_0^{pk}, Y_0, D_0, P_{t-1,0}^{bf}) dP^{bf} \tag{4.29}$$

Solving the integral 4.29 yields equation 4.30,

$$\Delta CS = -\left[(P_1^{bf} - P_0^{bf})\frac{\hat{\alpha}_{52}}{2} + (P_1^{bf} - P_0^{bf})\hat{\bar{\alpha}}^{cs}\right] \tag{4.30}$$

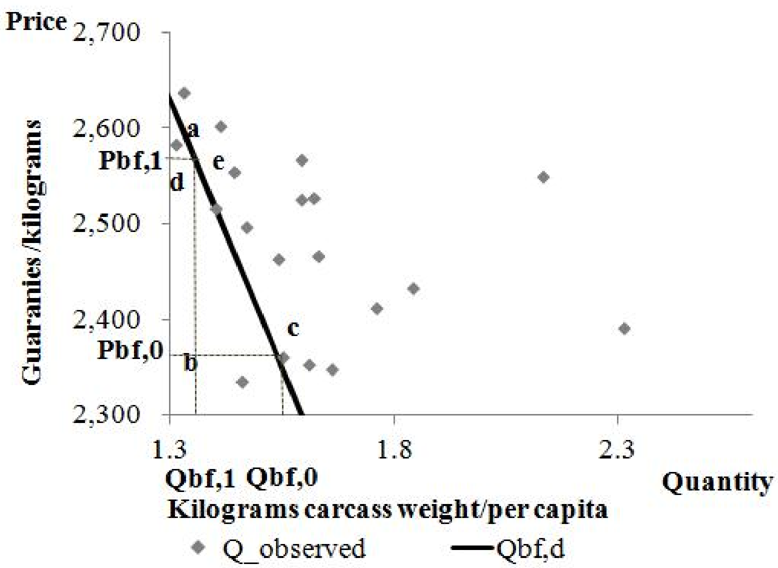
where $\hat{\bar{\alpha}}^{cs}$ is a constant calculated by multiplying average values of explanatory variables

effect and an income effect as follows:

$$\frac{\partial Q_i(P,Y)}{\partial P_j} = \frac{\partial H_i(P,U)}{\partial P_j} - \frac{\partial Q_i(P,Y)}{\partial Y}.Q_j$$

where $H_i(P,U)$ is the Hicksian demand, i.e. derived from expenditure minimization subject to a fixed level of utility (Deaton and Muelbauer, 1980)

Figure 4.2: Consumer surplus



and their estimated coefficients.

4.6.2 Producer surplus

The change in producers' welfare is assessed using a measure of quasi-rent $R = TR - TVC$, defined as the excess of gross receipts (TR) over total variable costs (TVC) (Just, Hueth, and Schmitz, 1982). Equivalently, quasi-rents in terms of profits (π) can be expressed as $R = \pi + TFC$, where $\pi = TR - TVC - TFC$ and TFC are total fixed costs. This measure of producer surplus (PS) is calculated as the area above the supply curve and below the price line of the corresponding firm or industry. Let $\pi(P, W)$ be the firm's maximized profits where P is the output price and W is the input price. The change in welfare due to a change in output and input prices is (O'Neil, 2012):

$$\Delta R = \pi(P^1, W^1) - \pi(P^0, W^0) = \int_L \frac{\partial \pi(P, W)}{\partial P} dP + \int_L \frac{\partial \pi(P, W)}{\partial W} dW \qquad (4.31)$$

Using Hotelling's Lemma which relates the firm's supply function of good *i* (Q_i) to the profit function, equation 4.31 can be written as follows,

$$\Delta R = \int_L Q_i^s(P, W)dP + \int_L -Q_j^d(P, W)dW \tag{4.32}$$

where $Q_i^s(P, W)$ is the quantity supplied of good i and $Q_j^d(P, W)$ is the quantity demanded of input j. From vector integral calculus theory, it can be shown that the line integral in 4.31 is independent of path L (O'Neil, 2012). From equation 4.26, the definite integral of equation 4.31 used to compute ΔR is:

$$\Delta R = \int_{P_0}^{P_1} Q_i^s(P, W)dP - \int_{W_0}^{W_1} Q_j^d(P, W)dW \tag{4.33}$$

Equation 4.33 is used to calculate welfare changes for slaughterhouses, feeder producers and breeder producers.

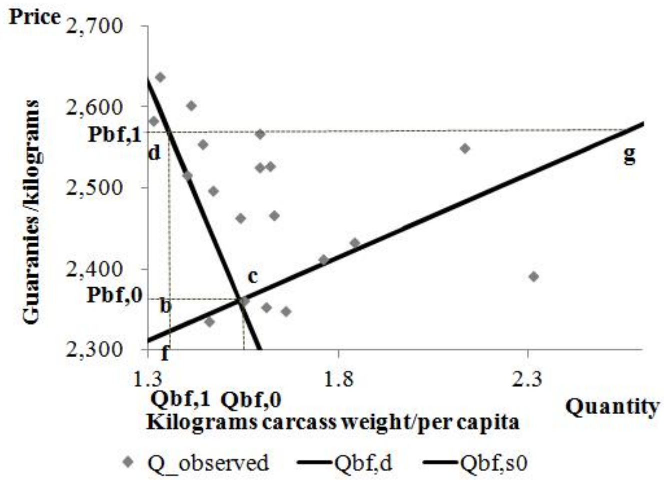
Slaughterhouses surplus

The supply curve in the output market of the slaughterhouses is plotted by using equation 4.8 and converting the dependent beef quantity into levels using equation 4.22. Also, derived input demand in the input market is plotted by using equation 4.4 and converting the dependent carcass quantity into levels using equation 4.22. Figure 4.3b shows observed data around the equilibrium levels only.

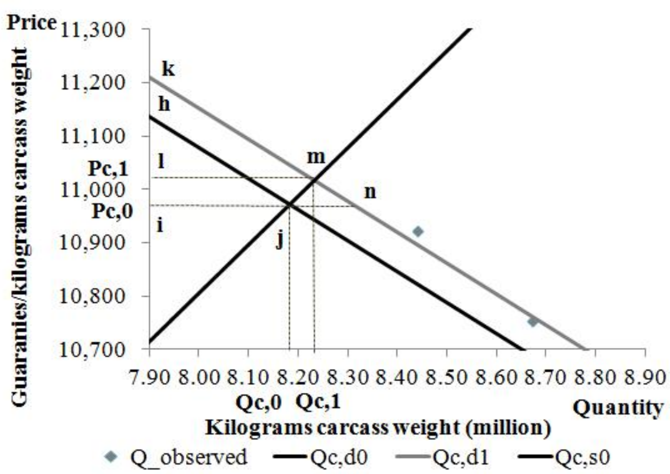
The initial slaughterhouses surplus (SS) is represented by areas *bfc* in the output market and *kin* in the input market as shown in Figure 4.3, with the initial equilibrium levels P_0^{bf} and Q_0^{bf} in the output market and P_0^c and Q_0^c in the input market. A change of P^{bf} from P_0^{bf} to P_1^{bf} in the Beef Retail Market shifts $Q^{c,d}$ upward in equation 4.4 from the Slaughter Market which in turn changes P^c to a new level from P_0^c to P_1^c. The change of P_t^{bf} from P_0^{bf} to P_1^{bf} implies a move along the supply curve $Q^{bf,s}$. The new SS is represented by the following areas *dfg* in the output market and *klm* in the input market as shown in Figure 4.3. The new equilibrium levels in the output market are P_1^{bf} and Q_1^{bf} and P_1^c and Q_1^c in the input market. Equations 4.34 and 4.35 are used to measure the welfare change, which is represented by the area *dbcg* in Figure 4.3a and area *linm* in Figure 4.3b.

Figure 4.3: Slaughterhouses surplus

(a) **Output market**



(b) **Input market**



$$\Delta SS = \left[Q^{bf,s}(P_1^{bf}, P_0^c, K_0, P_{t-1,0}^{bf,s}) - Q^{c,d}(P_1^c, P_1^{bf}, E_0, D_0, Q_{t-1,0}^{c,d}, P_{t-2,0}^c)\right] - \\ - \left[Q^{bf,s}(P_0^{bf}, P_0^c, K_0, P_{t-1,0}^{bf,s}) - Q^{c,d}(P_0^c, P_1^{bf}, E_0, D_0, Q_{t-1,0}^{c,d}, P_{t-2,0}^c)\right] \quad (4.34)$$

$$\Delta SS = \int_{P_0^{bf}}^{P_1^{bf}} Q^{bf,s}(P^{bf}, P_0^c, K_0, P_{t-1,0}^{bf,s}) dP^{bf} - \\ - \int_{P_0^c}^{P_1^c} Q^{c,d}(P^c, P_1^{bf}, E_0, D_0, Q_{t-1,0}^{c,d}, P_{t-2,0}^c) dP^c \tag{4.35}$$

Equation 4.35 is integrated and yielded equation 4.36,

$$\Delta SS = \left[(P_1^{bf} - P_0^{bf}) \frac{\hat{\alpha}_{62}}{2} + (P_1^{bf} - P_0^{bf}) \hat{\overline{\alpha}}^{ss1} \right] Pop - \\ - \left[(P_1^c - P_0^c) \frac{\hat{\alpha}_{42}}{2} + (P_1^c - P_0^c) \hat{\overline{\alpha}}^{ss2} \right] \tag{4.36}$$

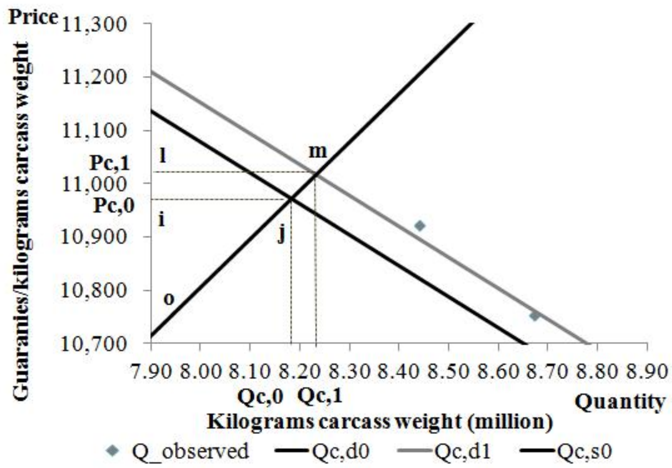
where $\hat{\overline{\alpha}}^{ss1}$ and $\hat{\overline{\alpha}}^{ss2}$ are constants calculated by multiplying average values of explanatory variables and their estimated coefficients from the output and input markets respectively, and Pop is total Paraguayan population.

Feeder producers surplus

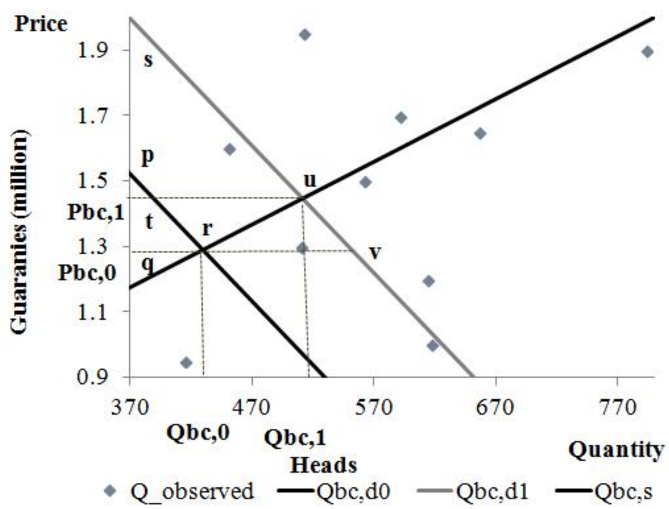
Equation 4.5 is used to plot the supply curve in the feeder producers output market and the dependent carcass quantity is converted into levels by using equation 4.22. The derived input demand in the input market is plotted by using equation 4.1 and converting the dependent bull calf quantity into levels using equation 4.22. Figure 4.4a shows observed data around the equilibrium levels only. The initial feeder producers surplus (FPS) is represented by the areas *ioj* in the output market and *sqv* in the input market as shown in Figure 4.4. The initial equilibrium levels are P_0^c and Q_0^c in the output market and P_0^{bc} and Q_0^{bc} in the input market. In the Slaughter Market, changing P^c from P_0^c to P_1^c implies a move along the carcass supply curve $Q^{c,s}$ which in turn shifts $Q^{bc,d}$ upward in equation 4.1 and P^{bc} changes to a new level from P_0^{bc} to P_1^{bc}. Thus, the new FPS is represented by the areas *lom* in the output market and *stu* in the input market as shown in Figure 4.4. The final equilibrium levels are P_1^c and Q_1^c in the output market and P_1^{bc} and Q_1^{bc} in the input market. Equations 4.37 and 4.38 are used to measure the welfare change, which is represented by area *lijm* in Figure 4.4a and area *tqvu* in Figure 4.4b.

Figure 4.4: Feeder producers surplus

(a) **Output market**



(b) **Input market**



$$\Delta FPS = \left[Q^{c,s}(P_1^c, P_0^{bc}, P_0^h, Q_0^h, P_0^{cc}, W_0, D_0, Q_{t-1,0}^{c,s}, P_{t-2,0}^{c,s}) + Q^{bc,d}(P_1^{bc}, P_1^c, S_0, P_{t-1}^{bc})\right] - \\ - \left[Q^{c,s}(P_0^c, P_0^{bc}, P_0^h, Q_0^h, P_0^{cc}, W_0, D_0, Q_{t-1,0}^{c,s}, P_{t-2,0}^{c,s}) - Q^{bc,d}(P_0^{bc}, P_1^c, S_0, P_{t-1,0}^{bc})\right] \tag{4.37}$$

$$
\begin{aligned}
\Delta FPS = &\int_{P_0^c}^{P_1^c} Q^{c,s}(P^c, P_0^{bc}, P_0^h, Q_0^h, P_0^{cc}, W_0, D_0, Q_{t-1,0}^{c,s}, P_{t-2,0}^{c,s})dP^c \\
&- \int_{P_0^{bc}}^{P_1^{bc}} Q^{bc,d}(P^{bc}, P_1^c, S_0, P_{t-1,0}^{bc})dP^{bc}
\end{aligned} \tag{4.38}
$$

Equation 4.39 is obtained after solving the integral 4.38,

$$
\begin{aligned}
\Delta FPS = &\left[(P_1^c - P_0^c)\frac{\hat{\alpha}_{32}}{2} + (P_1^c - P_0^c)\hat{\bar{\alpha}}^{fps1}\right] - \\
&- \left[(P_1^{bc} - P_0^{bc})\frac{\hat{\alpha}_{12}}{2} + (P_1^{bc} - P_0^{bc})\hat{\bar{\alpha}}^{fps2}\right]
\end{aligned} \tag{4.39}
$$

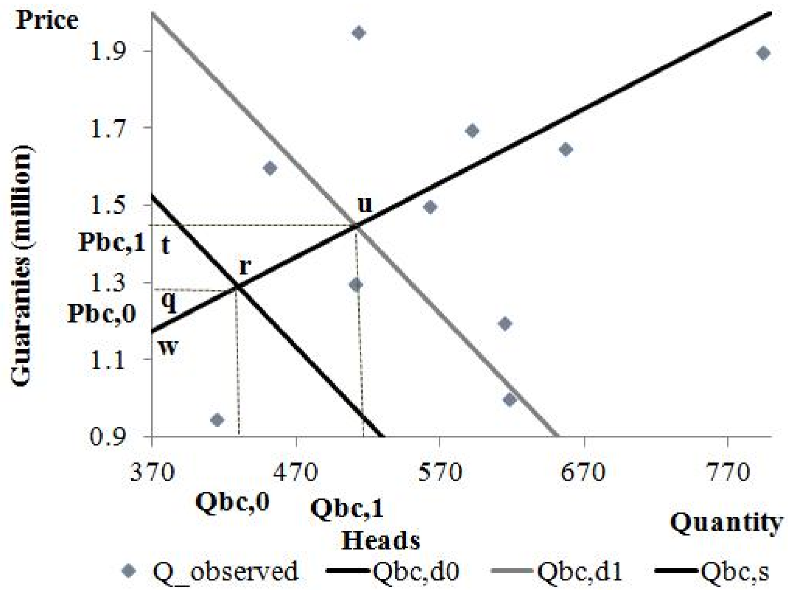
where $\hat{\bar{\alpha}}^{fps1}$ and $\hat{\bar{\alpha}}^{fps2}$ are constants calculated by multiplying average values of explanatory variables and their estimated coefficients from the output and input markets respectively.

Breeder producers surplus

To calculate welfare change for the breeder producers, equation 4.2 is used to plot the supply curve from the Fattening Market. The increase in P^{bc} from P_0^{bc} to P_1^{bc} while holding everything else constant implies a move along the supply curve as shown in Figure 4.5. The initial breeder producer surplus (BPS) is represented by area *qwr* which initial equilibrium levels are P_0^{bc} and Q_0^{bc}; and, the final BPS is represented by area *twu* with P_1^{bc} and Q_1^{bc} as final equilibrium levels. The welfare change for the breeder producers (ΔBPS) is represented by area *tqru*. Equations 4.40 and 4.41 are used to compute welfare changes.

$$
\begin{aligned}
\Delta BPS = &Q^{bc,s}(P_1^{bc}, P_0^h, Q_0^h, P_0^{cc}, P_0^b, R_0, I_0, P_{t-1,0}^{bc}) - \\
&- Q^{bc,s}(P_0^{bc}, P_0^h, Q_0^h, P_0^{cc}, P_0^b, R_0, I_0, P_{t-1,0}^{bc})
\end{aligned} \tag{4.40}
$$

Figure 4.5: Breeder producers surplus



$$\Delta BPS = \int_{P_0^{bc}}^{P_1^{bc}} Q^{bc,s}(P^{bc}, P_0^h, P_0^{cc}, P_0^b, R_0, I_0, P_{t-1,0}^{bc})dP^{bc} \quad (4.41)$$

Solving equation 4.41 yields equation 4.42,

$$\Delta BPS = (P_1^{bc} - P_0^{bc})\frac{\hat{\alpha}_{22}}{2} - (P_1^{bc} - P_0^{bc})\hat{\bar{\alpha}}^{bps} \quad (4.42)$$

where $\hat{\bar{\alpha}}^{bps}$ is a constant calculated by multiplying average values of explanatory variables and their estimated coefficients.

Chapter 5

Results

5.1 Beef Supply Chain model

Tables 5.1, 5.2 and 5.3 show the estimated coefficients and their respective standard errors in the structural equations 4.1 to 4.9 of the Paraguayan Beef Supply Chain.

In the first system (Table 5.1), in equation 4.1, the estimated coefficient for price P_t^{bc} implies that with an increase of Gs 1 in bull calf price change, the change of quantity of bull calf demanded will decrease by less than 0.01 head, assuming that everything else remains constant. This result suggests that during the period of increased beef exports bull calf demanded quantities are not too sensitive to an increase in bull calf price. The price P_t^c has the expected positive sign since it represents income for producers. The estimated coefficient for P_t^c implies that with an increase of Gs 1 in carcass price change, the change of quantity of bull calf demanded will increase by 0.09 head approximately. The price P_t^c has experienced an upward trend, with an increase of 15.67% during the period under study which may motivate producers to increase their demand for bull calves in order to fat them and to sell them when these animals are ready to be slaughtered[1]. The ratio S_t has the expected positive sign and it is significant at a 5% level. The estimated coefficient implies that an increase of 1 in the change of ratio S_t, the bull calf demanded will increase by 430

[1]Total traded steers has increased by 16% during the period under study.

heads approximately. This variable appears to be relevant for breeder producers in decision making processes to increase or decrease the herd. In fact, Ferreira and Vasconsellos (2006) indicate that this ratio is key to increase beef production in Paraguay since the country has one of the lowest levels of S_t in the region. The lagged variable P_{t-1}^{bc} estimate indicates that the change of the current price P_t^{bc} will increase less than 0.01 with an increase of Gs 1 in the previous period P_{t-1}^{bc}. In equation 4.2, the estimated coefficient for P_t^{bc} implies that with an increase of Gs 1 in bull calf price change, the change of quantity of bull calves supplied will increase by less than 0.01 head. This result suggests that bull calf supplied quantities are not sensitive to the increase of bull calf price. The price P_t^h has an unexpected negative sign since heifers represent a by-product for the feeder producer and it is significant at 10% level. It may occur because the heifer value for feeding and slaughtering purpose is less than its value for breeding purposes (Jarvis, 1974). In fact, heifer quantity traded in the auction market has decreased by 57% during the period under study. However, variable Q_t^h has positive sign as by-product and it is significant at 1% level. The estimated coefficient implies that an increase of 1 head in the change of quantity Q_t^h results in a 0.36 head increase in the change of quantity of bull calf supplied. The price P_t^{cc} has the expected positive sign as a by-product for the feeder-producer as well. The estimated coefficient implies that an increase of Gs 1 in the change of price P_t^{cc} results in a 0.14 head increase in the change of quantity of bull calf supplied. These producers may sell cull cows in order to renew their herd and increase their supply of bull calves. The price P_t^b has the expected negative sign since it represents an input variable. The estimated coefficient implies that an increase of Gs 1 in the change of price P_t^b results in a 0.17 head decrease in the change of quantity of bull calf supplied. The variable R_t has a negative sign which was not expected since rain helps increase the quantity and quality of pastures in livestock areas. This unexpected negative sign may be related to the fact that breeder producers use low quality land for bull calves (Ferreira and Vasconsellos, 2006). The variable I_t has the expected positive sign since it represents livestock investments. The estimated coefficient implies that an increase of Gs 1 in the change of investments results in less than 0.01 head increase in the change of quantity of bull calf supplied.

Table 5.1: Estimation results of the Fattening Market

Dependent variable: ΔQ_t^{bc}			
Equations	*Variables*	*Coefficients*	*Standard errors*
	$Constant$	-8.09	34.87
	ΔP_t^{bc}	< -0.01	< 0.01
Demand	ΔP_t^{c}	0.09	0.09
	ΔS_t	429.37^{**}	201.83
	ΔP_{t-1}^{bc}	< 0.01	< 0.01
	$Constant$	-5.97	28.84
	ΔP_t^{bc}	< 0.01	< 0.01
	ΔP_t^{h}	$< -0.01^{***}$	< 0.01
	ΔQ_t^{h}	0.36^{*}	0.09
Supply	ΔP_t^{cc}	0.14	0.16
	ΔP_t^{b}	-0.17	0.16
	ΔR_t	-0.95^{**}	0.46
	ΔI_t	< 0.01	< 0.01
	ΔP_{t-1}^{bc}	$< 0.01^{*}$	< 0.01
Note:	$*$,$**$,$***$ indicate 1%, 5% and 10% level of significance		

In the second system (Table 5.2), in equation 4.4, the estimated coefficient for price P_t^c is significant at the 5% level and implies that with an increase of Gs 1 in carcass price change, the change of quantity of carcass demanded will decrease by 1,721 kilograms, assuming that everything else remains constant. The price P_t^{bf} has the expected positive sign since it represents income. The estimated coefficient implies that an increase of Gs 1 in beef price change results in approximately 823 kilograms increase in the change of quantity of carcass demanded. The variable E_t has the expected negative sign since it represents international beef prices. The lower E_t, the lower the carcass quantity exported and the higher the carcass quantity available for the domestic market. The estimated coefficient implies that an increase of the change of one unit in the exchange rate results in a 1,670 kilograms decrease in the change of quantity of carcass demanded. In equation 4.5, the estimated coefficient for price P_t^c implies that with an increase of Gs 1 in carcass price change, the change of quantity of carcass supplied will increase by approximately 1,102 kilograms, assuming that everything else remains constant. The price P_t^{bc} has the negative expected sign since it represents an input variable for slaughterhouses. The estimated coefficient implies that an increase of Gs 1 in bull calf price change results in a 0.17 kilograms decrease in the change of quantity of carcass supplied. In addition, price P_t^h and price P_t^{cc} have the expected negative signs since they represent input variables for slaughterhouses as well. An increase of Gs 1 in the change of P_t^h implies a 0.14 kilograms decrease in the change of quantity of carcass supplied. An increase of Gs 1 in the change of P_t^{cc} implies a 1,209 kilograms decrease in change of quantity of carcass supplied. Price P_t^{bc} and price P_t^h have decreased by 21% and 15% during the period under study respectively, and price P_t^{cc} has increased by 21% during the period under study, making the cull cow a more expensive input than bull calf and heifer. The dummy variable W_t has the expected negative sign since during winter the carcass quantities are lower than in other seasons. This coefficient implies that during the winter, the change of quantity of carcass supplied decreases by 428,923 kilograms.

Table 5.2: Estimation results of the Slaughter Market

Dependent variable: ΔQ_t^c			
Equations	*Variables*	*Coefficients*	*Standard errors*
Demand	$Constant$	$1,810.73$	$157,950.60$
	ΔP_t^c	$-1,721.00^{***}$	986.76
	ΔP_t^{bf}	822.92	$1,388.00$
	ΔE_t	$-1,670.20$	$1,192.76$
	D_t	$2,875,179.00^{*}$	$1,018,182.00$
	ΔQ_{t-1}^c	-0.38^{**}	0.16
	ΔP_{t-2}^c	-119.73	519.52
Supply	$Constant$	$182,704.00$	$168,868.20$
	ΔP_t^c	$1,101.57$	$1,240.36$
	ΔP_t^{bc}	-0.17	0.68
	ΔP_t^h	-0.14	0.55
	ΔP_t^{cc}	$-1,208.89^{***}$	705.34
	W_t	$-428,923.30$	$267,630.60$
	D_t	$3,423,370.00^{*}$	$688,649.50$
	ΔQ_{t-1}^c	-0.41^{*}	0.12
	ΔP_{t-2}^c	-714.03	448.66
Note:	$*$,$**$,$***$ indicate 1%, 5% and 10% level of significance		

In the third system (Table 5.3), in equation 4.7, the estimated coefficient for price P_t^{bf} suggests that with an increase of Gs 1 in beef price change, the change of quantity demanded of beef per capita will decrease by less than 0.01 kilograms per capita, assuming that everything else remains constant. The price P_t^{ck} and the price P_t^{pk} have expected positive signs which indicate that these are substitute goods for beef in the Paraguayan meat market. An increase of Gs 1 in the change of price P_t^{ck} results in an increase less than 0.01 kilograms per capita in the change of beef demand. In the same manner, an increase of Gs 1 in the change of price P_t^{pk} results in an increase of less than 0.01 kilograms per capita in the change of beef demand. Previous work indicates that poultry and pork per capita consumption in Paraguay has been increasing in the past 5 years[2] mainly because of higher beef prices (United States Department of Agriculture - USDA, Foreign Agricultural Service - FAS, 2012). In fact, price P_t^{ck} has decreased 2% during the period under study. However, price P_t^{pk} has increased 5% which is less than the beef price increase (6.53%). The variable Y_t is significant at the 5% level and has the expected positive sign since it represents income per capita in demand equation 4.7. An increase of Gs 1 in the change of income Y_t implies an increase in the change of demand of less than 0.01 kilograms per capita. This variable has increased by 13% over the period under study. The estimated coefficient for price P_t^{bf} in equation 4.8 suggests that with an increase of Gs 1 in beef price change, the change of quantity of beef per capita will increase by less than 0.01 kilograms per capita, assuming that everything else remains constant. As mentioned before, beef price has increased by 6.53%, however, beef supply for the domestic market is subject to carcass availability. The price P_t^c has the negative expected sign since it represents an input variable in the supply equation 4.8. The estimated coefficient implies that an increase of Gs 1 in carcass price change results in less than 0.01 kilograms per capita in the change of quantity of beef supplied. The variable K_t in supply equation 4.8 is positive, which was not expected since it represents capital cost for the slaughterhouses. It may be because slaughterhouses do not

[2]The estimated poultry per capita consumption is 15 kilograms in 2011 and the pork per capita consumption is 16 kilograms (United States Department of Agriculture - USDA, Foreign Agricultural Service - FAS, 2012).

make as much investments as meat processing plants since slaughterhouses do not need to meet all the regulations that meat processing plants are require to meet.

Table 5.3: Estimation results of the Beef Retail Market

Dependent variable: ΔQ_t^{bf}			
Equations	*Variables*	*Coefficients*	*Standard errors*
Demand	$Constant$	-0.01	0.03
	ΔP_t^{bf}	< -0.01	< 0.01
	ΔP_t^{ck}	< 0.01	< 0.01
	ΔP_t^{pk}	< 0.01	< 0.01
	ΔY_t	< 0.01**	< 0.01
	D_t	0.16	0.14
	ΔP_{t-1}^{bf}	< -0.01	< 0.01
Supply	$Constant$	< -0.01	0.08
	ΔP_t^{bf}	< 0.01	< 0.01
	ΔP_t^{c}	< -0.01	< 0.01
	ΔK_t	0.20	0.27
	ΔP_{t-1}^{bf}	< 0.01	< 0.01
Note:	$*$,$**$,$***$ indicate 1%, 5% and 10% level of significance		

5.2 Elasticities

The own-price demand and the own-price supply short-run elasticities are computed using the estimated coefficients of prices P_t^{bc}, P_t^c and P_t^{bf} and average quantities and prices, as indicated in equation 4.23. Table 5.4 shows the estimated elasticities for bull calf, carcass and beef. In addition, cross-price demand elasticities for chicken and pork are computed as indicated in equation 4.24, using the estimated coefficients of prices P_t^{ck} and P_t^{pk}.

The first pair of elasticities indicates that bull calf demand will decrease by 0.72% when the bull calf price increases by 1% and, in turn, the quantity of bull calf supplied will increase by 1.47% when the bull calf price increases by 1%, assuming that everything else remains constant. On the demand side, quantities appear to be inelastic since feeder producers make buying bull calves decisions according to their ratio between total slaughtered animals and total herd. Feeder producers are less sensitive to bull calf price changes;

increasing this ratio allows them to increase their supply in the slaughter market since carcass prices have shown an upward trend. Own-price supply elasticity appears to be elastic, indicating that breeder producers are sensitive to bull calf price increases. Agricultural economic theory indicates that supply elasticity tends to be inelastic since supply is fixed in the short-run as producers cannot change it with an increase or decrease of beef demand due to biological constraints. However, elastic supply appears to be related to producers who respond positively to price incentives. Bull calf behaves as a *store of wealth* and producers sell part of their cattle to meet economic needs (Gosalamang, 2010); therefore, a pricing strategy can be employed to enhance beef production in Paraguay (Gosalamang, 2010) by motivating producers (especially small producers) to increase their bull calves production.

The second pair of elasticities indicate that quantity of carcass demanded will decrease by 2.35% when carcass price increases by 1% and, in turn, quantity of carcass supplied will increase by 1.51% when carcass price increases by 1%, assuming that everything else remains constant. In this case, own-price demand elasticity is greater than one, therefore it is assumed to be elastic. Slaughterhouses do not have sufficient economic capacity to face carcass price increases since they do not make as much investments as meat processing plants do; therefore, their demand appears to be sensitive to this price increase. In the supply side, elasticity is greater than one suggesting to be elastic. It may be because carcass supply depends on the total amount of steers ready to be slaughtered, for which the feed cycle lasts, on average, 18 - 24 months after weaned making it difficult for producers to react faster in the short-run to beef demand changes. Producers expect that each cow breed a bull calf every 12 months in order to increase bull calf supply and to satisfy the increase demand (Ferreira and Vasconsellos, 2006). Also, elasticity values below one may fall inside the 95% confidence interval around the reported point estimate.

The third pair of elasticities indicate that quantity of beef demanded will decrease by 1.30% when the beef price increases by 1% and the quantity of beef supplied will increase by 7.13% when the beef price increases by 1%, assuming that everything else remains constant. The own-price demand elasticity is greater than one, suggesting it to be elastic;

however, elasticity values below one may fall inside the 95% confidence interval. Beef price changes seem not to affect beef demand due to the strong preference that Paraguayan consumers have for this good relative to other meats (Ferreira and Vasconsellos, 2006). Aguilera (2002), Alfonzo and Hanawa-Peterson (2006) and Lema et al. (2007) have estimated beef demand elasticities for Paraguay. The methodology employed in the previous studies used household survey data for a particular year, 1997/1998 for Aguilera (2002) and Alfonzo and Hanawa-Peterson (2006) and 2000 for Lema et al. (2007), whereas this research employs time series data. These household surveys collect cross-sectional data by observing individuals at the same point of time in their consumption expenditures and providing a snapshot of that population at one point in time. There is no way to know if beef consumption is increasing or decreasing with this type of data; it only describes the current value of beef consumption. Cross-sectional data differs from time series data since the latter focuses on following beef changes over the course of time. Although the type of data that Aguilera (2002), Alfonzo and Hanawa-Peterson (2006) and Lema et al. (2007) used is different than this research, it is observed that the sign of the own-price beef demand elasticity obtained in this research is in line with Aguilera (2002) and Alfonzo and Hanawa-Peterson (2006); however, it differs from Lema et al. (2007). In turn, cross-price demand elasticities are estimated and they indicate that both chicken (0.12) and pork (0.24) are substitute goods for beef. Ferreira and Vasconsellos (2006) suggest that chicken and pork are not strong substitutes for beef due to the strong preference of Paraguayan consumers for beef; however, they did not compute cross-price demand elasticities. As explained previously, in spite of the methodology and data that Alfonzo and Hanawa-Peterson (2006) and Lema et al. (2007) used, they estimated cross-price elasticities for chicken and other meats and they provided mixed results. While Alfonzo and Hanawa-Peterson (2006) suggest that chicken is a complement for beef and other meats (including pork) are substitutes, Lema et al. (2007) suggest that chicken is a substitute for beef. Finally, own-price beef supply elasticity is greater than one, suggesting it to be elastic. In this market, the animal has already been slaughtered and supermarkets have beef to sell to consumers. Beef price

Table 5.4: Short-run elasticities

Product	*Own-price demand*	*Own-price supply*
Q_t^{bc}	-0.72	1.47
Q_t^{c}	-2.35	1.51
Q_t^{bf}	-1.30	7.13

changes dramatically affect quantity availabilities of beef for consumers because supermarkets are willing to sell beef at better price since they have beef storage and they can take advantage of the domestic market scenario. They may withheld temporarily some animals for slaughter purposes expecting higher beef prices (Jarvis, 1974) since beef prices have shown an upward trend during the period under study.

5.3 Welfare changes

Paraguayan beef exports experienced an important leap and an unusual growth rate of 126% from 2003 to 2004. Exports continued to grow, accumulating a growth rate of 246% from January 2003 to August 2011 (Banco Central del Paraguay, 2012). Beef exports represented more than US$ 600 million for the Paraguayan economy in 2011 and Paraguay provided 2% of total beef to the world (Banco Central del Paraguay, 2012 and United Nations Statistical Division, UN COMTRADE, 2012). This growth has had economic impacts on the domestic market, specifically on the four domestic economic agents from the Paraguayan Beef Supply Chain (breeder producers, feeder producers, slaughterhouses and domestic consumers). Estimated welfare changes for these economic agents indicate that some of them are better off and others are worse off. Welfare changes were measured using equations 4.29, 4.35, 4.38 and 4.41 which used estimated coefficientss from structural equations 4.1, 4.2, 4.4, 4.5 4.7 and 4.8 for the period February 2008 to August 2011. Table 5.5 reports point estimates of the welfare changes for all four economic agents.

Welfare changes were also computed using the OLS, 2SLS, 3SLS and SUR estimates reported in Tables A.1.1, A.1.2, A.1.3, A.1.4, A.1.5 and A.1.6. The results are shown in

Table 5.5: Welfare changes

Economic agents	*Guaranies (constant values)*
Consumer surplus (per capita), ΔCS	-97
Consumer surplus (total population, million), ΔCS	-614
Slaughterhouse surplus (million), ΔSS	$-27,823$
Feeder producers surplus (million), ΔFPS	$44,981$
Breeder producers surplus (million), ΔBPS	180
Society overall (million)	$\mathbf{16,725}$

Note: US$/Gs 4,077 (Source: Banco Central del Paraguay, 2012)

Table 5.6. As an overall, society is better off regardless of the estimator used. However, the magnitudes are different; 3SLS estimates are the highest whereas the SUR estimates are the lowest. Contrary to the results from OLS, 3SLS and SUR estimates, welfare change for consumers is positive when 2SLS estimates are used. Breeder producers welfare change is negative using OLS, 2SLS and SUR estimates and it is positive using 3SLS estimates. Welfare changes for slaughterhouses and feeder producers have the same sign (negative and positive, respectively) and similar magnitude for all four estimation methods.

Table 5.6: Welfare changes using OLS, 2SLS, 3SLS and SUR estimates

Economic agents	OLS	2SLS	3SLS	SUR
Consumer surplus (per capita), ΔCS	-115	128	-97	-299
Consumer surplus (total population, million), ΔCS	-728	813	-614	$-1,897$
Slaughterhouses surplus (million), ΔSS	$-34,753$	$-28,972$	$-27,823$	$-28,920$
Feeder producers surplus (million), ΔFPS	$42,582$	$45,004$	$44,981$	$33,320$
Breeder producers surplus (million), ΔBPS	-300	-249	180	-82
Society overall (million)	$\mathbf{6,801}$	$\mathbf{16,595}$	$\mathbf{16,725}$	$\mathbf{2,420}$

Note: Values are in *Gs. constant values*. US$/Gs 4,077 (Source: Banco Central del Paraguay, 2012)

Paraguayan consumers' welfare change is less than Gs 100 per capita, which for total Paraguayan consumers represent a loss of Gs 614 million as shown in Table 5.5. In fact, this welfare change may be lower due to the strong preference of Paraguayan consumers for beef and the increase of domestic beef prices during the period of increased beef exports. Consumers continue eating beef in spite of showing a decrease on their beef consumption level by 20%. Consumers' welfare change may be lower if the analysis would have considered some other aspects such as expenditure distribution, income distribution, geographic areas and beef quality. Aguilera (2002) shows that the total Paraguayan consumers spend the higher amount of their food budget on beef based on the Paraguayan Household Survey 1997/1998 data. In fact, they spend 15.3% of their total budget on beef and there is not much expenditure differences on this good between rural and urban areas. This information confirms what Ferreira and Vasconsellos (2006) have indicated about Paraguayan consumers' beef preference and the findings of a lower welfare change for consumers. In terms of geographic areas and income distribution, people from rural areas spend 61% on food and people with lower income spend 60% of their budget on food (Aguilera, 2002); therefore, beef price increases may affect the welfare of people from rural areas more than the welfare of people from urban areas and higher incomes, due to the higher share beef has in Paraguayan consumer budgets. In other words, total welfare lost could be even greater considering groups of lower income and higher income since beef price changes affect people with lower income levels more than people with higher income levels. Besides, consumers' welfare change may be lower if quality beef is considered since Paraguayan consumers may consume lower quality beef due to the beef price increases and reduced availability of higher quality beef due to the beef exports growth.

Welfare change for slaughterhouses shows the highest loss from all economic agents in the supply chain (Gs 27,823 million) as shown in Table 5.5. The increase in domestic beef prices is not enough to cover production costs since the increase in carcass price is higher than the increase of beef price. In fact, with the increase in the carcass price, slaughterhouses became less competitive since they couldn't absorb such price changes and their profits reduced over time. According to the model for this market, carcass price is the main input for slaughterhouses; therefore, this price plays an important role for this welfare loss since, as mentioned before, slaughterhouses do not have sufficient economic capacity to face these input price increases.

Both producers are better off as shown in Table 5.5. Feeder producers are better off as they serve both slaughterhouses and meat processing plants (Gs 44,981 million). Breeder producers are better off with a welfare change of Gs. 180 million, in spite of the bull calf price decrease of 21.31%. This positive result for both producer agents may be due to an increase in the carcass price, which is a consequence of the beef exports growth. Producers made large investments at the farm level which resulted in good sanitary cattle conditions that promote trade in both domestic and international markets. It is expected that the herd size increases, making available larger quantities of cattle for slaughter, resulted in higher ratio of extraction level for the country. The expansion for both producers is driven by the export sector, however, the domestic market is important as these producers are the only suppliers since there is no imported cattle or beef in Paraguay.

In summary, cattle producers (feeders and breeders) show a positive welfare change while consumers and slaughterhouses experienced a negative welfare change. Cattle producers' positive change exceeds all other sectors' negative change, yielding an overall positive change for the Paraguayan Beef Supply Chain.

Conclusions

The main purpose of this research was to develop a complete system of equations for each market in the Paraguayan Beef Supply Chain and, in turn, to measure welfare changes for each economic agent in the chain. The main driver for the research was the growth of beef exports in recent years, which created a new environment in the livestock sector. The research followed a vertical multi-market approach using the linkages among the three markets: Fattening, Slaughter and Beef Retail. Paraguayan beef production has increased dramatically as a response to the increased international demand; however, the quantity of beef in the domestic market has decreased over time. Little research has been performed to assess the impact of the boom of beef exports on the Paraguayan supply chain participants.

Findings of this research indicate that the ratio S_t in the Fattening Market is relevant as a key to increase beef production in Paraguay. In turn, prices P_t^c and P_t^{cc} are significant variables for slaughterhouses and feeder producers, respectively in the Slaughter Market. The carcass price plays an important role in the slaughterhouses' buying decisions. Feeder producers seem to follow cull cow prices for their management decisions such as selling cull cows in order to renew herd and to better use grassland. Besides, supply and demand of bull calf, carcass and beef have had different responses related to price changes during the beef exports growth period. Bull calf price does not significantly explain bull calf demand since feeder producers respond positively to increases of the ratio S_t and to the upward trend of carcass prices. Carcass demand appears to be elastic since slaughterhouses do not have sufficient economic capacity to face carcass price increases. Carcass supply elasticity appears to be elastic, indicating that feeder producers are sensitive to carcass price changes. Chicken and pork appear to be substitute goods for beef. Besides, beef supply appears to be elastic which allows supermarkets to set beef prices according to the domestic market scenario. In summary, the Paraguayan Beef Supply Chain seems to be elastic and to respond to price changes due to moves/shifts in the demand and/or supply curves where the Slaughter Market appears to be the most sensitive in the demand side; the Beef Retail Market appears to be the most sensitive on the supply side and the Fattening Market appears to be inelastic on the demand side.

Results of the welfare analysis suggest that consumers and slaughterhouses are worse off and feeder and breeder producers are better off in the new production and export environment. Overall, society is better off. Consumers' welfare loss may be lower due to the strong preference of Paraguayan consumers for beef and beef price increases. Welfare change for slaughterhouses shows the highest loss among all economic agents in the supply chain due to increased carcass prices as a main input for these agents. Feeder producers are better off as they serve both slaughterhouses and meat processing plants. Breeder producers are better off in spite of the decrease in bull calf prices. This positive result for both producer agents may be due to an increase in the carcass price, as a consequence of the beef exports growth. Consumers' and slaughterhouses' loss may be reduced by increasing beef production. Increasing total cattle herd and in turn total slaughtered ratio, improving cattle management which will reduce the time needed for the animal to be ready to be slaughtered, and improving access to low interest rate loans that benefit small and large producers would create conditions that enhance profitability and encourage producers to improve efficiency. These recommendations are related to increased producers productivity and to increase beef production for both domestic and international markets.

Research limitations are mostly related to data availability. The starting point of this analysis, February 2008, is determined by the Fattening Market series which come from one of the three auction markets in Paraguay. This fact does not allow this analysis to be performed before beef exports growth occurred, in order to compare market changes during these two periods. Besides, this lack of information means analysis could not be conducted from the start of the beef exports growth which, occured in 2004, in order to have a better analysis of the new environment. Moreover, welfare change for slaughterhouses could be different if data from unregistered slaughterhouses is collected. Also, if the analysis for consumers' welfare change considers some other aspects such as expenditure distribution, income distribution, geographic areas and beef quality, welfare changes for consumers could be different. Finally, beef prices and beef consumption per capita series are proxies for the actual series since there is no record of them; therefore, Beef Retail Market results could have been more precise if the actual series of these variables were used. These conclusions are based on point estimates. Confidence intervals for the elasticities can provide a better understanding of the effect of prices in the markets analyzed. Data limitations suggest the importance of improving data collection from these markets. Better data must go along with the growth of this sector; it would allow analysis that can provide a better understanding of the linkages among markets, and could help policy makers in their decision making process to support and improve this sector. Finally, the model proposed here can be used to measure welfare changes in the Paraguayan Beef Supply Chain due to the outbreak in foot-and-mouth disease that occured in September 2011 and January 2012.

Appendices

A.1 Comparison of estimated coefficients from OLS, 2SLS, 3SLS and SUR methods.

Tables A.1.1, A.1.2, A.1.3, A.1.4, A.1.5 and A.1.6 compare results of estimating OLS, 2SLS, 3SLS and SUR methods. Discussion about these results is presented in Chapter 4.

Autocorrelation and heteroskedasticity were tested by performing Durbin-Watson test and BreuschPagan test, respectively. Autocorrelation for equations 4.4 and 4.5 was tested by Durbin's h test since a lagged dependant variable is present in the right-hand-side of both equations. Disturbances from equations 4.1, 4.2 and 4.8 show no autocorrelation (d= 1.95, d=2.47 and d= 2.32) and constant variance (χ^2= 0.69, χ^2= 0.50 and χ^2= 1.02). Disturbances from equations 4.4 and 4.7 show no autocorrelation (h= 0.43 and d= 2.29); however, they show no constant variance (χ^2= 16.31 and χ^2= 10.33). To correct heteroskcedasticity, White corrected standard errors was performed. Disturbances from equation 4.5 show serial correlation (h= 2.86) and constant variance (χ^2= 0.77). To correct for autocorrelation, Generalized Methods of Moments (GMM) was used and results are shown in Table A.1.7.

Table A.1.1: Comparison results in the Fattening Market model - Demand equation

Dependent variable: ΔQ_t^{bc}								
	OLS		2SLS		3SLS		SUR	
	Coefficient	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*
$Constant$	-1.51	34.02	12.01	37.34	-8.09	34.87	4.29	31.39
ΔP_t^{bc}	< -0.01	< 0.01	< -0.01	< 0.01	< -0.01	< 0.01	< 0.01	< 0.01
ΔS_t	394.07^{***}	197.19	451.42^{**}	218.41	429.37^{**}	201.83	225.43	146.23
ΔP_t^c	0.15	0.10	0.18	0.11	0.09	0.09	0.05	0.08
ΔP_{t-1}^{bc}	$< 0.01^{***}$	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	$< 0.01^{**}$	< 0.01

Note: *,**,*** indicate 1%, 5% and 10% level of significance.

Table A.1.2: Comparison results in the Fattening Market model - Supply equation

	Dependent variable: ΔQ_t^{bc}							
	OLS		2SLS		3SLS		SUR	
	Coefficient	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*
$Constant$	12.95	32.98	11.11	34.99	-5.97	28.84	9.18	26.24
ΔP_t^{bc}	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
ΔP_t^{h}	< -0.01***	< 0.01	< -0.01	< 0.01	< -0.01***	< 0.01	< -0.01*	< 0.01
ΔQ_t^{h}	0.49*	0.12	0.49*	0.12	0.36*	0.09	0.27	0.07
ΔR_t	-0.71	0.48	0.76	0.58	-0.95**	0.46	-0.47	0.31
ΔF_t	< -0.01	< 0.01	< -0.01	< 0.01	< 0.01	< 0.01	< -0.01	< 0.01
ΔP_t^{b}	-0.29	0.23	-0.17	0.16	-0.17	0.16	-0.12	0.14
ΔP_t^{cc}	0.18	0.23	0.19	0.23	0.14	0.16	0.07	0.14
ΔP_{t-1}^{bc}	< 0.01**	< 0.01	< 0.01**	< 0.01	< 0.01*	< 0.01	< 0.01*	< 0.01

Note: *,**,*** indicate 1%, 5% and 10% level of significance.

Table A.1.3: Comparison results in the Slaughter Market model - Demand equation

	Dependent variable: ΔQ_t^c							
	OLS		2SLS		3SLS		SUR	
	Coefficient	*Rob. Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*
$Constant$	$-55,188.47$	$147,392.10$	-469.19	$175,667.10$	$1,810.73$	$157,950.60$	$-27,600.13$	$133,617.40$
ΔP_t^c	-621.70	525.97	$-1,706.08$	$1,097.59$	$-1,720.99^{***}$	986.76	57.74	433.96
ΔP_t^{bf}	-804.67	$1,080.53$	607.45	$1,781.31$	822.92	$1,387.95$	-265.50	756.45
ΔE_t	$-1,736.12$	$1,154.70$	$-1,780.10$	$1,400.71$	$-1,670.20$	$1,192.76$	-213.47	578.28
D_t	$658,017.40$	$1,837,798.00$	$2,861,874.00^{**}$	$1,132,091.00$	$2,875,179.00^{*}$	$1,018,182.00$	$3,457,257.00^{*}$	$820,867.10$
ΔQ_{t-1}^c	-0.19	0.15	-0.38^{**}	0.18	-0.38^{**}	0.16	-0.33^{**}	0.14
ΔP_{t-2}^c	-237.77	428.77	-104.08	580.67	-119.90	519.52	-533.31	409.91

Note: *,**,*** indicate 1%, 5% and 10% level of significance. Rob. Std. Err. is robust standard error.

Table A.1.4: Comparison results in the Slaughter Market model - Supply equation

	Dependent variable: ΔQ_t^c							
	OLS		2SLS		3SLS		SUR	
	Coefficient	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*
$Constant$	$174,015.10$	$180,681.9$	$194,602.20$	$211,288.30$	$182,704$	$168,868.2$	$42,961.10$	$127,484.20$
ΔP_t^c	778.82	485.32	$1,039.93$	$1,453.80$	$1,101.57$	$1,240.36$	303.21	371.74
ΔP_t^{bc}	-0.68	0.96	-0.67	0.96	-0.17	0.68	-0.25	0.49
ΔP_t^h	-0.79	0.63	-0.71	0.76	-0.14	0.56	-0.28	0.32
ΔP_t^{cc}	$-1,001.21^{***}$	518.70	$-1,123.74$	827.57	$-1,208.89^{***}$	705.34	-334.07	260.61
W_t	$-443,652.30$	$281,427.10$	$-485,647.60$	$358,518.80$	$-428,923.30$	$267,630.60$	$-152,187.20$	$142,525.80$
D_t	$3,625,228.00^{*}$	$790,551.80$	$3,605,744.00^{*}$	801171.60	$3,423,370^{*}$	$688,649.50$	$3,542,576^{*}$	$670,617.60$
ΔQ_{t-1}^c	-0.46^{*}	0.15	-0.46^{*}	0.15	-0.41^{*}	0.12	-0.38^{*}	0.12
ΔP_{t-2}^c	-561.49	393.85	-626.84	523.65	-714.02	448.66	-559.33^{***}	335.84

Note: *,**,*** indicate 1%, 5% and 10% level of significance.

Table A.1.5: Comparison results in the Beef Retail Market model - Demand equation

	Dependent variable: ΔQ_t^{bf}							
	OLS		2SLS		3SLS		SUR	
	Coefficient	*Rob. Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*
$Constant$	-0.01	0.03	< -0.01	0.03	-0.01	0.03	< -0.01	0.03
ΔP_t^{bf}	$< 0.01^{**}$	< 0.01	< -0.01	< 0.01	< -0.01	< 0.01	< -0.01	< 0.01
ΔP_t^{ck}	< -0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< -0.01	< 0.01
ΔP_t^{pk}	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
ΔY_t	$< 0.01^{**}$	< 0.01	$< 0.01^{***}$	< 0.01	$< 0.01^{**}$	< 0.01	< 0.01	< 0.01
D_t	0.15	0.41	0.16	0.15	0.16	0.14	0.03	0.05
ΔP_t^{bf}	< -0.01	< 0.01	< -0.01	< 0.01	< -0.01	< 0.01	< -0.01	< 0.01

Note: *,**,*** indicate 1%, 5% and 10% level of significance. Rob. Std. Err. is robust standard error.

Table A.1.6: Comparison results in the Beef Retail Market model - Supply equation

	Dependent variable: ΔQ_t^{bf}							
	OLS		2SLS		3SLS		SUR	
	Coefficient	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*	*Coefficient*	*Std. Err.*
$Constant$	< -0.01	0.03	< -0.01	0.08	< -0.01	0.08	< -0.01	0.03
ΔP_t^{bf}	< -0.01	< 0.01	< 0.01	0.01	< 0.01	0.01	< -0.01	< 0.01
ΔP_t^c	< -0.01	< 0.01	< -0.01	< 0.01	< -0.01	< 0.01	< 0.01	< 0.01
ΔK_t	0.01	0.05	0.19	0.28	0.19	0.27	0.01	0.02
ΔP_{t-1}^{bf}	< -0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< -0.01	< 0.01
Note:	*,**,*** indicate 1%, 5% and 10% level of significance.							

Table A.1.7: GMM estimation of the demand equation in the Slaughter Market

Variable	*Coef.*	*Rob. Std. Err.*	*t-value*
$Constant$	$-55,188.47$	$134,186.70$	-0.41
P_t^c	-621.70	478.46	-1.30
P_t^{bf}	-804.67	982.58	-0.82
E_t	$-1,736.12$	$1,051.82$	-1.65
D_t	$658,017.40$	$1,672,118.00$	0.39
Q_{t-1}^c	-0.19	0.13	-1.52
P_{t-2}^c	-237.77	389.16	-0.61
Note:	Rob. Std. Err. is robust standard error.		

A.2 Order condition

The order condition presented in Chapter 4 can be examined using the following rule (Johnston and DiNardo, 1996):

- For an identified system $K - k_i = m_i - 1$;
- For an overidentified system $K - k_i > m_i - 1$; and,
- For an underidentified system $K - k_i < m_i - 1$

where K is the total number of exogenous variables in the system of structural equations, k_i is the total number of exogenous variables included in the *i*th structural equation, and m_i is the total number of endogenous variables included in the *i*th structural equation .

Then, the identification results for each system (4.1 and 4.2, 4.4 and 4.5, 4.7 and 4.8) in the Paraguayan Beef Supply Chain is as follows:

- The system in the Fattening Market is overidentified since K = 9, k_1 = 3, k_2 = 7 and m_1 = m_2 = 2 where K is compounded by variables P_t^c, S_t, P_t^h, Q_t^h, P_t^{cc}, P_t^b, R_t, I_t and P_{t-1}^{bc}; k_1 is compounded by variables P_t^c, S_t and P_{t-1}^{bc}; k_2 is compounded by variables P_t^h, Q_t^h, P_t^{cc}, P_t^b, R_t, I_t and P_{t-1}^{bc}; and, m_1 = m_2 are compounded by variables Q_t^{bc} and P_t^{bc}.

- The system in the Slaughter Market is overidentified since K = 9, k_1 = 5, k_2 = 7 and m_1 = m_2 = 2 where K is compounded by variables P_t^{bf}, E_t, P_t^{bc}, P_t^h, P_t^{cc}, W_t, D_t, Q_{t-1}^c and P_{t-2}^c; k_1 is compounded by variables P_t^{bf}, E_t, D_t, Q_{t-1}^c and P_{t-2}^c; k_2 is compounded by variables P_t^{bc}, P_t^h, P_t^{cc}, W_t, D_t, Q_{t-1}^c and P_{t-2}^c; and m_1 = m_2 are compounded by variables $Q_t^{c,d}$ and P_t^c.

- The system in the Beef Retail Market is overidentified because K = 7, k_1 = 5, k_2 = 3 and m_1 = m_2 = 2 where K is compounded by variables P_t^{ck}, P_t^{pk}, Y_t, D_t, P_t^c, K_t and P_{t-1}^{bf}; k_1 is compounded by variables P_t^{ck}, P_t^{pk}, Y_t, D_t and P_{t-1}^{bf}; k_2 is compounded by variables P_t^c, K_t and P_{t-1}^{bf}; and, m_1 = m_2 are compounded by variables $Q_t^{bf,d}$ and P_t^{bf}.

A.3 Rank condition

To examine the rank condition, all endogenous and exogenous variables in equation *i* are written on the left hand side and the disturbance on the right-hand-side. For example, the first system (equations 4.1 and 4.2) is written as:

$$\Delta Q_t^{bc,d} - \alpha_{11} - \alpha_{12}\Delta P_t^{bc} - \alpha_{13}\Delta P_t^c - \alpha_{14}\Delta S_t - \alpha_{15}\Delta P_{t-1}^{bc} = \epsilon_t^{bc,d}$$

$$\begin{aligned}\Delta Q_t^{bc,s} - \alpha_{21} - \alpha_{22}\Delta P_t^{bc} - \alpha_{23}\Delta P_t^h - \alpha_{24}\Delta Q_t^h - \alpha_{25}\Delta P_t^{cc} - \alpha_{26}\Delta P_t^b - \\ - \alpha_{27}\Delta R_t - \alpha_{28}\Delta I_t - \alpha_{29}\Delta P_{t-1}^{bc} = \epsilon_t^{bc,s}\end{aligned}$$

Then, an auxiliary table was constructed with the estimated coefficients α_{ii} (Table A.3.1). In the table, the coefficients for equations 4.1, 4.2, 4.4, 4.5, 4.7 and 4.8 are grouped for each system. Variables which appear in equation *i* remain with their coefficients and variables which do not appear in equation *i* have 0 as coefficient. As specified in Chapter 4, each system includes two equations (demand and supply) and one equation that states the market clearing condition which is not used in the calculation of the rank condition.

To calculate the rank condition of each system, a submatrix for equation *i* is formed by selecting the columns that correspond to the variables that do not appear in equation *i* and deleting the row corresponding to equation *i*. Submatrix *i* is therefore formed exclusively by coefficients that do not appear in equation *i*. Since all systems have two equations, all submatrices have only one row of coefficients of the variables that are excluded from equation *i*, indicating that this equation is linearly independent, i.e. rank of these submatrices is one in all cases. Then, following the rule, the rank has to be at least as equal as $M-1$ in a model containing M equations in M endogenous variables to indicate that equation *i* is identified (Gujarati, 2004). In all cases, $M-1=1$ and rank is one indicating that the three systems are identified.

Table A.3.1: Auxiliary table for the rank condition

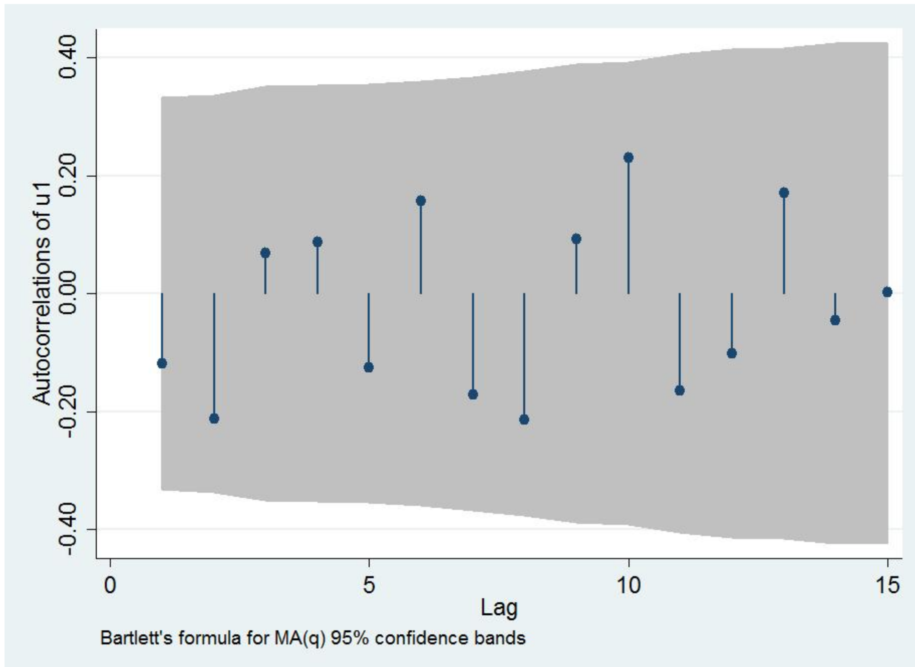
						Fattening Market						
Eq.	ΔQ_t^{bc}	$Constant$	ΔP_t^{bc}	ΔP_t^{c}	ΔS_t	ΔP_{t-1}^{bc}	ΔP_t^{h}	ΔQ_t^{h}	ΔP_t^{cc}	ΔP_t^{b}	ΔR_t	ΔI_t
4.1	1	$-\alpha_{11}$	$-\alpha_{12}$	$-\alpha_{13}$	$-\alpha_{14}$	$-\alpha_{15}$	0	0	0	0	0	0
4.2	1	$-\alpha_{21}$	$-\alpha_{22}$	0	0	$-\alpha_{29}$	$-\alpha_{23}$	$-\alpha_{24}$	$-\alpha_{25}$	$-\alpha_{26}$	$-\alpha_{27}$	$-\alpha_{28}$
						Slaughter Market						
Eq.	ΔQ_t^{c}	$Constant$	ΔP_t^{c}	ΔP_t^{bf}	ΔE_t	D_t	ΔQ_{t-1}^{c}	ΔP_{t-2}^{c}	ΔP_t^{bc}	ΔP_t^{h}	ΔP_t^{cc}	W_t
4.4	1	$-\alpha_{31}$	$-\alpha_{32}$	$-\alpha_{33}$	$-\alpha_{34}$	$-\alpha_{35}$	$-\alpha_{36}$	$-\alpha_{37}$	0	0	0	0
4.5	1	$-\alpha_{41}$	$-\alpha_{42}$	0	0	$-\alpha_{47}$	$-\alpha_{48}$	$-\alpha_{49}$	$-\alpha_{43}$	$-\alpha_{44}$	$-\alpha_{45}$	$-\alpha_{46}$
						Beef Retail Market						
Eq.	ΔQ_t^{bf}	$Constant$	ΔP_t^{bf}	ΔP_t^{ck}	ΔP_t^{pk}	ΔY_t	D_t	ΔP_{t-1}^{bf}	ΔP_t^{c}	ΔK_t		
4.7	1	$-\alpha_{51}$	$-\alpha_{52}$	$-\alpha_{53}$	$-\alpha_{54}$	$-\alpha_{55}$	$-\alpha_{56}$	$-\alpha_{57}$	0	0		
4.8	1	$-\alpha_{61}$	$-\alpha_{62}$	0	0	0	0	$-\alpha_{66}$	$-\alpha_{63}$	$-\alpha_{64}$		

A.4 Autocorrelation and Partial autocorrelation functions

The ACF and PACF for each disturbance in the three systems were plotted in order to verify the presence of a lag structure. For the Fattening Market and the Beef Retail Market, Figures A.4.1, A.4.5 and A.4.6 indicate that there is no presence of lag structure for the residuals in any equation. Figure A.4.2 indicate that there may be a lag structure for the residuals $\epsilon_t^{bc,d}$ and $\epsilon_t^{bc,s}$; however, adding a lag structure yields similar results. Residuals of the Slaughter Market system do not present a lag structure (Figures A.4.3, A.4.4), but a lagged dependent variable Q_{t-1}^c was included in both equations of the system as an explanatory variable (the ACF and PACF were estimated for the residuals of the model which included Q_{t-1}^c as an explanatory variable.)

Figure A.4.1: Autocorrelation function of residuals from demand (a) and supply (b) equations in the Fattening Market

(a) **Residual** $\epsilon_{\mathbf{t}}^{\mathbf{bc,d}}$



(b) **Residual** $\epsilon_{\mathbf{t}}^{\mathbf{bc,s}}$

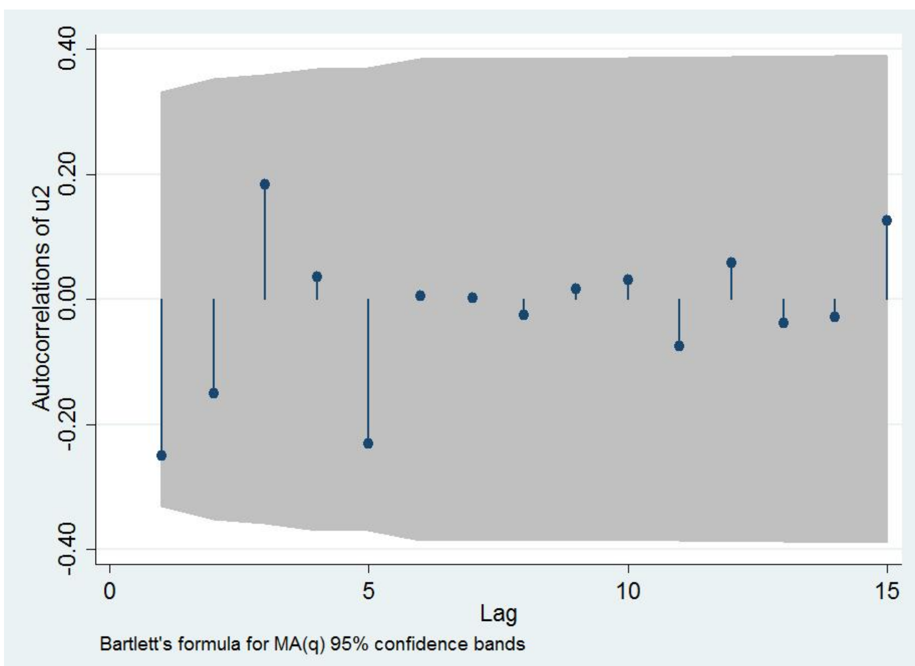
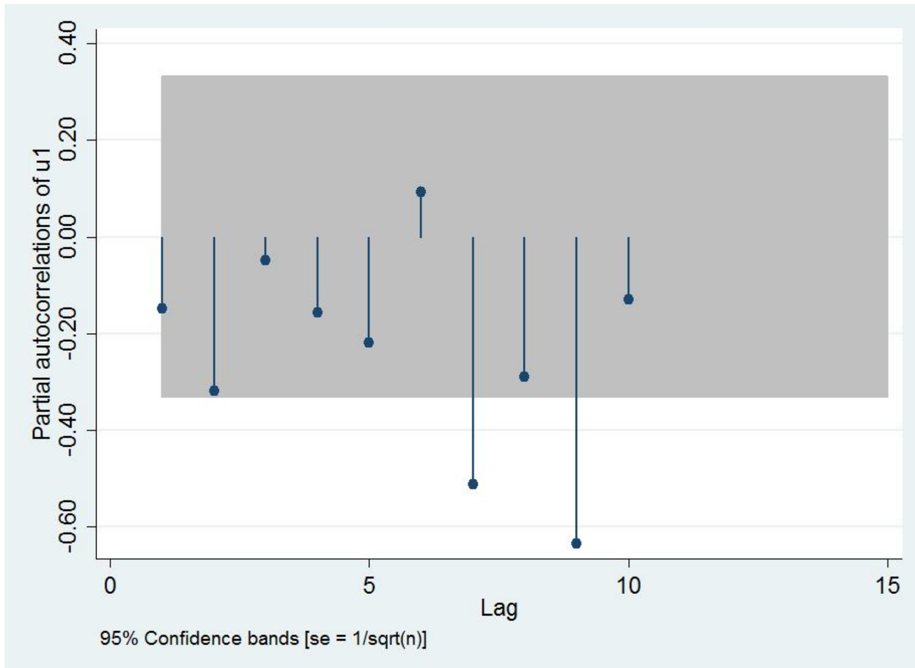


Figure A.4.2: Partial autocorrelation function of residuals from demand (a) and supply (b) equations in the Fattening Market

(a) **Residual** $\epsilon_{\mathbf{t}}^{\mathbf{bc,d}}$



(b) **Residual** $\epsilon_{\mathbf{t}}^{\mathbf{bc,s}}$

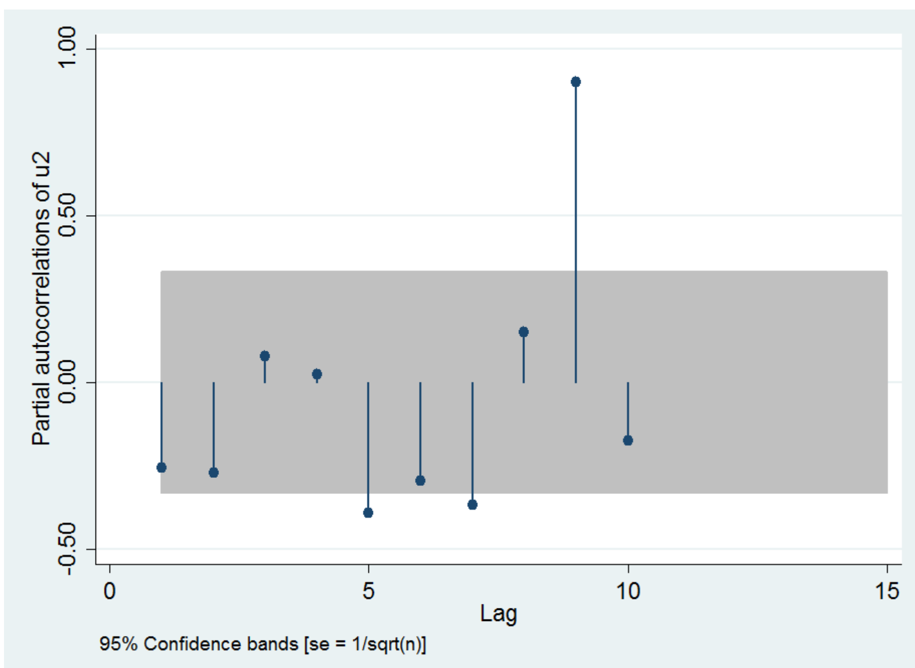
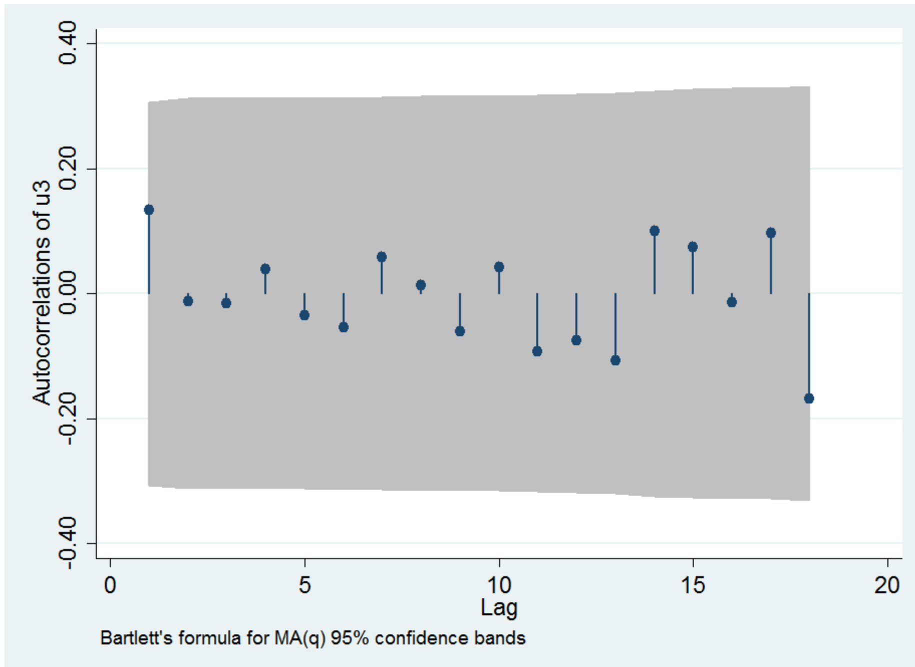


Figure A.4.3: Autocorrelation function of residuals from demand (a) and supply (b) equations in the Slaughter Market

(a) **Residual** $\epsilon_t^{c,d}$



(b) **Residual** $\epsilon_t^{c,s}$

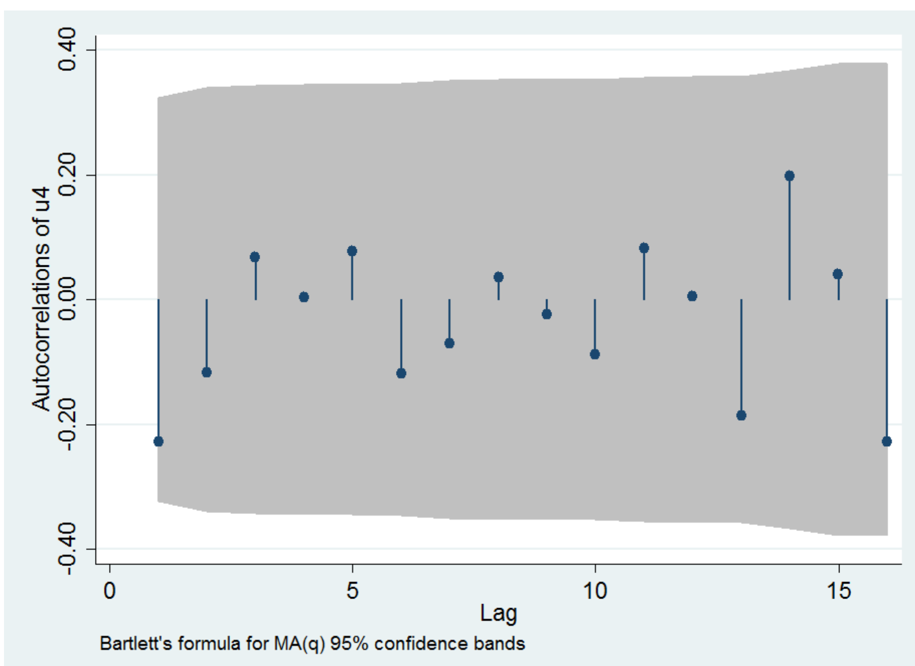
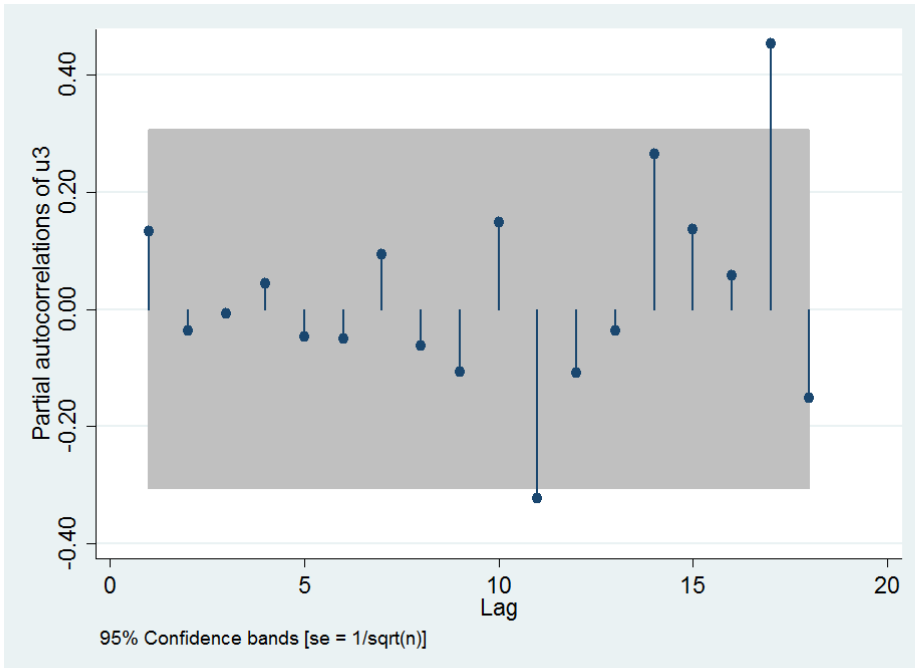


Figure A.4.4: Partial autocorrelation function of residuals from demand (a) and supply (b) equations in the Slaughter Market

(a) **Residual** $\epsilon_t^{c,d}$



(b) **Residual** $\epsilon_t^{c,s}$

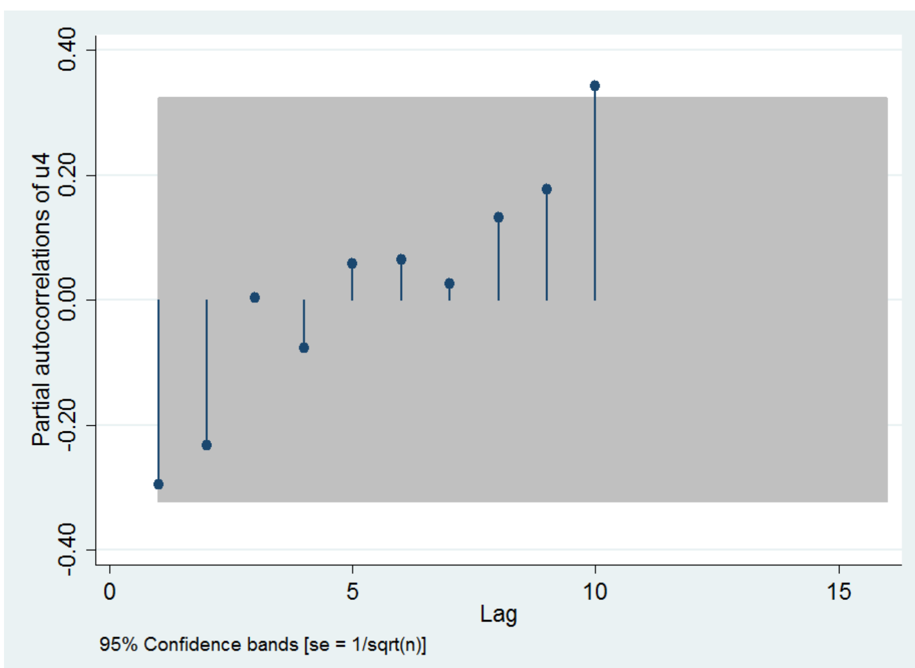
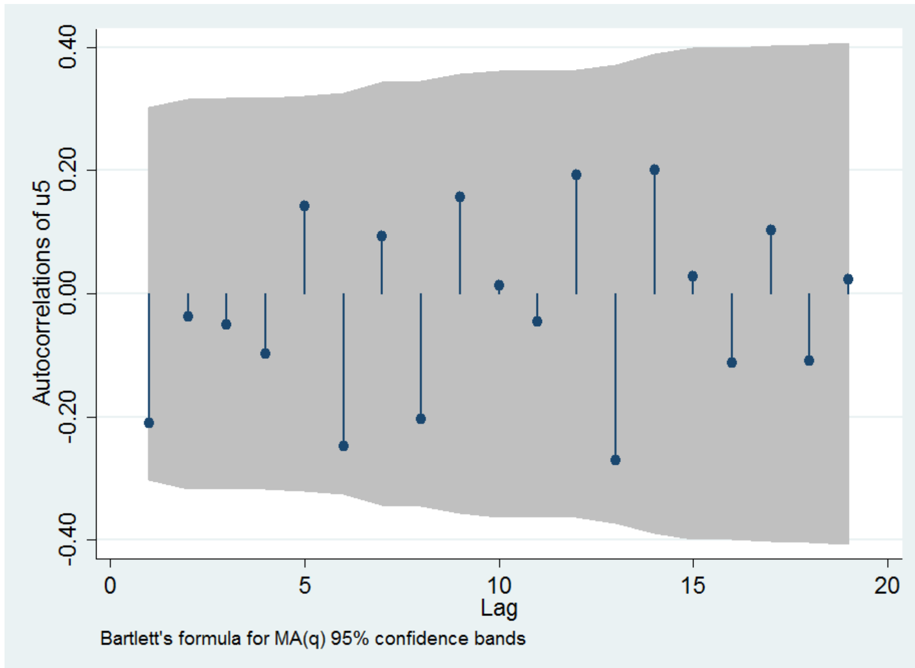


Figure A.4.5: Autocorrelation function of residuals from demand (a) and supply (b) equations in the Beef Retail Market

(a) **Residual** $\epsilon_t^{bf,d}$



(b) **Residual** $\epsilon_t^{bf,s}$

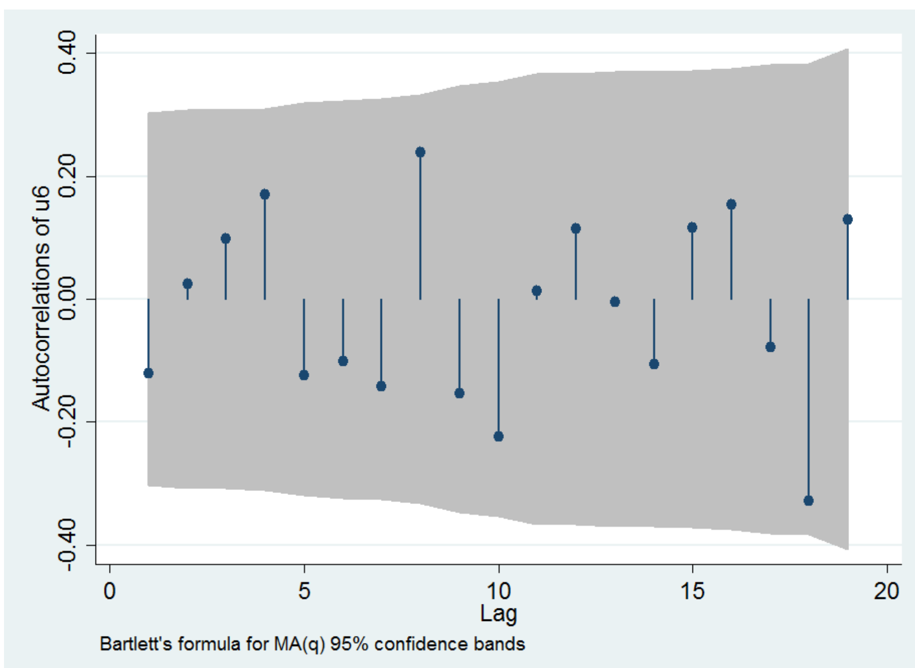
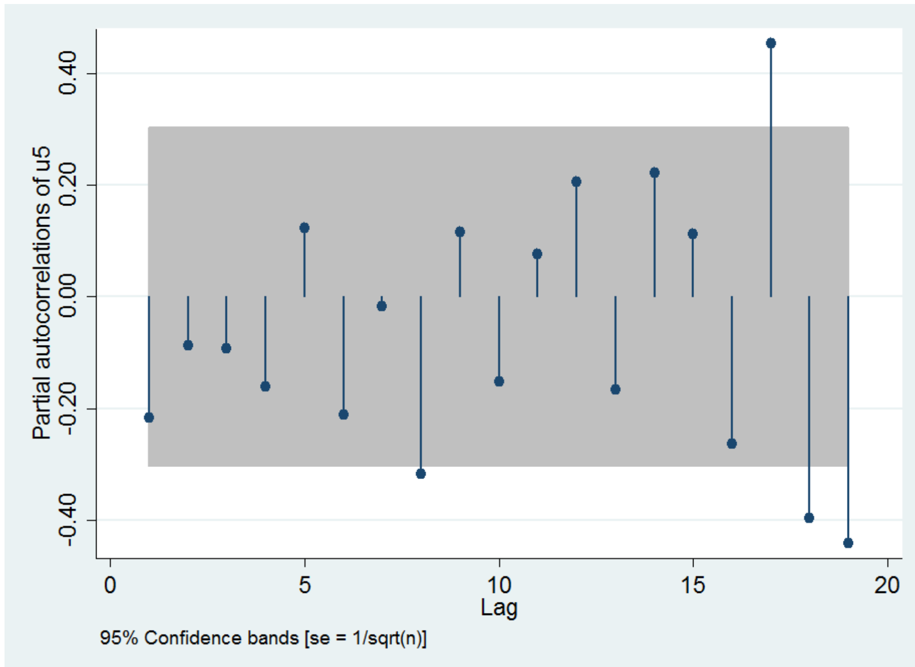
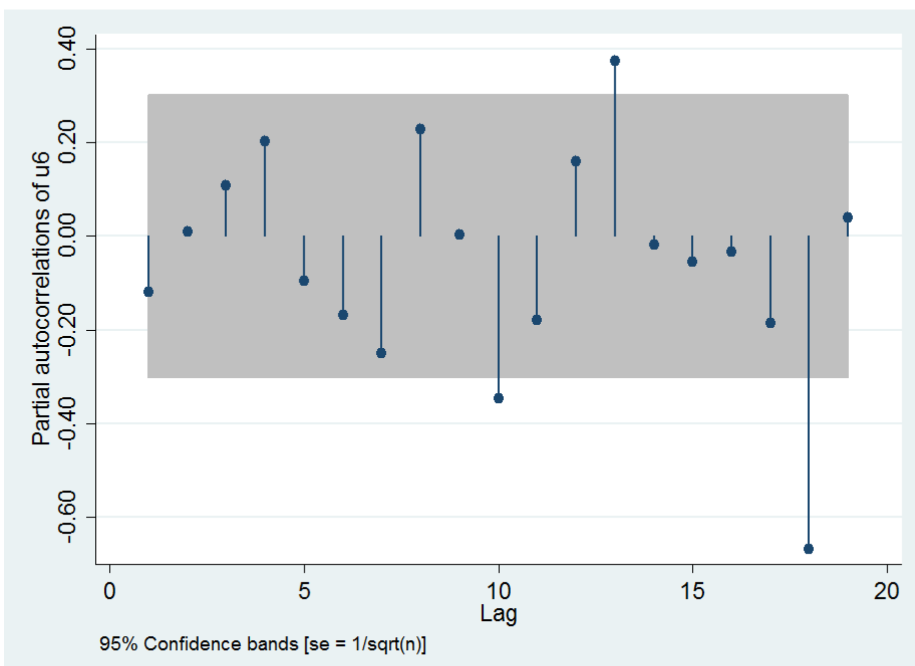


Figure A.4.6: Partial autocorrelation function of residuals from demand (a) and supply (b) equations in the Beef Retail Market

(a) **Residual** $\epsilon_t^{\mathbf{bf,d}}$



(b) **Residual** $\epsilon_t^{\mathbf{bf,s}}$



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