FOOD SAFETY IMPACTS ON U.S. DOMESTIC MEAT DEMAND AND INTERNATIONAL RED MEAT TRADE

by

XIA SHANG

B.S., Southwest University, China, 2009
M.S., North Dakota State University, 2011

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

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Abstract

Few things facing the U.S. meat industry in recent years have garnered more attention of economic researchers than food safety events, policies, and mitigation efforts. This dissertation has two main essays and themes focusing on both domestic and international food safety issues. Contributing new insights to this situation, the impacts of FSIS (Food Safety Inspection Service) recalls on consumer meat demand in the United States are estimated by a series of Rotterdam models in the first study using monthly grocery-scanner data. Multiple model specifications are employed to further assess effects across meat products and geographic regions. Recall variables are constructed separately as beef *E. coli* recall, beef non-*E. coli* recall, pork recall, and poultry recall variables to facilitate finer assessment of demand impacts. Results suggest beef *E. coli* recalls significantly reduce the demand for ground beef contemporaneously among most, but not all, regions in the United States. The ultimate finding of food safety effects neither being fully homogeneous nor entirely heterogeneous warrants appreciation.

In order to protect domestic consumers and meat industries from potential food safety hazards, some member countries of the WTO implement sanitary and phytosanitary (SPS) measures as non-tariff barriers. The second study focuses on investigating the determinants of red meat trade patterns and associated impacts of SPS regulations. This analysis uses multiple product-level gravity equation models and PPML (Poisson Pesudo Maximum-likelihood estimators to overcome sample selection bias and heteroscedasticity and examine the trade relationship among other factors. Results indicate that, trade values of frozen beef and pork are significantly reduced by the implementation of SPS measures. Also, the spillover effects across meat products on trade were detected which provides essential information to the meat industry, policy makers, and trade representatives.

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Dedication

This dissertation is dedicated to my wife and parents

Chapter 1 - General Introduction and Main Results Preview

In domestic markets, meat demand is driven by multiple factors including traditional economic determinants (prices and incomes) and non-traditional determinants (food safety information, changes in consumer lifestyles, animal welfare, new product characteristics, and other non-price factors). Within non-traditional meat demand determinants, the impacts of food safety on consumer demand have been of great interest to researchers (Burton and Young, 1996; Henneberry *et al*., 1999; Thomsen and McKenzie, 2001; Piggott and Marsh, 2004; Marsh *et al*., 2004; Tonsor *et al*., 2010; Ishida *et al.*, 2010). Foodborne pathogens have been detected in different food types, but meat products remain a major source. The occasional outbreaks of meat contaminations are the subject of public attention and can adversely affect consumer demand for the implicated meat products (Piggott and Marsh, 2004). Examining food safety issues in additional depth will provide supplementary and complementary insights for food policy and industry leaders.

Food safety and animal health issues not only affect domestic consumer consumption behavior, but also increasingly influence international agricultural trade (Unnevehr, 2000). Meat products are exposed to a great number of market failures (Schlueter *et al*., 2009), which could be a good example of market intervention (Koo *et al*. 1994). Sanitary and Phytosanitary (SPS) measures have become an important factor in negotiations on meat trade issues. SPS measures related to animal health, human health, maximum residue limits, and other requirements may act as non-tariff barriers which may reduce the flow of meat to some countries as well as impose additional costs on red meat producers and exporters. Conversely in some other cases, SPS measures could behave like "catalysts" and imply positive trade impacts. Therefore, understanding the effects of food safety and SPS measures on red meat trade is essential for meat producers and exporters' decisions in many production and marketing activities, such as pricing, targeting countries, and implementing of production standards.

This dissertation consists of two studies on the topics of meat safety economic impacts. The primary purpose is to 1) investigate the effects of food safety information on domestic meat consumption, with particular attention to different types of meat recalls and regional residence heterogeneity, and 2) investigate the determinants and impacts of SPS measures on red meat international trade, especially focusing on direct and spillover effects.

In light of domestic meat demand, the first study estimates the own- and cross-effects (elasticities) of *E. coli*, separate from the effects of other recalls, on the demand for beef (ground beef and other beef), pork, chicken, and turkey, using Rotterdam model specifications. Throughout this article, recall variables are constructed separately by beef *E. coli* recall, beef non-*E. coli* recall, pork recall, and poultry recall respectively in order to investigate differences on meat demand across eight U.S. regions. Furthermore, since ground beef is a product most often involved in *E. coli* recalls, this study separates beef products into ground beef and other beef (e.g. steak, roast, etc.) in the empirical models, and examines the heterogeneous effects of beef *E. coli* recalls for different regions between ground beef and other beef demand. Through multiple assessments, results suggest beef *E. coli* recalls significantly reduce the demand for ground beef contemporaneously among most, but not all, regions in the United States. Although the majority of other food safety recalls do not reveal statistically significant effects on meat demand in most of regions, joint tests of food safety recall effects still indicate that U.S. meat demand is affected by food safety incidents.

In the first study, a multitude of pairwise comparisons provide insights into the question of whether food safety recalls present heterogeneous effects on meat demand across different regions in the country. These comparisons fail to reject the hypothesis of no differences among regions in most cases, which indicates that the majority of food safety recalls have the same effects on consumer meat demand across regions. One important sub-point however is that poultry recalls are more prevalent in having heterogeneous regional impacts than beef *E. coli*¸ beef non-*E. coli* recall, and pork recalls. This suggests societal investments (e.g. allocation of tax based government expenditures) in mitigating poultry recalls present heterogeneous net benefits to U.S. residents based upon their region of residence.

The second study applies a series of product-specific gravity equation models to evaluate the effects of SPS measures on red meat trade and investigate the determinants of red meat trade patterns. The red meat data, which is grouped at the level of four-digit Harmonized System (HS) codes, is analyzed using gravity equations. Using a frequency approach, detailed information on SPS regulations are counted and complied for use in estimated models. By disaggregating the SPS regulations into specific goals, we additionally examine the various effects of SPS measures related to animal health, human health, and maximum residue limits (MRLs) on red meat trade values.

Two stylized features of trade data, sample selection bias and heteroscedasticity challenge the estimation of gravity equations. Thus, multiple empirical frameworks are conducted in this study to account for the large presence of zero trade flows and heteroscedasticity in the model specifications. The robustness to extensive zeros and the acceptance of RESET tests suggest that the Poisson Pseudo-maximum Likelihood (PPML) is a correctly specified estimator. The results based on PPML estimators suggest that trade expenditures of frozen beef and pork are more likely to be negatively affected by SPS measures than fresh/chilled beef in world market. Also, factors including importing country's GDP per capita, free trade agreements, and exporter’s production are confirmed as facilitators for red meat international trade. This study also finds evidence that spillover effects of trade exist across meat products, which help improving our understanding of red meat trade in the world market.

In this dissertation, the first and second studies are presented in Chapter 2 and 3, respectively. Several sections as well as subsections are organized within this two chapters. In Chapter 4, the key findings and contributions from the two studies are summarized.

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Chapter 2 - Food Safety Recall Effects across Meat Products and Regions

Section 1 Introduction

Meat demand is driven by multiple factors including traditional economic determinants (prices and incomes) and non-traditional determinants (food safety information, changes in consumer lifestyles, health, new product characteristics, and other non-price factors). The non-traditional meat demand determinants have been of great interest to researchers (Capps and Schmitz, 1991; Chern *et al*., 1995; Verbeke *et al*., 2000; Marsh *et al*., 2004; Tonsor *et al*., 2010; Tonsor and Olynk, 2011; Schulz *et al*., 2012; Taylor and Tonsor, 2013). Given increasing food safety concerns with regard to contaminated meat products, a large body of research has been conducted to better understand the effects of food safety on meat demand in the United States. Significant research has broadly focused on safety issues such as evaluating how consumption changes in response to outbreaks of food safety incidents or scandals (McCluskey *et al*., 2005; Peterson and Chen, 2005; Ishida *et al*., 2010), examining the impact of negative food safety recalls and/or media information on meat demand (Burton and Young, 1996; Verbeke *et al*., 2000; Verbeke and Ward, 2001; Piggott and Marsh, 2004; Marsh *et al*., 2004; Mazzocchi, 2006; Tonsor *et al*., 2010), using choice experiments to analyze consumer willingness to pay (WTP) for food safety risk reductions (Buzby *et al.*, 1998; Shogren *et al*., 1999), and quantifying determinants of food safety risk perceptions of consumers (Schroeder *et al*., 2007; Tonsor *et al*., 2009).

The primary objective of this study is to provide a deeper assessment of how specific recall information impacts U.S. meat demand across products and residents in different geographic regions. Most previous studies have considered beef recalls and consumers in a fairly aggregated and homogeneous manner (Marsh *et al*., 2004; Tonsor *et al*., 2010; Tonsor and Olynk, 2011). For example, Marsh *et al*. (2004) estimated the impact of FSIS recalls on meat demand using net "lagged" disappearance data. We further estimate the own- and cross-effects of *Escherichia coli* (*E. coli*), separate from the effects of other recalls, on the demand for beef (ground beef and other beef), pork, chicken, and turkey. Throughout this article, recall variables are constructed separately by beef *E. coli* recall, beef non-*E. coli* recall, pork recall, and poultry recall respectively in order to investigate differences on meat demand across eight U.S. regions. Furthermore, since ground beef is a product most often involved in *E. coli* recalls, we separate beef products into ground beef and other beef in the empirical models, and examine the heterogeneous effects of beef *E. coli* recalls for different regions between ground beef and other beef (e.g. steak, roast, etc.) demand.

Section 2 Literature Review and Motivation

Key pathogens on contaminated meat include but are not limited to *Shiga toxin-producing Escherichia coli* (STEC), *Listeria monocytogenes*, *Salmonella*, and *Campylobacter jejuni* (Centers for Disease Control and Prevention, 2013). The FSIS ranks the level of threat by three classifications: Class I, II, and III. Specifically, Class I indicates the highest risk level of foodborne disease which may cause health problems or even death; Class II represents a health hazard condition where the use of the food may lead to a remote probability of adverse health problems; and Class III describes the situation in which eating the food will not cause health issues (USDA Recall Classifications). As a Class I health hazard which is categorized by the USDA Food Safety and Inspection Service (FSIS), *E. coli* is ranked as one of the top five pathogens contributing to domestically acquired foodborne illnesses resulting in hospitalization in 2011 (CDC, 2011). *E. coli* contaminations causing human illness are costly to society. Scharff (2012) indicates the average economic cost per case of *E. coli* infection is $9,606 (in 2010), which is substantially higher than the cost of infections of *Salmonella* ($4,312) and other major foodborne illnesses. Some epidemiological studies also find *E. coli* infections have geographical and longitude patterns. For example, Sodha *et al*. (2014) discover that the isolation rate of *E. coli* infection is highest in northern states. However, most existing applied economics articles on meat demand regarding food safety only consider the effect on the national level (Piggott and Marsh, 2004; Marsh *et al*., 2004; Tonsor *et al*., 2010). It is possible that consumers in some parts of the country are more or less sensitive to recalls. Whether consumers residing in different regions across the U.S. have differential responses to *E. coli* contaminations as well as other recalls is still an unanswered question leaving an economically important knowledge gap. To provide desired answers, several hypotheses are identified and examined using a myriad of empirical demand models and tests.

In formulating food safety variables as a demand shifter, researchers use information from a variety of sources including government recalls, academic studies, and social media. Marsh *et al*. (2004) emphasize that government issued recalls are important sources of information regarding meat safety and quality providing a consistent data series over time. They hypothesize that meat recalls from USDA FSIS indicate lower quality control during meat processing which may make consumers substitute away from the recalled products to other meat or non-meat foods. FSIS recalls can be proxies for food safety information received by consumers which represents the perceived level of food safety hazards in analyzing impacts on meat demand, prices, and financial markets (Marsh *et al*., 2004; Lusk and Schroeder, 2000; Thomsen and McKenzie, 2001; Tonsor *et al*., 2010). When a recall occurs, FSIS distributes a Recall Release and general public notification through the general news media[1], which directly reflects information consumers receive about specific food safety events. Furthermore, the prior literature typically "linearly aggregates" the number and type of FSIS issued recall events quarterly for beef, pork, and poultry in order to build measures of meat products recalls (Burton and Young, 1996; Kinnucan *et al*., 1996; Marsh *et al*., 2004; Tonsor *et al*., 2010). To make deeper statements concerning recall events, one must not only consider recalls by meat types, but also the specific source or pathogen (e.g. *E. coli* or *Salmonella*). To get at this, we separate beef recalls into beef *E. coli* recall and beef non-*E. coli* recall (e.g. *Listeria*, *Salmonella*, etc.), and

[1] See USDA-FSIS, Recall of Meat and Poultry Products, FSIS Directive 8080.1 Reversion 7, 09/09/2013 at www.fsis.usda.gov.

aggregate the number of recall events monthly providing a more precise assessment both temporally and across recall type.

There is a large body of literature evaluating the effect of food safety information on U.S. demand utilizing per capita aggregate disappearance data from USDA (Piggott and Marsh, 2004; Marsh *et al*., 2004; Tonsor *et al*., 2010; Tonsor and Olynk, 2011). Aggregate disappearance data works well in predicting and measuring national food supply because it refers to "the resulting food supply after food disappear into the food marketing system" (USDA-ERS). Such data however are limited in ability to assess heterogeneous preferences and cannot represent the current market condition (Capps, 1989). In addition, disappearance data will not completely reflect actual retail consumption (Brester and Wohlgenant, 1993). In disappearance data it is unclear where and how meat actually "disappears" into the market as some meat may be consumed or purchased by restaurants, food industries, or other commercial outfits as well as by consumers at grocery stores. Grocery-store scanner data are used in this study covering the meat sales of major U.S. grocery store and supermarket chains, providing significant advancement in understanding meat product marketing and consumer behavior (Capps and Love, 2002).

The current article contributes to the applied economics literature related to food safety recalls and meat demand in several keys. A series of Rotterdam models of consumer response are used to estimate own- and cross-effects of beef *E. coli* recall and beef non-*E. coli* recall on meat demand. Two model specifications varying in beef aggregation are constructed. The impacts of recall information are evaluated through a multi-regional modeling approach including total U.S. and eight separate regions facilitating regional comparisons. Combined, the multi-regional modeling approach, based upon monthly grocery-store scanner data, considering separate FSIS recall types, allows a much deeper understanding of current consumer responses to meat food safety events. These results will provide empirical evidence for U.S. meat industry to target different consumers based on the regions of residence. Also, as a leading meat exporter in the world, the U.S. has a complete inspection system. An *ex post* evaluation of FSIS recall domestic impacts meets the need for additional information to improve U.S. meat safety policy and exporting regulations to trading partners.

The next section specifies our econometric methods of investigating consumer responses to food recalls across meat products and regions and describes the scanner data utilized. The results of the study and the hypothesis tests concerning heterogeneities of food safety recall impacts are then presented. We conclude with a discussion of economic implications.

Section 3 Research Methods

The research process contains multiple steps best described in sequence. Generally, we have two fundamental model specifications (Model 1 and Model 2) focusing on different meat product levels. The model 1 with emphasis on aggregated beef is constructed following the standard assumptions of weak separability. Then, the meat (beef, pork, chicken, and turkey) demand for the whole nation and eight different regions associating with national meat safety recalls are estimated by nine Rotterdam frameworks individually informed by geographically distinct data sets (Figure 2.1). For each sub-model, employment of autocorrelation corrections and Wald tests jointly determine lag length of recall effects and identify preferred empirical models. In model 2, we further separate the aggregated beef products into ground beef and other beef and create a meat separable model with an integral ground beef specification. Here, pork and turkey are grouped into "other meat" by the assumption of weak separability. This model is specified to test whether there have been varied food safety recall impacts on the demand patterns of different beef products in the U.S. consistent with our introduction. This estimation of model 2 is valuable given ground beef is a product most often involved in *E. coli* recalls. The effects of *E. coli* recalls on ground beef consumption and regional heterogeneity between ground beef and other beef (e.g. steak, roast, etc.) can be evaluated by model 2. Model 2 also has nine individual sub-models and follows the same estimation strategy as model 1.

3.1 Conceptual Framework

Suppose the utility function for a given consumer is represented by $U(\mathbf{x}, \mathbf{q})$, where $\mathbf{x}$ is the vector of quantities consumed and $\mathbf{q}$ is a vector of quality perceptions reflecting relative information. Assume the consumer utility maximization problem is given by:

(2.1)

$$\underset{\mathbf{x},\boldsymbol{\lambda}}{\text{Max}}\, U(\mathbf{x},\mathbf{q}) + \lambda(M - \mathbf{p}'\mathbf{x}),$$

where λ is the Lagrange multiplier, M is total expenditure, and $\mathbf{p}$ is a vector of prices.

Following Mojduszka and Caswell (2000), Piggott and Marsh (2004), and Tonsor *et al*. (2010), we assume that publicly available information impacts consumer perceptions of meat quality. In the present study, the vector of FSIS recalls (**R**) has been included in the demand system regarding food safety hazards and concerns posed by meat consumption. The first-order conditions yields the Marshallian demand for meat *i*: $\mathbf{x}_i^m(\mathbf{p}, M, \mathbf{R})$.

3.2 Rotterdam Model with Weak Separability Assumption

One of the most common approaches to estimating demand systems which incorporate demand shifters is the Rotterdam model. In multiple studies of meat demand, previous literature (Brester and Schroder 1995; Kinnucan *et al*., 1997; Marsh *et al*., 2004; Peterson and Chen, 2005; Tonsor *et al*., 2010; Tonsor and Olynk, 2011; Schulz *et al*., 2012; Taylor and Tonsor, 2013) also supports use of an absolute price version of the Rotterdam model in this study. The Rotterdam model, which is derived from consumer demand theory, was first presented by Barten (1964) and Theil (1965). It can be estimated to satisfy the adding-up, homogeneity, and symmetry restrictions, and is sufficiently flexible to capture demand elasticities and variations in consumer behavior (Brester and Wohlgenant, 1991; Capps and Love, 2002; Schulz *et al*., 2012). The Rotterdam model is also a valid discrete approximation in variable space and is linear in parameters (Marsh *et al*., 2004). In addition, price and quantity variables are expressed in logarithmic differences, which are an advantage for the Rotterdam model over other demand system such as Almost Idea Demand System (AIDS) in handling non-stationary data[2] (Capps and Love, 2002). Furthermore, the Rotterdam model may outperform the AIDS model in out-of-sample forecasting accuracy (Kastens and Brester, 1996).

The FSIS recall information may have important implications and can be exogenous shift variables in modelling Rotterdam demand systems. The theoretically correct specification of exogenous demand shifter is allowed in Rotterdam model even without imposing restrictions on shifters (Brown and Lee, 1993). The *priori* expectations are that an increase the number of recalls will shift down the demand for recalled products. Spillover or cross-effects can also be examined.

Previous studies commonly make weak separability assumptions in a food and meat demand system (Nayga and Capps, 1994; Henneberry *et al*., 1999; Marsh *et al*., 2004; Dhar and Foltz 2005; Tonsor *et al*., 2010; Tonsor and Olynk, 2011; Taylor and Tonsor, 2013). Dhar and Foltz (2005) indicated that weak separability is a reasonable assumption and because of data constraints, it is impossible to estimate a full demand system which includes all products with retail scanner data. In the present study, we specify the demand system at the level of monthly meat purchases in eight different regions across the U. S. and implicitly assume meat purchases are weakly separable from other food. Further, we expand upon previous work and set up the Rotterdam models applying two different separable forms: a meat separable model considering

[2] We also conducted Augmented Dickey-Fuller (ADF) tests of the dependent variables in each model. All of the null hypotheses of non-stationarity are rejected at the 1% significance level, which indicate that the application of Rotterdam model in our study does not involve non-stationary issues.

beef broadly (Model 1) and a meat separable model distinguishing ground beef (Model 2). Model 1 is estimated using the partition of beef, pork, chicken and turkey, whereas Model 2 is estimated using the partition of ground beef, other beef, chicken, and other meat. Ground beef is a product most often involved in *E. coli* recalls, therefore the estimation of Model 2 can evaluate and compare the different effects of *E. coli* Recalls on the demand of ground beef and other beef (steak, roast, etc.) respectively. The *i*th equation of our estimated Rotterdam model is specified as:

(2.2)

$$\mathrm{w}_i^r \Delta \ln(x_i^r) = a_i^r + \sum_{j=1}^{3} d_{ij}^r D_{ij}^r + \sum_{j=1}^{n} c_{ij}^r \Delta \ln\left(p_j^r\right) + \beta_i^r \Delta \ln(\bar{q}^r) + \sum_{k=1}^{K} \sum_{l=0}^{L} \lambda_{ikl}^r \Delta \ln(R_{kl}^r) + v_i^r$$

where the superscript r denotes different regions (i.e.: $r = \text{California}$); w_i^r is budget share of the *i*th good (*i* = 1, …, 4); Δ is the standard first difference operator (i.e.: $\Delta \ln x_t^r = \ln x_t^r - \ln x_{t-1}^r$); x_i^r is the quantity of good *i*; D_{ij}^r are quarterly dummy variables to account for seasonality; p_j^r is the price of good *j*; $\Delta \ln(\bar{q}^r)$ is the Divisia volume index where $\Delta \ln(\bar{q}^r) = \sum_{i=1}^{n} \mathrm{w}_i^r \Delta \ln(x_i^r)$; R_{kl}^r represents the *k*th FSIS food safety recall with lag length *l*. Specifically, *k* represents beef *E. coli* recalls, beef non-*E. coli* recalls, pork recalls, and poultry recalls. v_i^r is a random error term; a_i^r, d_{ij}^r, c_{ij}^r, β_i^r, and λ_{ikl}^r are parameters to be estimated. The intercept term a_i^r in the Rotterdam model represents a linear time trend, which is included for structural changes or trends not captured by other variables (Piggott *et al*., 1996; Marsh *et al*., 2004; Tonsor *et al*., 2010; Tonsor and Olynk, 2011; Taylor and Tonsor, 2013). Following this specific procedure, the final model specifications intend to estimate the contemporaneous effects (lag length = 0) as well as long-run effects (lag length = 1 to 4) of all FSIS food safety recall variables. By doing so, one can determine how long the effects of FSIS recalls last on consumer meat demand in the U.S.

It is standard to drop one share equation from the empirical models to prevent singularity in the estimated covariance matrices. Here, the share equation of turkey and other meat was dropped from model 1 and 2, respectively. The parameters of the deleted equation are recovered using adding-up restrictions. Symmetry and homogeneity restrictions are imposed to guarantee the system is consistent with demand theory. The adding-up restrictions are:

(2.3) $$\sum_{i=1}^{n} c_{ij}^{r} = 0; \sum_{i=1}^{n} \beta_{i}^{r} = 1; \sum_{i=1}^{n} \lambda_{ikl}^{r} = 0; \sum_{j=1}^{n} d_{ij}^{r} = 0$$

Homogeneity and symmetry are imposed by

(2.4) $$\sum_{j=1}^{n} c_{ij}^{r} = 0 \, ; c_{ij}^{r} = c_{ji}^{r}$$

Following the suggestions of Brester and Schroder (1995), Kinnucan *et al*. (1997), Marsh *et al*. (2004), Tonsor *et al*. (2010), Tonsor and Olynk (2011), and Taylor and Tonsor (2013), equations (2.2) to (2.4) generate the compensated price, expenditure, and FSIS meat safety recall effect elasticities of different regions:

(2.5) $$\varepsilon_{ij}^{r} = \frac{c_{ij}^{r}}{\mathrm{w}_{i}^{r}}, \eta_{i} = \frac{\beta_{i}^{r}}{\mathrm{w}_{i}^{r}}, \kappa_{ikl}^{r} = \frac{\sum_{l=0}^{L} \lambda_{ikl}^{r}}{\mathrm{w}_{i}^{r}}$$

Using equation (2.5), κ_{ik0}^{r} yields a contemporaneous recall elasticity estimate and κ_{ikl}^{r} yields a long-run recall elasticity estimate.

3.3 Grocery-store Scanner Data

The meat demand data utilized in this study were obtained from IRI (Information Resources, Inc) FreshLook Perishable Service from January 2009 through February 2014. Their service provides scanner-based sales information on perishable items (including fresh meat products of central interest in this study) sold in the U.S. from over 15,000 grocery stores, 7,000 mass merchandisers, and 800 club stores. This data includes measures of pounds (volume in lbs) and price (average retail price paid per pound). The dataset used in this study is derived from meat department information reflecting approximately 82% of total U.S. sales that occur in the retail channel. The eight geographic regions are defined by IRI Freshlook Perishable Service based on InfoScan Standard Regions and the coverage of U.S. all-commodity volume (ACV) (Figure 2.2).

This grocery-store scanner data offers significant advances in understanding current meat market, which tracks the point-of-sale and random-weight sale from retail food stores[3]. What consumers actually pay for meat products can be reflected more accurately by the volume-weighted prices provided by scanner data than the more commonly applied BLS (Bureau of Labor Statistics) summary of posted prices (Lensing and Purcell, 2006). In addition, the scanner data are available monthly, which allows for more accuracy in conducting hypothesis tests and matching FSIS event dates (Taylor and Tonsor, 2013). Furthermore, the availability of scanner data for less aggregated product categories enables us to model impacts directly on ground beef demand consistent with the category's actual higher prevalence of *E. coli* recalls compared to other beef categories.

Table 2.1 (A and B) provides a summary of the entire scanner data used in models 1 and 2, including the average amounts of meat products sold in the U.S. retail channels every months, the average prices, and the expenditure shares. Underlying each model, we apply the Rotterdam framework to data for the whole nation as well as individually to eight different U.S. regions. Upon inspection of the expenditure shares (Table 2.1 A), it is apparent that the representative U.S. household allocates the highest percentage of expenditure on beef products, which is almost 50% compared to pork (20%), chicken (24%), and turkey (6%). Meanwhile, the demand for meat

[3] Food safety recalls may also have different effects on restaurants and fast-food chains. Due to data limitations, the current study does not consider food-away-from-home (FAFH), which remains a good direction for future work.

products reveals several geographic patterns (Table 2.1 A) that is typically masked in aggregated analyses. To provide a clear explanation, we compare the proportion of meat purchases to the population proportion of each region. For example, people in South Central (Oklahoma, Arkansas, Texas, and Louisiana) have the highest ratio of red meat consumption relative to their population. With 11.97% of the total U.S. population, South Central residents consume 14.40% of the beef and 13.73% of the pork purchased in the whole country. People in the Northeast (Maine, Vermont, New Hampshire, Massachusetts, New York, Connecticut, Rhode Island, Pennsylvania, and New Jersey) have 17.92% of the U.S. population and purchase 22.33% of the total chicken consumed in the country. Furthermore, there are also regional differences among disaggregated beef products (Table 2.1 B). For instance, people in the Plains region (North Dakota, Minnesota, South Dakota, Nebraska, Iowa, Kansas, and Missouri), accounting for 6.67% of total U.S. population, purchase 8.41% of ground beef in the whole nation. In contrast, people in California who account for 12.12% of total U.S. population, only purchase 7.14% of ground beef consumed nationally. In addition, the average prices for meat products also vary by regions. For example, the beef price ranges from $3.61 in the South Central to $4.30 in the Southeast.

FSIS meat recalls may contain important information about meat quality which may be an important demand shifter. Although the meat recalls may contain detailed information such as specific location and amount, we follow previous studies and collect nationwide recalls information without considering their origin in our empirical models (Marsh *et al*., 2004; Piggott and Marsh, 2004; Tonsor *et al*., 2010). This follows the FSIS recalls being issued nationwide by a public notification and convey a negative view to consumers’ perceptions directly. Our study further disaggregates the sources of recall in order to capture the specific information about beef recall-related impacts of meat demand, we distinguish beef recall information by the sources of infection and grouped them into beef *E. coli* recall and beef non-*E. coli* recall (e.g. *Listeria*, *Salmonella*, and etc.). Figure 2.3 presents the variability of monthly beef *E. coli* and non-*E. coli* recalls from January 2009 to February 2014. Beef *E. coli* infections contribute to the major reason for FSIS issued beef recalls which reached its record level in May 2009, with 4 recalls in that month. Marsh *et al*. (2004) found significant cross-commodity impacts from meat recalls, indicating that recall impacts might have spillover effects by species. Thus, we select the number of FSIS recalls (Class I & II) by each month with regard to pork and poultry to include and consider similar spillover effects. FSIS recalls for pork and poultry averaged 1.61 and 1.79 cases per month, respectively, over the January 2009 to February 2014 period (Table 2.2).

3.4 Estimation Procedures

The logarithmic transformations in the Rotterdam model require all variables to be positive values over all observations. Therefore, we follow the suggestions of Brester and Schroeder (1995) and Tonsor *et al*. (2010) and add 0.1 to each FSIS recall variable (the value of FSIS recalls was zero for some months). This approach guarantees that all explanatory variables of meat safety recalls are globally positive[4].

All of the empirical Rotterdam models (model 1 and 2) are estimated through an iterative seemingly unrelated regression (ITSUR) with monthly scanner data spanning from January 2009 to February 2014. ITSUR is a widely used econometrical tool in previous meat demand studies associating with shifter variables (Hayes *et al*., 1990; Eales and Wessells, 1999; Piggott and Marsh, 2004; Marsh *et al*., 2004; Taylor and Tonsor, 2013). Considering the potential

[4] We also consider an alternative approach which replace all zeros with 1 in the recall series. This approach generates very similar results.

autocorrelations in the empirical Rotterdam models, multiple autocorrelation corrections are evaluated following the suggestion of Piggott *et al.* (1996), Holt and Goodwin (1997), Piggott and Marsh (2004), Tonsor and Marsh (2007), Tonsor *et al*. (2010), and Tonsor and Olynk (2010). Three different Berndt and Savin (1975) correction matrices were considered: i) the null matrix which restricts all elements to zero, specifies no autocorrelation correction ($\rho_{ij} = 0\ \forall_{ij}$), ii) the diagonal matrix which restricts all off-diagonal elements to zero ($\rho_{ij} = 0\ \forall_{i \neq j}$ and $\rho_{ij} \neq 0\ \forall_{i=j}$), and iii) a complete matrix which allows all elements to differ from zero ($\rho_{ij} \neq 0\ \forall_{ij}$).

Since adjusted likelihood ratio tests[5] were usually used to compare alternative model specifications in previous research (Bewley, 1986). To investigate if these food safety impacts were distributed over time, Wald tests were carried out jointly with adjusted likelihood ratio tests to determine the preferred model specifications (lag length of recall variables) and test the joint significances of all recalls on aggregate meat demand for each model.[6] Table 2.3 reports the results of hypothesis tests for lag lengths of FSIS recall variables. The FSIS recall variables for most model specifications have the lag length equal to four which indicate that the effect of FSIS recalls will last four months in most regions. The “N/As” in the table means the specific FSIS recalls do not have any significant effects on meat demand based on the results of adjusted likelihood ratio test and Wald tests jointly. Therefore, such recall variables were not included in the preferred models.

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[5] We have applied multiple hypothesis tests in this research. To avoid confusion, a summary of hypothesis tests is provided in Appendix.

[6] The aim of hypothesis tests here is to identify the lag length and test the joint significances of all four FSIS recall variables.

When examining the U.S. in aggregate, following most past research our model 1 approach finds each recall type to have a significant impact on **overall *meat*** (four meat categories together) demand (Table 2.3). When conducting this assessment regionally, this finding holds for most, but not all regions. For instance, beef *E. coli* recalls do not have statistically significant effects on meat demand in the regions of the Mid-south and Northeast while meat demand of West residents is not significantly influenced by pork and poultry recalls. Conversely, beef non-*E. coli* recalls have significant impacts in all eight examined regions. When model 2 is considered, the impacts of beef *E. coli* and beef non-*E. coli* recalls have varied significance. Our model 2 approach indicates that each recall type also have significant impact on meat demand for most regions. For example, beef *E. coli* recalls have statistically significant effects in short run period on ground beef demand in each region except for Northeast and Plains.

Because we are estimating empirical models with eight regions, it is valuable to investigate if differences in parameter estimates across regions exist due to the reginal heterogeneity. We follow Lusk and Schroeder (2004) and De-Magistris (2013) and use a broad likelihood ratio (LR) test[7] of the joint equality for the estimated parameters to examine whether estimates from separate regional models are equivalent to a stacked model with pooled data (and common parameters) from eight regions. The null hypothesis of the test is that the parameters are equal across regions and the stacked model. If the hypothesis is rejected, pairwise comparisons

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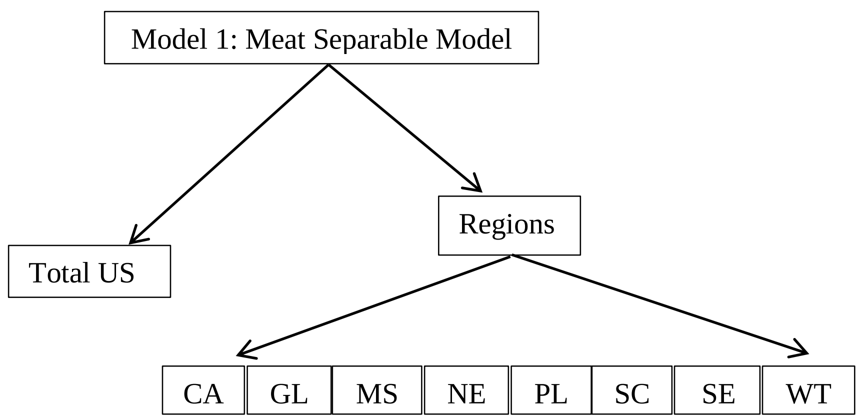
[7] The test statistic for quality is $2 \times (LL^R - \sum LL^{UR})$, which is distributed χ^2 with $K(M-1)$ degree of freedom. LL^R is the log likelihood value for the restricted model (stacked model), $\sum LL^{UR}$ is the summation of log likelihood values for the different unrestricted models (eight region-specific models), K is the number of coefficients in each estimated model, and M is the number of regions.

for regional heterogeneity, which will be discussed in next section, would be appropriate and reasonable because the underlying demand patterns are heterogeneous across consumers in different regions.

Figure 2.1: The Structure of Theoretical Framework for Model 1 with Aggregated Beef (same as model 2)



Notes: CA, GL, MS, NE, PL, SC, SE, and WT denote the regions of California, Great Lakes, Mid-south, Northeast, Plains, South Central, Southeast, and West, respectively.

Figure 2.2: The Definition of Geographic Regions of IRI Freshlook Scanner Data

Figure 2.3: The FSIS monthly beef *E. coli* Recalls versus Beef non-*E. coli* Recalls, Jan 2009-Feb 2014

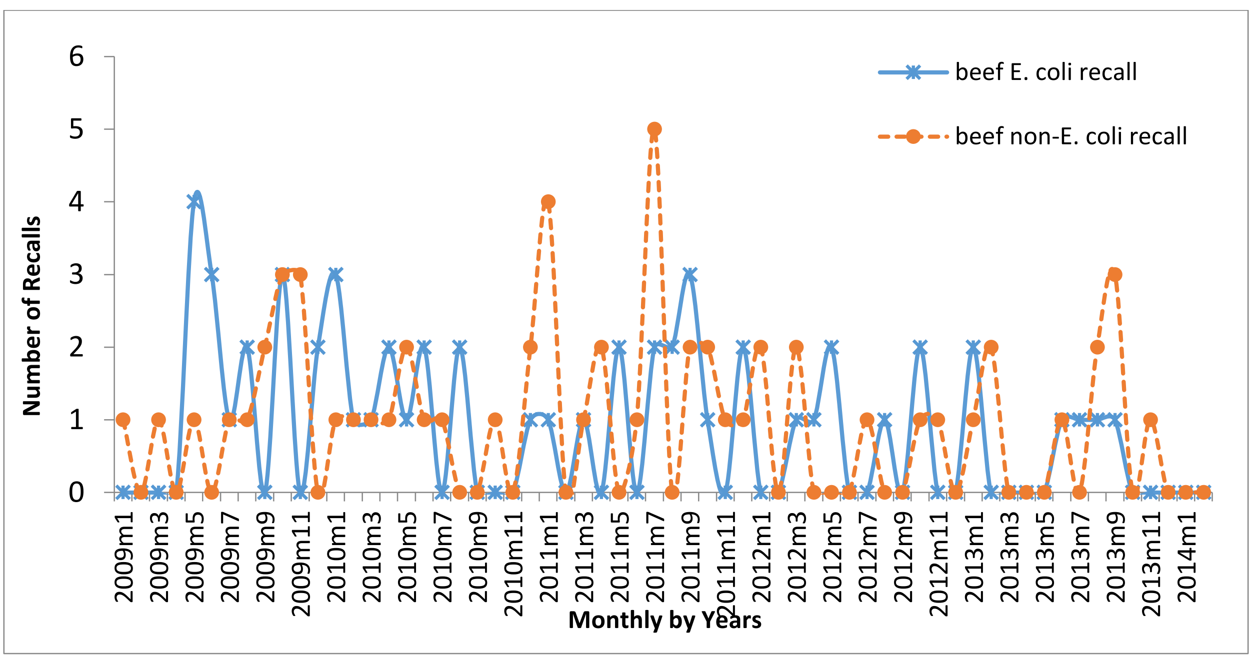


Table 2.1: Average Meat Purchases, Price, Expenditure Share, Percentage of Meat Purchases by regions, and Percentage of Population in Model 1 and 2, Jan 2009 – Feb 2014.

A. Model 1: Meat Separable Model

Regions	**Total US**				**California**				**Great Lakes**			
Model 1: Meat Separable	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions
Beef	437,802,264	3.99	0.50	100%	42,868,244	3.97	0.51	9.79%	61,983,960	3.83	0.52	14.16%
Pork	271,109,249	2.61	0.20	100%	22,308,165	2.50	0.16	8.23%	39,349,804	2.61	0.22	14.51%
Chicken	390,187,704	2.07	0.24	100%	45,777,755	1.89	0.26	11.73%	43,604,439	2.08	0.20	11.18%
Turkey	109,794,923	2.48	0.06	100%	11,476,280	2.87	0.07	10.45%	14,969,529	2.47	0.06	13.63%
% of Population	100%				12.18%				14.98%			

Regions	**Mid-South**				**Northeast**				**Plains**			
Model 1: Meat Separable	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions
Beef	55,665,010	4.02	0.50	12.71%	72,113,035	4.26	0.46	16.47%	31,727,168	3.90	0.53	7.25%
Pork	34,703,587	2.61	0.20	12.80%	46,020,063	2.74	0.19	16.97%	20,313,327	2.63	0.23	7.49%
Chicken	51,920,571	2.05	0.24	13.31%	87,122,237	2.23	0.29	22.33%	19,961,184	2.25	0.19	5.12%
Turkey	14,618,143	2.38	0.06	13.31%	22,269,362	2.50	0.06	20.28%	7,822,347	2.31	0.05	7.12%
% of Population	12.20%				17.92%				6.67%			

Regions	**South Central**				**Southeast**				**West**			
Model 1: Meat Separable	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions
Beef	62,608,483	3.61	0.54	14.30%	60,526,045	4.30	0.49	13.82%	50,310,318	3.90	0.55	11.49%
Pork	37,215,780	2.47	0.22	13.73%	43,659,654	2.66	0.22	16.10%	27,538,870	2.62	0.20	10.16%
Chicken	46,194,914	1.82	0.20	11.84%	60,571,019	2.12	0.24	15.52%	35,035,585	2.03	0.20	8.98%
Turkey	11,631,284	2.32	0.04	10.59%	15,661,491	2.47	0.05	14.26%	11,346,489	2.56	0.05	10.33%
% of Population	11.97%				13.38%				10.70%			

(Table 2.1 continued)

B. Model 2: Meat Separate Model-Ground Beef Specification

Regions	**Total US**				**California**				**Great Lakes**			
Model 2: Ground Beef Specification	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions
Ground Beef	212,085,569	3.13	0.19	100%	15,148,441	3.34	0.15	7.14%	35,260,958	2.95	0.23	16.63%
Other Beef	225,716,695	4.80	0.31	100%	27,719,803	4.31	0.36	12.28%	26,723,002	5.01	0.29	11.84%
Chicken	390,187,704	2.07	0.23	100%	45,777,755	1.90	0.26	11.73%	43,604,439	2.08	0.20	11.18%
Other Meat	380,904,172	2.53	0.27	100%	33,784,445	2.52	0.23	8.87%	54,319,332	2.52	0.28	14.26%
% of Population	100%				12.18%				14.98%			

Regions	**Mid-South**				**Northeast**				**Plains**			
Model 2: Ground Beef Specification	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions
Ground Beef	29,413,472	3.09	0.20	13.87%	34,030,667	3.40	0.17	16.05%	17,846,536	3.12	0.24	8.41%
Other Beef	26,251,538	5.07	0.30	11.63%	38,082,368	5.04	0.29	16.87%	13,880,632	4.93	0.29	6.15%
Chicken	51,920,571	2.05	0.24	13.31%	87,122,237	2.23	0.29	22.33%	19,961,184	2.25	0.19	5.12%
Other Meat	49,321,729	2.51	0.26	12.95%	68,289,425	2.62	0.25	17.93%	28,135,674	2.50	0.28	7.39%
% of Population	12.20%				17.92%				6.67%			

Regions	**South Central**				**Southeast**				**West**			
Model 2: Ground Beef Specification	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions	Avg LBs	Avg Price ($)	Expenditure Share	% of LBs by Regions
Ground Beef	28,473,031	2.92	0.20	13.43%	30,067,780	3.22	0.18	14.18%	21,844,684	3.06	0.19	10.30%
Other Beef	34,135,452	4.18	0.34	15.12%	30,458,266	5.37	0.31	13.49%	28,465,633	4.55	0.36	12.61%
Chicken	46,194,914	1.82	0.20	11.84%	60,571,019	2.12	0.24	15.52%	35,035,585	2.03	0.20	8.98%
Other Meat	48,847,064	2.39	0.26	12.82%	59,321,145	2.56	0.27	15.57%	38,885,358	2.53	0.25	10.21%
% of Population	11.97%				13.38%				10.70%			

Note: Avg LBs is the monthly mean of meat purchases. The population data come from US Census Bureau. % of population is calculated by the average of population in the year of 2011, 2012, and 2013. Total U.S. excludes the non-contiguous states of Alaska and Hawaii. Great Lakes includes WI, MI, IL, IN, and OH; Mid-South includes KY, WV, VA, DE, MD, TN, and NC; Northeast includes ME, VT, NH, MA, NY, CT, RI, PA, and NJ; Plains includes ND, MN, SD, NE, IA, KS, and MO; South Central includes OK, AR, TX, and LA; Southeast includes MS, AL, GA, SC, and FL; West includes WA,ID, MT, OR, WY, NV, UT, CO, AZ, and NM.

Table 2.2: Summary of Statistics of Monthly FSIS Recalls (Class I & II), Jan 2009-Feb2014

	Average	Std. Dev	Minimum	Maximum
Beef *E. coli* Recalls	0.887	1.042	0.000	4.000
Beef non-*E. coli* Recalls	0.968	1.086	0.000	5.000
Pork Recalls	1.613	1.136	0.000	5.000
Poultry Recalls	1.790	1.570	0.000	6.000

Table 2.3: Autocorrelation Correction and Hypothesis Tests for Lag Lengths and Significances of FSIS Recall Variables

Model 1: Meat Separable	Autocorrelation Correction	Significance of Recalls and Lag Length Tests			
		Beef *E. coli* Recalls	Beef non-*E. coli* Recalls	Pork Recalls	Poultry Recalls
Total US	Complete Matrix	Yes (L=4)	Yes (L=4)	Yes (L=4)	Yes (L=4)
California	Complete Matrix	Yes (L=4)	Yes (L=4)	Yes (L=4)	Yes (L=4)
Great Lakes	Complete Matrix	Yes (L=4)	Yes (L=4)	Yes (L=3)	Yes (L=4)
Mid-South	Complete Matrix	No (N/A)	Yes (L=4)	Yes (L=4)	Yes (L=4)
Northeast	Complete Matrix	No (N/A)	Yes (L=2)	Yes (L=2)	Yes (L=2)
Plains	Complete Matrix	Yes (L=4)	Yes (L=4)	Yes (L=2)	Yes (L=4)
South Central	Complete Matrix	Yes (L=4)	Yes (L=4)	No (N/A)	Yes (L=4)
Southeast	Complete Matrix	Yes (L=4)	Yes (L=4)	Yes (L=3)	Yes (L=4)
West	Complete Matrix	Yes (L=4)	Yes (L=4)	No (N/A)	No (N/A)
Model 2: Ground Beef Specification	Autocorrelation Correction	Significance of Recalls and Lag Length Tests			
		Beef *E. coli* Recalls	Beef non-*E. coli* Recalls	Pork Recalls	Poultry Recalls
Total US	Diagonal Matrix	Yes (L=4)	No (N/A)	Yes (L=4)	Yes (L=2)
California	Diagonal Matrix	Yes (L=4)	Yes (L=4)	Yes (L=4)	Yes (L=4)
Great Lakes	Complete Matrix	Yes (L=1)	No (N/A)	No (N/A)	No (N/A)
Mid-South	Diagonal Matrix	Yes (L=4)	Yes (L=4)	Yes (L=4)	Yes (L=4)
Northeast	Diagonal Matrix	Yes (L=4)	No (N/A)	No (N/A)	No (N/A)
Plains	Complete Matrix	Yes (L=2)	No (N/A)	Yes (L=1)	Yes (L=4)
South Central	Diagonal Matrix	Yes (L=2)	Yes (L=3)	Yes (L=0)	Yes (L=4)
Southeast	Complete Matrix	Yes (L=4)	Yes (L=4)	Yes (L=4)	Yes (L=4)
West	Complete Matrix	Yes (L=4)	No (N/A)	No (N/A)	Yes (L=0)

Note: The results presented for all of the models are estimated using Berndt and Savin (1975) autocorrelation corrections. The estimated results for log-likelihood and likelihood-ratio tests are available in the Appendix. Wald tests are used to determine the joint significance of recalls and lag length. "Yes (L=4)" indicates that the effect of this food safety recall could impact the demand for meat at least four months period, and "No (N/A)" means the specific recall does not have effect on meat demand, therefore it was not included in the preferred models. This Table provides detailed information about how to add FSIS recall variables in different empirical estimation.

Section 4 Results and Hypothesis Tests

This section reports estimated elasticities for model 1 and model 2. Also, detailed analyses about the tests for regional heterogeneity contribute to another important part of this section. The appendix reports the estimated coefficients for the eighteen Rotterdam Model specifications and further comparisons of regional differences.

4.1 Elasticities of Preferred Models

The preferred Rotterdam specifications for model 1 and 2 fit the data well as goodness of fit, measured by R-square value, indicates that both of the two models captured the in-sample variation of each category similarly to those previous meat demand studies. Curvature restrictions are satisfied at the data means as the estimated price coefficient matrices are negative semi-definite[8]. Since the coefficient estimates have limited value except for calculating compensated elasticities (Tonsor *et al*., 2010), we mainly focus on the model's elasticities. Krinsky-Robb (1986) simulations are conducted to evaluate whether each elasticity estimate of food safety recall differed from zero within the same region and if own-price and expenditure elasticities were different from -1.0 and 1.0, respectively. Using random draws from a multivariate normal distribution based on each preferred model's estimated variance-covariance matrix, we generate 1,000 values of each elasticity estimate. The *p*-value associated with the one-sided hypothesis test is obtained by calculating the proportion of observations with simulated values greater than the critical values (i.e. 0, 1.0, or −1.0). From Table 2.4 to Table 2.21, we report eighteen tables for the compensated elasticities of the preferred Rotterdam specification in different regions for both model 1 and 2, respectively.

[8] The estimated coefficients for all models are reported in the Appendix.

Table 2.4 suggests that the own-price compensated elasticity estimates are −1.00, −2.59, −1.18, and −4.66 for beef, pork, chicken, and turkey, respectively, using the national model. All estimated price and expenditure elasticities in the nine model 1 specifications are consistent with the results reported by Taylor and Tonsor (2013) except for the expenditure elasticities for turkey. The turkey inconsistency may be explained by different time periods or alternative model specification. We also find that pork is more elastic than beef and chicken, which is similar to Tonsor *et al*. (2010), Tonsor and Marsh (2007), and Brester and Schroeder (1995) who utilized disappearance data. Our grocery store scanner-data based estimations have more elastic estimates for turkey on price compared with previous work, probably due to the volatile consumption by seasons. To understand regional variation in consumer meat demand, consider the magnitudes of own-price elasticity for beef range from −0.64 (West, Table 2.12) to −0.95 (Plains, Table 2.9). Similarly, consumers in the Mid-south (Table 2.7) have the least elastic own-price elasticity for chicken (−1.23), while people residing in the Southeast (Table 2.11) have the most elastic demand (-1.92).

In case of individual food safety recalls, our analysis does not support the commonly implicit assumption that beef *E. coli* recall and beef non-*E. coli* recall have common and significant effects on the total U.S. demand for beef, pork, chicken and turkey, respectively, in both short run and long run (Table 2.4). This result differs from Tonsor *et al*. (2010) who found beef FSIS recalls have negative and significant effects on beef demand, but is consistent with Marsh *et al*. (2004), who discovered beef demand to be unaffected by beef recalls. The reason for the differences may stem from the different model specification, data sources, and time periods. However, in some regions such as the South Central (Table 2.10) and Southeast (Table 2.11), beef demand is significantly and negatively impacted by beef *E. coli* recalls in the long run (also in the short run in the Southeast). A 100% increase in beef *E. coli* recalls reduces beef demand in the Southeast by 0.7% in the short run and 1.3% in the long run. Also beef *E. coli* recalls decrease chicken demand in California (Table 2.5) and increase pork demand in the Southeast (Table 2.11) and West (Table 2.12) contemporaneously. In addition, beef non-*E. coli* recalls have negative and significant long-run effects on beef demand in Northeast (Table 2.8) and Plains (Table 2.9), which indicates that a 100% increase in beef non-*E. coli* recalls decreases beef demand by 2.5% in Northeast and 3.5% in Plains. Beef non-*E. coli* recalls also have spillover effects on turkey demand in Northeast, both in the short and long run. It seems that effects of pork recalls have been recovered within four months in Great Lakes (Table 2.6) and Northeast, because such recalls have positive and significant effects on pork demand in the long run.

Table 2.13 shows the compensated elasticities from the meat separable model with ground beef specification (model 2). The own-price elasticities of the total U.S. model for ground beef, other beef, chicken, and other meat are −0.83, −0.70, −0.74, and −2.57, respectively. All of the ground beef price elasticity estimates for the nine models are consistent with the estimation of Brester and Wohlgenant (1991). The magnitudes of own-price elasticities for ground beef range from −0.61 (Plains, Table 2.18) to −1.28 (Southeast, Table 2.20), and the elasticities for other beef vary from −0.46 (Northeast, Table 2.17) to −1.50 (Great Lakes, Table 2.15). The range in these estimates likely reflects different cultural patterns and use of beef items as ingredients in varied meals across the country. The demand for ground beef is more elastic than other beef in the total U.S. and some regions (Mid-south in Table 2.16, Northeast in Table 2.17, Southeast in Table 2.20, and West in Table 2.21). The magnitudes of expenditure elasticities of other beef are higher than ground beef, except in the Southeast.

Similar with model 1, Table 2.13 also suggests that beef *E. coli* and beef non-*E. coli* recalls have not impacted ground beef or other beef demand significantly in model 2 at the national level as recall effects are not statistically different from zero in individual tests. However, further investigation by region reveals this initial conclusion of no national-level impact is masking regional variation. For instance beef *E. coli* recalls have significant and negative effects across regions on ground beef demand contemporaneously in six regions (not in Northeast and Plains). For example, a 100% increase in the number of beef *E. coli* recalls reduces ground beef demand by 0.9% in California (Table 2.14) in the short run. Most of beef *E. coli* recalls across the U.S. only impact ground beef demand for a very short period as long-run effects were significant only in the Southeast (Table 2.20). Beef *E. coli* recalls have not impacted other beef demand except for significant impacts in the Southeast and Mid-south (Table 2.16).

4.2 Hypothesis Tests for Regional Heterogeneity

Based on the broad Likelihood Ratio test of equality between the stacked model and eight regional specifications, the null hypothesis of equal parameters across models is rejected, which makes the further tests of regional heterogeneity of recalls appropriate. One of this article's unique contributions is that we conduct a series of hypothesis tests through pairwise comparisons to identify whether the national level FSIS food safety recalls have heterogeneous effects across the eight areas in the United States (regional heterogeneity). To do so, Krinsky-Robb (1986) simulations are conducted again to generate such series of pairwise comparisons (Poe *et al*. 2005; Tonsor and Marsh, 2007).

Table 2.22 (A and B) provides the summary of pairwise comparisons for California only because of size limitation[9]. The null hypothesis of each comparison is that the effects of specific recalls (both short- or long-run elasticities) are homogeneous between two regions (i.e.: California and Great Lakes). The effects of recalls would not display regional heterogeneity if this hypothesis is rejected. Overall, about nine hundred pairwise comparisons for heterogeneous food recall effects including short- and long-run effects have been conducted through the simulations in each model. The null hypotheses that specific food safety recalls have the same effects on meat demand across regions cannot be rejected in most cases for model 1 (Table 2.22 A). We rejected 105 null hypotheses over 896 pairwise comparisons[10] which indicate there are 105 heterogeneous effects of food safety recalls across regions and a rejection rate of 11.7% in the model 1 approach[11]. Within these heterogeneous effects, 12.38%, 33.33%, 24.76%, and 29.52% of these significant differences are from beef *E. coli*, beef non-*E. coli*, pork, and poultry recalls, respectively. This suggests beef non-*E. coli* and poultry recalls are more heterogeneous in impacts across regions than beef *E. coli* and pork recalls. The observation of beef *E. coli* recall effects being the most homogeneous across regions particularly stands out.

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[9] The details on pairwise comparisons for all eight regions are reported in Appendix. The simulated *p*-values for regional heterogeneity and short-run versus long-run effects are available by requests.

[10] The total of 896 pairwise comparisons reflects short- and long-run comparisons of the effects of four recalls on four meat categories using different separability approaches.

[11] By applying the Bonferroni correction through the multiple comparisons, the probability of heterogeneity between two regions in a single test is 0.013%. The Bonferroni correction sets the significant cut-off aα/N. In our case, with 896 pairwise comparison tests and rejection rate of 11.7%, the probability of rejecting a null hypothesis is 0.117/896 = 0.013%

The impacts of FSIS food safety recalls is not consistent with the often implicitly imposed assumption of fully homogeneous impacts (e.g. all eight regions are the same) nor with entirely heterogeneous impacts (e.g. every signal FSIS recall impact is unique to a given region). The fact we find some heterogeneity and some homogeneity is not necessarily surprising. Some key findings of heterogeneous FSIS recall impacts are important to appreciate. For instance, beef *E. coli* recalls have heterogeneous effects between Great Lakes and Southeast, and also across Mid-south, South Central, and West. In addition, hypothesis tests also indicate that most of food safety recalls across the U.S. do not have effects on meat demand that differ in the short- and long-run.

Table 2.22 B also suggests that the effects of food safety recall do not display regional differences between majority of regions and California in model 2. Overall, only 54 null hypotheses of the 896 pairwise tests were rejected by the simulated comparisons (refer appendix) which makes a rejection rate of 6%[12]. The finding of equality being rejected about two times as much using model 1 may reflect the more specific consideration of beef products (ground beef and other beef) in model 2. Consumers across some regions like California, Great Lakes, and Southeast have different demand reactions to beef *E. coli* recalls. The effects of beef *E. coli* recall have different effects on other beef in some region pairs statistically, but this condition does not hold for most of regions. Poultry recalls and beef *E. coli* recalls contribute to 44.44% and 31.48% of the 54 identified heterogeneous regional impacts across the eight regions. As in model 1, there are no differences between short-run and long-run food safety recall effects across the eight regions.

[12] Bonferroni correction indicates that the probability of rejecting the null hypothesis for each test is 0.006%

Table 2.4: Estimated Compensated Elasticities of Model 1, Total US

Regions		**Total US**		
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.9095***†	1.0542***	0.8364***†	2.9131***†
Beef Price	-0.9980***	0.6158***	0.1936**	0.1886***
Pork Price	1.7036***	-2.5902***‡	0.7534***	0.1331***
Chicken Price	0.3769**	0.5303***	-1.1805***‡	0.2732***
Turkey Price	2.3308***	0.5945**	1.7338***	-4.6591***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0040	0.0023	-0.0068	0.0822
Beef non-*E. coli* recall	-0.0092*	-0.0109	0.00004	0.1622
Pork recall	-0.0009	-0.0070	0.0034	0.0213
Poultry recall	0.0016	0.0071	0.0013	-0.0602
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0053	0.0166	-0.0178	0.1036
Beef non-*E. coli* recall	-0.0151	-0.0140	0.0046	-0.2199
Pork recall	0.0185	0.0220	0.0045	-0.3553
Poultry recall	0.0054	0.0078	-0.0020	-0.0890

Table 2.5: Estimated Compensated Elasticities of Model 1, California

Regions		**California**		
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.9503***	0.9340***†	0.8777***†	2.3067**†
Beef Price	-0.9321***	0.4485***	0.1296**	0.3540***
Pork Price	1.4385***	-2.1484***‡	0.6404**	0.0694
Chicken Price	0.2416**	0.3721***	-1.0732***	0.4594***
Turkey Price	3.4053***	0.2082	2.3710***	-5.9845***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0059	0.0029	-0.0102**	0.1002
Beef non-*E. coli* recall	-0.0054	-0.0027	0.0034	0.0427
Pork recall	-0.0036	-0.0143*	0.0130*	0.0103
Poultry recall	-0.0005	0.0088*	-0.0052	0.0054
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0035	0.0096	-0.0203	0.1096
Beef non-*E. coli* recall	-0.0185	-0.0046	-0.0102	0.2441
Pork recall	0.0428*	0.0441	0.0068	-0.5789
Poultry recall	0.0119	0.0127	-0.0016	-0.1448

Table 2.6: Estimated Compensated Elasticities of Model 1, Great Lakes

Regions	**Great Lakes**			
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.7178***†	1.0898***	0.6752***†	6.1969***†
Beef Price	-0.9288***	0.6736***	0.0598	0.1954***
Pork Price	1.8154***	-2.9202***‡	0.6662***	0.4386***
Chicken Price	0.1333	0.5511***	-1.0153***	0.3309***
Turkey Price	2.5742**	2.1436***	1.9554***	-6.6732***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	0.0041	0.0049	-0.0016	-0.0689
Beef non-*E. coli* recall	-0.0034	-0.0114	0.0045	0.0743
Pork recall	0.0188**	0.0182	0.0199**	-0.4542**
Poultry recall	-0.0058*	0.0063	-0.0013	0.0538
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	0.0046	0.0406	0.0001	-0.2594
Beef non-*E. coli* recall	-0.0127	-0.0456	0.0007	0.3855
Pork recall	0.0257**	0.0843**	0.0292*	-0.9225**
Poultry recall	-0.0148**	0.0252	-0.0072	0.1137

Table 2.7: Estimated Compensated Elasticities of Model 1, Mid-south

Regions	**Mid-south**			
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.8240***†	1.0819***	0.7783***†	4.0352***†
Beef Price	-0.9592***	0.5429***	0.1671***	0.2492***
Pork Price	1.5700***	-2.6780***‡	0.9870***	0.1211**
Chicken Price	0.3119**	0.6370***	-1.2265***‡	0.2776***
Turkey Price	2.8388***	0.4768*	1.6944***	-5.0101***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef E. coli recall	N/A	N/A	N/A	N/A
Beef non-E. coli recall	-0.0034	-0.0028	0.0019	0.0380
Pork recall	0.0125	0.0154	0.0092*	-0.2594**
Poultry recall	-0.0024	0.0029	-0.0024	0.0301
----------------Long-run Recall Elasticities--------------				
Beef E. coli recall	N/A	N/A	N/A	N/A
Beef non-E. coli recall	-0.0067	-0.0097	0.0029	0.0971
Pork recall	0.0323	0.063	0.0198**	-0.7371**
Poultry recall	-0.0035	0.0029	-0.0112	0.0966

Table 2.8: Estimated Compensated Elasticities of Model 1, Northeast

Regions		**Northeast**		
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.8726***†	0.7665†	0.7438†	4.4551***†
Beef Price	-0.8962***	0.5999***	0.1388	0.1576***
Pork Price	1.6241	-2.6177***‡	0.8922***	0.1014**
Chicken Price	0.1936***	0.4598**	-0.9289***‡	0.2756***
Turkey Price	1.3704***	0.3256**	1.7180***	-3.4140***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef E. coli recall	N/A	N/A	N/A	N/A
Beef non-E. coli recall	-0.0126**	-0.0062	-0.0027	0.1467**
Pork recall	-0.0005	0.015	0.0105*	-0.1088
Poultry recall	0.0042	0.0031	0.002	-0.0592
----------------Long-run Recall Elasticities--------------				
Beef E. coli recall	N/A	N/A	N/A	N/A
Beef non-E. coli recall	-0.0253**	-0.0333**	-0.0148*	0.4192**
Pork recall	0.0052	0.0489**	0.0166	-0.3055**
Poultry recall	0.0078	0.0263**	0.0085	-0.2057*

Table 2.9: Estimated Compensated Elasticities of Model 1, Plains

Regions		**Plains**		
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.8281***†	1.0238***	0.6823***†	5.1846***†
Beef Price	-0.9508***	0.6917***	0.0296	0.2296***
Pork Price	1.8096***	-2.2262***‡	0.3311**	0.0854*
Chicken Price	0.0732	0.3132**	-0.7133***	0.3269***
Turkey Price	3.2993***	0.4692*	1.8988***	-5.6673***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef E. coli recall	-0.0021	-0.0015	-0.005	0.0677
Beef non-E. coli recall	-0.0063	-0.0058	0.0031	0.1042
Pork recall	0.0051	-0.0017	0.0228**	-0.1963
Poultry recall	-0.0034	-0.0136**	-0.0006	0.127
Beef E. coli recall	0.0289*	0.0217	-0.0019	-0.5238*
Beef non-E. coli recall	-0.0349**	-0.0352	-0.002	0.7071*
Pork recall	0.007	0.0214	0.032**	-0.4039
Poultry recall	-0.0053	-0.0085	0.0011	0.117

Table 2.10: Estimated Compensated Elasticities of Model 1, South Central

Regions	**South Central**			
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	1.0004***†	1.1322***†	0.8717***†	1.0240†
Beef Price	-0.7756***‡	0.5310***	-0.0026	0.2472***
Pork Price	1.4778***	-1.9959***‡	0.5317***	0.2743
Chicken Price	-0.0062***	0.4603***	-0.6674***‡	0.2133
Turkey Price	4.5396***	-0.08943	1.6257***	-6.0759***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0013	-0.0043	-0.0032	0.0767
Beef non-*E. coli* recall	-0.0042	0.0006	-0.0002	0.0748
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	-0.0098***	-0.0033	-0.0159***	0.3222**
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0040*	-0.0002	-0.0069	0.1273*
Beef non-*E. coli* recall	-0.0192**	-0.0020	-0.0117*	0.4558**
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	-0.0029	-0.0155	-0.0038	0.1837

Table 2.11: Estimated Compensated Elasticities of Model 1, Southeast

Regions	**Southeast**			
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.7626***†	0.9336***†	0.7775***†	6.6041***†
Beef Price	-0.7529***‡	0.5830***	-0.0094	0.1793***
Pork Price	1.5095	-1.9220***‡	0.3962***	0.0164
Chicken Price	-0.0182	0.2958***	-0.5061***‡	0.2285***
Turkey Price	2.6570***	0.0936	1.7520***	-4.5026***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0073**	0.0083*	0.0017	0.0473
Beef non-*E. coli* recall	0.0012	-0.0036	0.0008	-0.0039
Pork recall	0.0131**	0.0056	0.0132**	-0.3271***
Poultry recall	-0.0007	0.003	-0.0004	-0.0036
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0134*	0.01	0.0034	0.1155
Beef non-*E. coli* recall	-0.0016	-0.0026	0.008	-0.0227
Pork recall	0.011	-0.002	0.0084	-0.2161
Poultry recall	0.0043	-0.0085	-0.0027	0.0052

Table 2.12: Estimated Compensated Elasticities of Model 1, West

Regions	**West**			
Model 1	Beef	Pork	Chicken	Turkey
Expenditure	0.8662***†	0.9822***†	0.8106***	4.3523***†
Beef Price	-0.6434***‡	0.4284***	0.0529	0.1621***
Pork Price	1.2136***	-1.9100***‡	0.5966***	0.0998**
Chicken Price	0.1258	0.5006***	-0.8951***	0.2688***
Turkey Price	2.4732***	0.5373**	1.7255***	-4.7359***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	0.0006	0.0129*	-0.0042	-0.0523
Beef non-*E. coli* recall	-0.0046	-0.0231**	0.0031	0.175
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0091	0.0456*	-0.0054	-0.073
Beef non-*E. coli* recall	0.0018	-0.0229	0.0062	0.0563
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A

Table 2.13: Estimated Compensated Elasticities of Model 2, Total US

Regions	**Total US**			
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.9213***	1.0096***	0.9117***	1.1610***
Ground Beef Price	-0.8297***	-0.0257	0.0974	0.7579***
Other Beef Price	-0.0172	-0.6955**	-0.0543	0.7670***
Chicken Price	0.0762	-0.0633	-0.7371***	0.7241***
Other Meat Price	0.6877***	1.0378***	0.8406***	-2.5660***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0038	-0.0028	-0.0032	0.0066
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	-0.0022	0.0076*	-0.0029	-0.005
Poultry recall	0.0023	-0.0015*	0.0017	-0.0021
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0043	-0.0165	0.0024	0.0235
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	-0.0073	0.0327*	-0.0214	-0.0129
Poultry recall	0.0042	0.0148*	-0.0046	-0.0186*

Table 2.14: Estimated Compensated Elasticities of Model 2, California

Regions	**California**			
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.9030***†	0.9661***	0.9681***	1.1670***
Ground Beef Price	-0.9892***	0.1544	0.0951	0.7396***
Other Beef Price	0.0635	-1.1441***	0.4303**	0.6503***
Chicken Price	0.0516	0.5684***	-1.2938***‡	0.6738***
Other Meat Price	0.5184***	1.1086***	0.8696***	-2.4965***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0094*	0.0029	0.0039	0.0016
Beef non-*E. coli* recall	0.0055	-0.0085*	0.0018	0.0084
Pork recall	-0.0075	0.0059	-0.0071	0.0043
Poultry recall	0.0017	-0.0016	0.0025	-0.0018
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0039	0.0073	0.0056	-0.0169
Beef non-*E. coli* recall	0.0016	-0.018	-0.0044	0.0352
Pork recall	-0.0623**	0.0455**	-0.0652**	0.0501
Poultry recall	-0.0001	0.0087	-0.0073	-0.0054

Table 2.15: Estimated Compensated Elasticities of Model 2, Great Lakes

Regions	**Great Lakes**			
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.8594***†	1.0533***	0.8420***	1.2461***
Ground Beef Price	-1.2363***‡	0.5580***	-0.1411**	0.8193***
Other Beef Price	0.5079***	-1.4988***‡	0.2758***	0.7151***
Chicken Price	-0.1498**	0.3218***	-0.9846***‡	0.8126***
Other Meat Price	0.8735***	0.8376***	0.8155***	-2.5266***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0055*	0.0045	-0.0021	0.0026
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0078	-0.005	-0.0007	0.0148*
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A

Table 2.16: Estimated Compensated Elasticities of Model 2, Mid-south

Regions	**Mid-south**			
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.8069***†	0.9986***	0.8074***†	1.4340***†
Ground Beef Price	-1.1298***‡	-0.0678	0.4597***	0.7379***
Other Beef Price	-0.0524	-0.475**‡	-0.3006**	0.828***
Chicken Price	0.3742***	-0.3164**	-0.7245***	0.6667***
Other Meat Price	0.7421***	1.0769***	0.8239***	-2.6430***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0065*	-0.0087*	0.0001	0.0177*
Beef non-*E. coli* recall	0.0046	-0.0029	0.0054*	-0.0075
Pork recall	-0.002	0.0086*	-0.0003	-0.0089
Poultry recall	-0.0005	-0.0025	-0.0008	0.0047
----------------Long-run Recall Elasticities--------------				
Beef *E. coli*	-0.013	-0.0199	-0.0011	0.0403
Beef non-*E. coli recall*	0.0064	-0.011	0.0142**	-0.0097
Pork recall	-0.0149	0.0186	-0.0119*	0.0054
Poultry recall	0.0031	0.0095	-0.0116	-0.0012

Table 2.17: Estimated Compensated Elasticities of Model 2, Northeast

Regions		**Northeast**		
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.9594***	1.0556***	0.9225***	1.0796***
Ground Beef Price	-1.1145***‡	-0.0337	0.4681***	0.6800***
Other Beef Price	-0.0226	-0.4575**‡	-0.2278*	0.7079***
Chicken Price	0.2620***	-0.1903*	-0.8022***	0.7304***
Other Meat Price	0.5634***	0.8751***	1.0810***	-2.5194***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	0.00003	0.0026	-0.0018	-0.0006
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A
----------------Long-run Recall Elasticities--------------				
Beef *E. coli*	0.0008	-0.0092	-0.0053	0.0185
Beef non-*E. coli recall*	N/A	N/A	N/A	N/A
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A

Table 2.18: Estimated Compensated Elasticities of Model 2, Plains

Regions		**Plains**		
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.9082***	1.0069***	0.8927***	1.1829***
Ground Beef Price	-0.6113***‡	0.0283	-0.1611**	0.7440***
Other Beef Price	0.0249	-0.9204***	0.1643**	0.7312***
Chicken Price	-0.1864**	0.2165**	-0.7440***	0.7138***
Other Meat Price	0.7698***	0.8619***	0.6385***	-2.2702***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0042	0.0015	0.0008	0.0018
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	-0.005	0.003	0.0042	-0.0022
Poultry recall	0.0113**	0.0015	0.0092**	-0.0217**
----------------Long-run Recall Elasticities--------------				
Beef *E. coli*	0.0025	-0.0041	-0.0003	0.0025
Beef non-*E. coli recall*	N/A	N/A	N/A	N/A
Pork recall	-0.0077	0.0075	0.0046	-0.005
Poultry recall	0.0112	0.0052	0.0068	-0.0239

Table 2.19: Estimated Compensated Elasticities of Model 2, South Central

Regions	**South Central**			
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.8657***	0.9568***	0.7941***†	1.3962***†
Ground Beef Price	-0.7203***‡	0.014	-0.0008	0.7071***
Other Beef Price	0.0089	-0.7868***‡	0.0127	0.7652***
Chicken Price	-0.0008	0.0188	-0.5697***‡	0.5516***
Other Meat Price	0.6620***	1.1327***	0.5533***	-2.3480***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0074*	-0.0007	-0.0023	0.0103
Beef non-*E. coli* recall	0.0067*	-0.0048	0.0074*	-0.0066
Pork recall	-0.0042	0.0072*	0.0027	-0.0094
Poultry recall	0.0022	0.0046*	-0.0012	-0.0076
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0119	-0.0006	-0.005	0.0170
Beef non-*E. coli* recall	-0.0005	-0.0085	0.003	0.0100
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	0.0014	0.0077	-0.0091	-0.0037

Table 2.20: Estimated Compensated Elasticities of Model 2, Southeast

Regions	**Southeast**			
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.9411***	0.8789***†	0.8006***†	1.4401***†
Ground Beef Price	-1.2788***‡	0.3656**	0.1091	0.8041***
Other Beef Price	0.2389**	-0.8621***	-0.0326	0.6557***
Chicken Price	0.0833	-0.0381	-0.6257***‡	0.5805***
Other Meat Price	0.6620***	1.1327***	0.5533***	-2.3480***‡
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0109**	-0.0064*	0.0003	0.0177**
Beef non-*E. coli* recall	0.0089**	-0.0049	0.0037	-0.0054
Pork recall	0.0033	0.0069	0.0085*	-0.0217**
Poultry recall	-0.0021	0.0005	0.0000	0.0012
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0231**	-0.0106	-0.0009	0.0353*
Beef non-*E. coli* recall	0.0110	-0.0091	0.0055	-0.0037
Pork recall	0.0185	-0.0063	0.0042	-0.0124
Poultry recall	0.0213**	0.0004	-0.0022	-0.0166

Table 2.21: Estimated Compensated Elasticities of Model 2, West

Regions			**West**	
Model 2	Ground Beef	Other Beef	Chicken	Other Meat
Expenditure	0.9798***	1.0070***	0.8720***	1.1346***
Ground Beef Price	-1.1128***	0.5304**	-0.0855	0.6679***
Other Beef Price	0.2845**	-0.9666***	0.1985	0.4836***
Chicken Price	-0.0709	0.3071	-0.9461***	0.7099***
Other Meat Price	0.5571***	0.7522***	0.7136***	-2.0229***
----------------Contemporaneous Recall Elasticities-----------------				
Beef *E. coli* recall	-0.0081**	0.0045	-0.0049	0.0048
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	0.0112**	-0.0068**	0.0096**	-0.0084
----------------Long-run Recall Elasticities--------------				
Beef *E. coli* recall	-0.0102	-0.0066	-0.0058	0.0246*
Beef non-*E. coli* recall	N/A	N/A	N/A	N/A
Pork recall	N/A	N/A	N/A	N/A
Poultry recall	N/A	N/A	N/A	N/A

Notes: All elasticities from Table 2.4 to Table 2.21 are calculated at the mean values of the explanatory variables for difference region area in the United States. Since specific recall does not have effect on some preferred model (refer to Appendix), N/A's indicates the elasticities which are not available to report. All of the *p*-values were obtained by using Krinsky-Robb (1986) simulation procedures. Long-run FSIS food safety recall elasticities capture both contemporaneous and its corresponding lagged effects. *, **, and *** denote elasticities significantly different from 0 at 10%, 5%, and 1% confidence levels, respectively. † indicates the expenditure elasticities are significantly different from 1.0 at 10% confidence level. ‡ means the own-price elasticities are significantly different from -1.0 at 10% confidence level. N/A's indicate that these recall variables were not included in the preferred models[13].

[13] See Appendix to find more information on how to derive the significances of elasticities

Table 2.22: Results of Pairwise Comparisons and Hypothesis Tests for Heterogeneity (*California Only*)

A: Meat Separate Model (Model 1)

Hypothesis Tests for Heterogeneity		***H_0: the effects of food safety recall do not have regional heterogeneity***															
California vs	Lag Length	Beef E. coli Recalls				Beef non-E. coli recalls				Pork Recalls				Poultry Recalls			
		Beef	Pork	Chicken	Turkey	Beef	Pork	Chicken	Turkey	Beef	Pork	Chicken	Turkey	Beef	Pork	Chicken	Turkey
Great Lakes	Short Run	No	No	No	No	No	No	No	No	**	**	No	**	No	No	No	No
	Long Run	No	No	No	No	No	No	No	No	No	No	No	No	*	No	No	No
Mid-south	Short Run	N/A	N/A	N/A	N/A	No	No	No	No	*	**	No	*	No	No	No	No
	Long Run	N/A	N/A	N/A	N/A	No	No	No	No	No	No	No	No	No	No	No	No
Northeast	Short Run	N/A	N/A	N/A	N/A	No	No	No	No	*	No	No	No	No	No	No	No
	Long Run	N/A	N/A	N/A	N/A	No	No	No	No	No	No	No	No	No	No	No	No
Plains	Short Run	No	No	No	No	No	No	No	No	No	No	No	No	No	***	No	No
	Long Run	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
South Central	Short Run	No	No	No	No	No	No	No	No	N/A	N/A	N/A	N/A	**	**	**	***
	Long Run	*	*	No	*	No	No	*	*	N/A	N/A	N/A	N/A	No	No	No	No
Southeast	Short Run	No	No	*	No	No	No	No	No	**	*	No	**	No	No	No	No
	Long Run	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
West	Short Run	No	*	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Long Run	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No

B: Meat Separate Model (Model 2)

Hypothesis Tests for Heterogeneity		***H_0: the effects of food safety recall do not have regional heterogeneity***															
California vs	Lag Length	Beef E. coli Recalls				Beef non-E. coli recalls				Pork Recalls				Poultry Recalls			
		Ground Beef	Other Beef	Chicken	Other Meat	Ground Beef	Other Beef	Chicken	Other Meat	Ground Beef	Other Beef	Chicken	Other Meat	Ground Beef	Other Beef	Chicken	Other Meat
Great Lakes	Short Run	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Long Run	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mid-south	Short Run	No	*	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Long Run	No	No	No	No	No	No	No	No	No	No	*	No	No	No	No	No
Northeast	Short Run	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Long Run	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Plains	Short Run	No	No	No	No	N/A	N/A	N/A	N/A	No	No	*	No	*	No	*	**
	Long Run	No	No	No	No	N/A	N/A	N/A	N/A	*	*	*	No	No	No	No	No
South Central	Short Run	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Long Run	No	No	No	No	No	No	No	No	N/A	N/A	N/A	N/A	No	No	No	No
Southeast	Short Run	No	*	No	No	No	No	No	No	No	No	*	**	No	No	No	No
	Long Run	No	No	No	No	No	No	No	No	*	*	**	No	No	No	No	No
West	Short Run	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	*	No	*	No
	Long Run	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Notes: "No" indicates the null hypothesis cannot be rejected, the effects of food safety recall do not have regional heterogeneity between California and other regions. The effects of recalls do not have differences among these regions. "N/A" the results of heterogeneous tests are not available to report because of different lag lengths. *, **, and *** denote 10%, 5%, and 1% confidence levels, respectively.

Section 5 Conclusions and Implications

Food safety recalls may signal lower quality products which can directly impact consumer meat demand. *Shiga toxin-producing Escherichia coli* (STEC) is a significant cause of foodborne illness in the United States and this pathogen is costly to society. Throughout this article, we use the nationwide recalls and emphasize the source of recalls and separate recall events into beef *E. coli* recall, beef non-*E. coli* recall, pork recall, and poultry recall respectively in order to investigate regional differences in impacts on meat demand across eight U.S. regions geographically.

Two Rotterdam model specifications are applied to monthly grocery-store scanner data from January 2009 to February 2014 to further assess the effects of food safety recall information on U.S. meat demand. To achieve this, we applied several approaches varying in imposed separability and autocorrelation corrections. We estimated meat demand models for different U.S. geographic regions for the first known time and found consumer meat demand significantly varies across regions of residence.

Results suggest beef *E. coli* recalls significantly reduce the demand for ground beef contemporaneously among most, but not all, regions in the United States. Although the majority of other food safety recalls do not reveal statistically significant effects on meat demand in most of regions, joint tests of food safety recall effects still indicate that U.S. meat demand is affected by food safety incidents. A multitude of pairwise comparisons provide insights into the question of whether food safety recalls present heterogeneous effects on meat demand across different regions in the country. Overall we find cases of heterogeneous effects and also several examples where the often imposed assumption of homogeneous effects effectively holds. That is, we fail to reject the hypothesis of no differences among regions in most cases, which indicates that the majority of food safety recalls have the same effects on consumer meat demand across regions. One important sub-point however is that poultry recalls are more prevalent in having heterogeneous regional impacts than beef *E. coli*¸ beef non-*E. coli* recall, and pork recalls. This suggests societal investments (e.g. allocation of tax based government expenditures) in mitigating poultry recalls present more heterogeneous net benefits to U.S. residents based upon their region of residence.

Given meat demand, especially ground beef demand, is influenced by beef *E. coli* recalls in most of regions, the study has multiple implications for food policy and industry leaders. Food safety events and its corresponding FSIS recalls can cause negative economic consequences for the society and particular meat firms. Although the impact of beef *E. coli* recalls on demand is relatively small, the meat industry still needs to pay attention and routinely detect contaminations of foodborne illness in order to minimize negative effects on demand. For example, since *E. coli* can contaminate beef products during the process of slaughtering process, the meat industry should continue to maintain strict quality and safety controls. This also reinforces the potential economic value of alternative mitigation strategies such as *E. coli* vaccines for fed cattle which have recently become available (Tonsor and Schroder, 2015). Since beef *E. coli* recalls have short-run effects on meat demand, federal agents such as the FSIS and CDC need to release recall and related health information to the public in a timely manner and continue to work with the industry to reduce recall prevalence.

Going further, the identification of significant beef *E. coli* recall impacts on demand and comparatively insignificant impacts of beef non-*E. coli*, pork, and poultry recalls suggest there may be societal value in reallocating resources, designing alternative food safety policies, developing food safety risk mitigating technologies, etc. with a stronger focus on *E. coli* risk mitigation relative to other food safety issues. While there is much more to such decisions than just consumer demand response (i.e. public health consequences, costs of alternative mitigation strategies, etc.), the varied impacts on meat demand certainly have an important role in the economics of resource allocation in the area of assuring and improving food safety.

Moreover, our in-depth consideration of regionally varied effects should be noted by researchers in other applications. The ultimate finding of food safety effects neither being fully homogeneous, (as often implicitly imposed in existing research) nor entirely heterogeneous (with each recall having a significantly unique impact in every region) warrants appreciation. This likely is simply one of several cases of applied research interest where the true economic impact falls between two extreme ends on the homogeneous-heterogeneous spectrum. Researchers are encouraged to note this not only in assessments of food safety impacts but in any evaluation of how consumers react to new information or events.

Finally, due to current data constraints and the difficulty of data collection, our study does not distinguish FSIS recall events by regions, does not consider the volume of product recalled, nor do we estimate the effects of meat recalls on restaurant food service and demand. The recall information may have different effects on restaurants and fast-food chains than grocery stores. Considering the increasing trend of food-away-from-home (FAFH) consumption, this is valuable for future work as corresponding data becomes available. Any future research examining additional market segments or recall impacts at less aggregated levels can enhance our understanding of demand and improve policy and industry food safety decisions.

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Appendix to: "Food Safety Recall Effects across Meat Products and Regions"

This appendix is provided to accompany the main article of Chapter 2. Table A1 provides a summary of hypothesis tests we applied in this study. Table A2 indicates additional details on the autocorrelation tests conducted. Tables A3 and A4 provide coefficient estimates and model fit details corresponding to the elasticities presented in the main text. Table A5 (A and B) is the summary of the pairwise hypothesis tests and key findings.

Using random draws from a multivariate normal distribution based on each preferred model's estimated variance-covariance matrix, we derive 1,000 values of each elasticity estimates for food safety recalls. Then we calculate the differences for same food safety recall effects between two regions (Table A4). A total of 1,000×1,000 differences have been generated for each recall effects between two regions. The *p*-value associated with the one-sided hypothesis test is calculated to investigate if the differences between two elasticity estimates from two regions differ from zero[14]. For example, to identify the heterogeneous effects of beef *E. coli* recall on beef demand between California and Great Lakes, one needs to calculate the effect differences within the two regions. The proportion of the differences with values greater than zero is the *p*-value to determine if beef *E. coli* recalls have heterogeneous effects between California and Great Lakes.

[14] Null hypothesis: food safety recalls do not represent regional differences.

Table A2.1: Summary of Hypothesis Tests in the Study

Key Tests	Descriptions
Adjusted Likelihood Ratio Test and Wald Test	Determine regional model specifications under autocorrelation correction and preferred models jointly
Likelihood Ratio (LR) Test of the Joint Equality	Test if estimates from eight regional models are equivalent to a stack model
Hypothesis Tests for Regional Heterogeneity (Pairwise Comparison)	Identify whether FSIS food safety recalls have heterogeneous effects across regions

Table A2.2: Likelihood Ratio Tests for Autocorrelation Corrections

Likelihood Ratio Tests	Ho: N-R Matrix Ha: D-R Matrix	Ho: N-R Matrix Ha: C-R Matrix	Ho: D-R Matrix Ha: C-R Matrix
Model 1			
Total US	54.84	119.57	64.53
California	42.86	92.47	49.47
Great Lakes	72.84	111.23	38.93
Mid-south	71.48	100.44	29.64
Northeast	45.96	81.03	35.23
Plains	81.08	93.83	13.87
South Central	60.86	103.47	42.89
Southeast	66.57	155.11	88.14
West	42.27	89.06	46.68
Model 2			
Total US	52.46	62.11	10.34
California	77.98	80.07	3.33
Great Lakes	43.87	55.94	12.59
Mid-south	39.71	46.09	6.93
Northeast	69.15	67.01	0.97
Plains	41.61	69.18	27.78
South Central	42.43	36.88	4.76
Southeast	33.24	75.10	41.70
West	40.05	81.12	41.03
degree of freedom	3	9	6
Chi-square C.V.	7.81	16.91	12.59

Note**:** the values of log likelihood ratio are reported in the table. N-R matrix, D-R matrix, and C-R matrix indicates null autocorrelation correction matrix, diagonal autocorrelation correction matrix, and complete autocorrelation correction matrix, respectively.

Table A2.3: Estimated Coefficients Meat Separable Model (Model 1)

Total US Complete Autocorrelation Correction			California Complete Autocorrelation Correction			Great Lakes Complete Autocorrelation Correction			Mid-South Complete Autocorrelation Correction			Northeast Complete Autocorrelation Correction		
Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err
c_{bf}	-0.5102***	0.0442	c_{bf}	-0.4775***	0.0322	c_{bf}	-0.4900***	0.0376	c_{bf}	-0.4871***	0.0272	c_{bf}	-0.4072***	0.0522
$c_{bf, pk}$	0.3148***	0.0178	$c_{bf, pk}$	0.2297***	0.0152	$c_{bf, pk}$	0.3553***	0.0171	$c_{bf, pk}$	0.2757***	0.0225	$c_{bf, pk}$	0.2725***	0.0261
$c_{bf, ch}$	0.0987**	0.0419	$c_{bf, ch}$	0.0664**	0.0317	$c_{bf, ch}$	0.0315	0.0319	$c_{bf, ch}$	0.0849***	0.0278	$c_{bf, ch}$	0.0630	0.0473
c_{pk}	-0.4787***	0.0258	c_{pk}	-0.3431***	0.0113	c_{pk}	-0.5716***	0.0330	c_{pk}	-0.4702***	0.0347	c_{pk}	-0.4393***	0.0217
$c_{pk, ch}$	0.1392***	0.0252	$c_{pk, ch}$	0.1023****	0.0150	$c_{pk, ch}$	0.1304***	0.0236	$c_{pk, ch}$	0.1733***	0.0182	$c_{pk, ch}$	0.1497***	0.0254
c_{ch}	-0.3099***	0.0515	c_{ch}	-0.2949***	0.0377	c_{ch}	-0.2403***	0.0379	c_{ch}	-0.3337***	0.0326	c_{ch}	-0.3025***	0.0514
β_1	0.4650***	0.0253	β_1	0.4868***	0.0264	β_1	0.3787***	0.0388	β_1	0.4184***	0.0297	β_1	0.3964***	0.0322
β_2	0.1948***	0.0115	β_2	0.1492***	0.0111	β_2	0.2133***	0.0197	β_2	0.1900***	0.0143	β_2	0.1286***	0.0126
β_3	0.2196***	0.0137	β_3	0.2412***	0.0133	β_3	0.1598***	0.0151	β_3	0.2118***	0.0129	β_3	0.2422***	0.0171
a_1	-0.0481***	0.0048	a_1	-0.0359***	0.0084	a_1	-0.0390***	0.0081	a_1	-0.0345***	0.0067	a_1	-0.0443***	0.0067
a_2	-0.0194***	0.0030	a_2	-0.0162***	0.0035	a_2	-0.0087	0.0054	a_2	-0.0085**	0.0039	a_2	-0.0108***	0.0031
a_3	-0.0241***	0.0031	a_3	-0.0160***	0.0047	a_3	-0.0133***	0.0036	a_3	-0.0155***	0.0031	a_3	-0.0263***	0.0039
$\lambda_{rbe(bf)-0}$	-0.0021	0.0028	$\lambda_{rbe(bf)-0}$	-0.0030	0.0028	$\lambda_{rbe(bf)-0}$	0.0022	0.0036	$\lambda_{rbe(bf)-0}$	–	–	$\lambda_{rbe(bf)-0}$	–	–
$\lambda_{rbe(bf)-1}$	0.0006	0.0031	$\lambda_{rbe(bf)-1}$	-0.0053	0.0036	$\lambda_{rbe(bf)-1}$	-0.0036	0.0040	$\lambda_{rbe(bf)-1}$	–	–	$\lambda_{rbe(bf)-1}$	–	–
$\lambda_{rbe(bf)-2}$	-0.0022	0.0030	$\lambda_{rbe(bf)-2}$	0.0054	0.0037	$\lambda_{rbe(bf)-2}$	-0.0019	0.0041	$\lambda_{rbe(bf)-2}$	–	–	$\lambda_{rbe(bf)-2}$	–	–
$\lambda_{rbe(bf)-3}$	-0.0019	0.0029	$\lambda_{rbe(bf)-3}$	-0.0003	0.0032	$\lambda_{rbe(bf)-3}$	0.0031	0.0039	$\lambda_{rbe(bf)-3}$	–	–	$\lambda_{rbe(bf)-3}$	–	–
$\lambda_{rbe(bf)-4}$	0.0028	0.0019	$\lambda_{rbe(bf)-4}$	0.0015	0.0032	$\lambda_{rbe(bf)-4}$	0.0027	0.0029	$\lambda_{rbe(bf)-4}$	–	–	$\lambda_{rbe(bf)-4}$	–	–
$\lambda_{rbn(bf)-0}$	-0.0047*	0.0025	$\lambda_{rbn(bf)-0}$	-0.0028	0.0027	$\lambda_{rbn(bf)-0}$	-0.0018	0.0036	$\lambda_{rbn(bf)-0}$	-0.0017	0.0025	$\lambda_{rbn(bf)-0}$	-0.0057**	0.0026
$\lambda_{rbn(bf)-1}$	0.0005	0.0030	$\lambda_{rbn(bf)-1}$	-0.0033	0.0037	$\lambda_{rbn(bf)-1}$	0.0007	0.0041	$\lambda_{rbn(bf)-1}$	0.0003	0.0025	$\lambda_{rbn(bf)-1}$	-0.0007	0.0030
$\lambda_{rbn(bf)-2}$	-0.0036	0.0028	$\lambda_{rbn(bf)-2}$	-0.0029	0.0040	$\lambda_{rbn(bf)-2}$	-0.0060	0.0039	$\lambda_{rbn(bf)-2}$	-0.0034	0.0026	$\lambda_{rbn(bf)-2}$	-0.0051*	0.0026
$\lambda_{rbn(bf)-3}$	0.0052	0.0026	$\lambda_{rbn(bf)-3}$	0.0001	0.0033	$\lambda_{rbn(bf)-3}$	0.0031	0.0035	$\lambda_{rbn(bf)-3}$	0.0040	0.0024	$\lambda_{rbn(bf)-3}$	–	–
$\lambda_{rbn(bf)-4}$	-0.0051**	0.0018	$\lambda_{rbn(bf)-4}$	-0.0007	0.0031	$\lambda_{rbn(bf)-4}$	-0.0027	0.0027	$\lambda_{rbn(bf)-4}$	-0.0025	0.0021	$\lambda_{rbn(bf)-4}$	–	–
$\lambda_{rcpk(bf)-0}$	-0.0005	0.0026	$\lambda_{rcpk(bf)-0}$	-0.0018	0.0037	$\lambda_{rcpk(bf)-0}$	0.0099	0.0039	$\lambda_{rcpk(bf)-0}$	0.0064*	0.0033	$\lambda_{rcpk(bf)-0}$	-0.0002	0.0034
$\lambda_{rcpk(bf)-1}$	0.0068*	0.0034	$\lambda_{rcpk(bf)-1}$	0.0103**	0.0040	$\lambda_{rcpk(bf)-1}$	0.0025	0.0047	$\lambda_{rcpk(bf)-1}$	0.0045	0.0036	$\lambda_{rcpk(bf)-1}$	-0.0001	0.0036
$\lambda_{rcpk(bf)-2}$	-0.0009	0.0034	$\lambda_{rcpk(bf)-2}$	0.0059	0.0050	$\lambda_{rcpk(bf)-2}$	0.0005	0.0044	$\lambda_{rcpk(bf)-2}$	0.0048	0.0034	$\lambda_{rcpk(bf)-2}$	0.0027	0.0033
$\lambda_{rcpk(bf)-3}$	0.0049	0.0032	$\lambda_{rcpk(bf)-3}$	0.0060	0.0043	$\lambda_{rcpk(bf)-3}$	0.0006	0.0033	$\lambda_{rcpk(bf)-3}$	-0.0004	0.0035	$\lambda_{rcpk(bf)-3}$	–	–
$\lambda_{rcpk(bf)-4}$	-0.0009	0.0020	$\lambda_{rcpk(bf)-4}$	0.0016	0.0036	$\lambda_{rcpk(bf)-4}$	–	–	$\lambda_{rcpk(bf)-4}$	0.0011	0.0026	$\lambda_{rcpk(bf)-4}$	–	–
$\lambda_{rcpo(bf)-0}$	0.0008	0.0014	$\lambda_{rcpo(bf)-0}$	-0.0003	0.0021	$\lambda_{rcpo(bf)-0}$	-0.0031	0.0021	$\lambda_{rcpo(bf)-0}$	-0.0012	0.0021	$\lambda_{rcpo(bf)-0}$	0.0019	0.0022
$\lambda_{rcpo(bf)-1}$	-0.0012	0.0033	$\lambda_{rcpo(bf)-1}$	0.0028	0.0034	$\lambda_{rcpo(bf)-1}$	-0.0072	0.0046	$\lambda_{rcpo(bf)-1}$	-0.0036	0.0026	$\lambda_{rcpo(bf)-1}$	-0.0037	0.0028
$\lambda_{rcpo(bf)-2}$	0.0021	0.0036	$\lambda_{rcpo(bf)-2}$	0.0057	0.0038	$\lambda_{rcpo(bf)-2}$	0.0078	0.0049	$\lambda_{rcpo(bf)-2}$	0.0066**	0.0025	$\lambda_{rcpo(bf)-2}$	0.0054**	0.0025
$\lambda_{rcpo(bf)-3}$	0.0008	0.0028	$\lambda_{rcpo(bf)-3}$	-0.0011	0.0030	$\lambda_{rcpo(bf)-3}$	-0.0001	0.0039	$\lambda_{rcpo(bf)-3}$	-0.0017	0.0023	$\lambda_{rcpo(bf)-3}$	–	–
$\lambda_{rcpo(bf)-4}$	0.0003	0.0016	$\lambda_{rcpo(bf)-4}$	-0.0009	0.0029	$\lambda_{rcpo(bf)-4}$	-0.0051	0.0025	$\lambda_{rcpo(bf)-4}$	-0.0019	0.0020	$\lambda_{rcpo(bf)-4}$	–	–
$\lambda_{rbe(pk)-0}$	0.0004	0.0016	$\lambda_{rbe(pk)-0}$	0.0005	0.0015	$\lambda_{rbe(pk)-0}$	0.0010	0.0021	$\lambda_{rbe(pk)-0}$	–	–	$\lambda_{rbe(pk)-0}$	–	–
$\lambda_{rbe(pk)-1}$	0.0021	0.0015	$\lambda_{rbe(pk)-1}$	-0.0002	0.0015	$\lambda_{rbe(pk)-1}$	0.0023	0.0023	$\lambda_{rbe(pk)-1}$	–	–	$\lambda_{rbe(pk)-1}$	–	–
$\lambda_{rbe(pk)-2}$	-0.0001	0.0014	$\lambda_{rbe(pk)-2}$	0.0007	0.0014	$\lambda_{rbe(pk)-2}$	0.0009	0.0022	$\lambda_{rbe(pk)-2}$	–	–	$\lambda_{rbe(pk)-2}$	–	–
$\lambda_{rbe(pk)-3}$	-0.0002	0.0014	$\lambda_{rbe(pk)-3}$	0.0004	0.0013	$\lambda_{rbe(pk)-3}$	0.0024	0.0021	$\lambda_{rbe(pk)-3}$	–	–	$\lambda_{rbe(pk)-3}$	–	–
$\lambda_{rbe(pk)-4}$	0.0009	0.0008	$\lambda_{rbe(pk)-4}$	0.0002	0.0010	$\lambda_{rbe(pk)-4}$	0.0014	0.0015	$\lambda_{rbe(pk)-4}$	–	–	$\lambda_{rbe(pk)-4}$	–	–
$\lambda_{rbn(pk)-0}$	-0.0020	0.0014	$\lambda_{rbn(pk)-0}$	-0.0004	0.0015	$\lambda_{rbn(pk)-0}$	-0.0022	0.0021	$\lambda_{rbn(pk)-0}$	-0.0005	0.0014	$\lambda_{rbn(pk)-0}$	-0.0011	0.0013
$\lambda_{rbn(pk)-1}$	-0.0016	0.0015	$\lambda_{rbn(pk)-1}$	-0.0011	0.0015	$\lambda_{rbn(pk)-1}$	-0.0035	0.0024	$\lambda_{rbn(pk)-1}$	-0.0015	0.0015	$\lambda_{rbn(pk)-1}$	-0.0016	0.0014
$\lambda_{rbn(pk)-2}$	-0.0014	0.0015	$\lambda_{rbn(pk)-2}$	-0.0009	0.0015	$\lambda_{rbn(pk)-2}$	-0.0035	0.0024	$\lambda_{rbn(pk)-2}$	-0.0018	0.0015	$\lambda_{rbn(pk)-2}$	-0.0029**	0.0010
$\lambda_{rbn(pk)-3}$	0.0023*	0.0014	$\lambda_{rbn(pk)-3}$	0.0014	0.0013	$\lambda_{rbn(pk)-3}$	0.0001	0.0021	$\lambda_{rbn(pk)-3}$	0.0011	0.0015	$\lambda_{rbn(pk)-3}$	–	–
$\lambda_{rbn(pk)-4}$	0.0001	0.0008	$\lambda_{rbn(pk)-4}$	0.0002	0.0009	$\lambda_{rbn(pk)-4}$	0.0002	0.0015	$\lambda_{rbn(pk)-4}$	0.0010	0.0012	$\lambda_{rbn(pk)-4}$	–	–
$\lambda_{rcpk(pk)-0}$	-0.0013	0.0015	$\lambda_{rcpk(pk)-0}$	-0.0023	0.0017	$\lambda_{rcpk(pk)-0}$	0.0036	0.0024	$\lambda_{rcpk(pk)-0}$	0.0027	0.0018	$\lambda_{rcpk(pk)-0}$	0.0025	0.0015
$\lambda_{rcpk(pk)-1}$	0.0020	0.0019	$\lambda_{rcpk(pk)-1}$	0.0001	0.0019	$\lambda_{rcpk(pk)-1}$	0.0052	0.0027	$\lambda_{rcpk(pk)-1}$	0.0018	0.0023	$\lambda_{rcpk(pk)-1}$	0.0016	0.0017
$\lambda_{rcpk(pk)-2}$	0.0010	0.0018	$\lambda_{rcpk(pk)-2}$	0.0025	0.0018	$\lambda_{rcpk(pk)-2}$	0.0048	0.0025	$\lambda_{rcpk(pk)-2}$	0.0024	0.0021	$\lambda_{rcpk(pk)-2}$	0.0041***	0.0012
$\lambda_{rcpk(pk)-3}$	0.0017	0.0018	$\lambda_{rcpk(pk)-3}$	0.0030*	0.0018	$\lambda_{rcpk(pk)-3}$	0.0029	0.0018	$\lambda_{rcpk(pk)-3}$	0.0024	0.0022	$\lambda_{rcpk(pk)-3}$	–	–
$\lambda_{rcpk(pk)-4}$	0.0007	0.0009	$\lambda_{rcpk(pk)-4}$	0.0036***	0.0011	$\lambda_{rcpk(pk)-4}$	–	–	$\lambda_{rcpk(pk)-4}$	0.0017	0.0015	$\lambda_{rcpk(pk)-4}$	–	–
$\lambda_{rcpo(pk)-0}$	0.0013	0.0009	$\lambda_{rcpo(pk)-0}$	0.0014	0.0010	$\lambda_{rcpo(pk)-0}$	0.0012	0.0015	$\lambda_{rcpo(pk)-0}$	0.0005	0.0013	$\lambda_{rcpo(pk)-0}$	0.0005	0.0010
$\lambda_{rcpo(pk)-1}$	0.0003	0.0017	$\lambda_{rcpo(pk)-1}$	-0.0003	0.0016	$\lambda_{rcpo(pk)-1}$	0.0009	0.0024	$\lambda_{rcpo(pk)-1}$	0.0001	0.0015	$\lambda_{rcpo(pk)-1}$	-0.0004	0.0012
$\lambda_{rcpo(pk)-2}$	0.0003	0.0015	$\lambda_{rcpo(pk)-2}$	0.0008	0.0014	$\lambda_{rcpo(pk)-2}$	0.0038	0.0024	$\lambda_{rcpo(pk)-2}$	0.0013	0.0015	$\lambda_{rcpo(pk)-2}$	0.0043	0.0011

$\lambda_{rcpo(pk)-3}$	-0.0005	0.0012	$\lambda_{rcpo(pk)-3}$	-0.0003	0.0011	$\lambda_{rcpo(pk)-3}$	0.0006	0.0019	$\lambda_{rcpo(pk)-3}$	-0.0004	0.0014	$\lambda_{rcpo(pk)-3}$	–	–
$\lambda_{rcpo(pk)-4}$	0.0000	0.0008	$\lambda_{rcpo(pk)-4}$	0.0005	0.0009	$\lambda_{rcpo(pk)-4}$	-0.0015	0.0014	$\lambda_{rcpo(pk)-4}$	-0.0010	0.0011	$\lambda_{rcpo(pk)-4}$	–	–
$\lambda_{rbe(ch)-0}$	-0.0018	0.0014	$\lambda_{rbe(ch)-0}$	-0.0028	0.0016	$\lambda_{rbe(ch)-0}$	-0.0004	0.0015	$\lambda_{rbe(ch)-0}$	–	–	$\lambda_{rbe(ch)-0}$	–	–
$\lambda_{rbe(ch)-1}$	0.0003	0.0015	$\lambda_{rbe(ch)-1}$	-0.0022	0.0021	$\lambda_{rbe(ch)-1}$	0.0002	0.0015	$\lambda_{rbe(ch)-1}$	–	–	$\lambda_{rbe(ch)-1}$	–	–
$\lambda_{rbe(ch)-2}$	-0.0011	0.0013	$\lambda_{rbe(ch)-2}$	0.0002	0.0019	$\lambda_{rbe(ch)-2}$	-0.0015	0.0015	$\lambda_{rbe(ch)-2}$	–	–	$\lambda_{rbe(ch)-2}$	–	–
$\lambda_{rbe(ch)-3}$	-0.0021	0.0014	$\lambda_{rbe(ch)-3}$	0.0010	0.0020	$\lambda_{rbe(ch)-3}$	0.0005	0.0015	$\lambda_{rbe(ch)-3}$	–	–	$\lambda_{rbe(ch)-3}$	–	–
$\lambda_{rbe(ch)-4}$	0.0000	0.0012	$\lambda_{rbe(ch)-4}$	-0.0018	0.0013	$\lambda_{rbe(ch)-4}$	0.0011	0.0011	$\lambda_{rbe(ch)-4}$	–	–	$\lambda_{rbe(ch)-4}$	–	–
$\lambda_{rbn(ch)-0}$	-0.0000	0.0013	$\lambda_{rbn(ch)-0}$	0.0009	0.0016	$\lambda_{rbn(ch)-0}$	0.0011	0.0015	$\lambda_{rbn(ch)-0}$	0.0005	0.0010	$\lambda_{rbn(ch)-0}$	-0.0009	0.0015
$\lambda_{rbn(ch)-1}$	0.0008	0.0014	$\lambda_{rbn(ch)-1}$	-0.0009	0.0022	$\lambda_{rbn(ch)-1}$	0.0006	0.0016	$\lambda_{rbn(ch)-1}$	0.0013	0.0011	$\lambda_{rbn(ch)-1}$	-0.0013	0.0016
$\lambda_{rbn(ch)-2}$	-0.0011	0.0014	$\lambda_{rbn(ch)-2}$	-0.0035	0.0021	$\lambda_{rbn(ch)-2}$	-0.0019	0.0015	$\lambda_{rbn(ch)-2}$	-0.0015	0.0011	$\lambda_{rbn(ch)-2}$	-0.0027*	0.0014
$\lambda_{rbn(ch)-3}$	0.0024*	0.0014	$\lambda_{rbn(ch)-3}$	0.0014	0.0020	$\lambda_{rbn(ch)-3}$	0.0008	0.0015	$\lambda_{rbn(ch)-3}$	0.0015	0.0011	$\lambda_{rbn(ch)-3}$	–	–
$\lambda_{rbn(ch)-4}$	-0.0009	0.0011	$\lambda_{rbn(ch)-4}$	-0.0007	0.0012	$\lambda_{rbn(ch)-4}$	-0.0004	0.0011	$\lambda_{rbn(ch)-4}$	-0.0010	0.0010	$\lambda_{rbn(ch)-4}$	–	–
$\lambda_{rcpk(ch)-0}$	0.0009	0.0016	$\lambda_{rcpk(ch)-0}$	0.0036*	0.0021	$\lambda_{rcpk(ch)-0}$	0.0047	0.0017	$\lambda_{rcpk(ch)-0}$	0.0025*	0.0015	$\lambda_{rcpk(ch)-0}$	0.0034*	0.0019
$\lambda_{rcpk(ch)-1}$	0.0008	0.0018	$\lambda_{rcpk(ch)-1}$	0.0008	0.0025	$\lambda_{rcpk(ch)-1}$	0.0014	0.0019	$\lambda_{rcpk(ch)-1}$	0.0021	0.0016	$\lambda_{rcpk(ch)-1}$	-0.0011	0.0020
$\lambda_{rcpk(ch)-2}$	0.0011	0.0017	$\lambda_{rcpk(ch)-2}$	0.0027	0.0027	$\lambda_{rcpk(ch)-2}$	0.0011	0.0018	$\lambda_{rcpk(ch)-2}$	0.0025	0.0015	$\lambda_{rcpk(ch)-2}$	0.0031*	0.0017
$\lambda_{rcpk(ch)-3}$	-0.0006	0.0018	$\lambda_{rcpk(ch)-3}$	-0.0022	0.0025	$\lambda_{rcpk(ch)-3}$	-0.0004	0.0013	$\lambda_{rcpk(ch)-3}$	-0.0009	0.0015	$\lambda_{rcpk(ch)-3}$	–	–
$\lambda_{rcpk(ch)-4}$	-0.0010	0.0013	$\lambda_{rcpk(ch)-4}$	-0.0030**	0.0013	$\lambda_{rcpk(ch)-4}$	–	–	$\lambda_{rcpk(ch)-4}$	-0.0008	0.0013	$\lambda_{rcpk(ch)-4}$	–	–
$\lambda_{rcpo(ch)-0}$	0.0003	0.0009	$\lambda_{rcpo(ch)-0}$	-0.0014	0.0012	$\lambda_{rcpo(ch)-0}$	-0.0003	0.0011	$\lambda_{rcpo(ch)-0}$	-0.0007	0.0009	$\lambda_{rcpo(ch)-0}$	0.0007	0.0013
$\lambda_{rcpo(ch)-1}$	-0.0006	0.0015	$\lambda_{rcpo(ch)-1}$	0.0026	0.0020	$\lambda_{rcpo(ch)-1}$	-0.0022	0.0017	$\lambda_{rcpo(ch)-1}$	-0.0015	0.0011	$\lambda_{rcpo(ch)-1}$	-0.0010	0.0015
$\lambda_{rcpo(ch)-2}$	0.0002	0.0015	$\lambda_{rcpo(ch)-2}$	0.0020	0.0021	$\lambda_{rcpo(ch)-2}$	0.0016	0.0017	$\lambda_{rcpo(ch)-2}$	0.0018	0.0011	$\lambda_{rcpo(ch)-2}$	0.0031**	0.0014
$\lambda_{rcpo(ch)-3}$	-0.0003	0.0013	$\lambda_{rcpo(ch)-3}$	0.0001	0.0018	$\lambda_{rcpo(ch)-3}$	0.0010	0.0015	$\lambda_{rcpo(ch)-3}$	-0.0009	0.0010	$\lambda_{rcpo(ch)-3}$	–	–
$\lambda_{rcpo(ch)-4}$	-0.0002	0.0010	$\lambda_{rcpo(ch)-4}$	-0.0037**	0.0012	$\lambda_{rcpo(ch)-4}$	-0.0019	0.0010	$\lambda_{rcpo(ch)-4}$	-0.0018*	0.0010	$\lambda_{rcpo(ch)-4}$	–	–
d_{bf1}	0.0421***	0.0072	d_{bf1}	0.0084***	0.0127	d_{bf1}	0.0231*	0.0108	d_{bf1}	0.0257**	0.0102	d_{bf1}	0.0379***	0.0099
d_{bf2}	0.0493***	0.0057	d_{bf2}	0.0337***	0.0123	d_{bf2}	0.0422***	0.0082	d_{bf2}	0.0350***	0.0088	d_{bf2}	0.0476***	0.0085
d_{bf3}	0.0472***	0.0057	d_{bf3}	0.0345***	0.0105	d_{bf3}	0.0386***	0.0083	d_{bf3}	0.0333***	0.0080	d_{bf3}	0.0415***	0.0081
d_{pk1}	0.0197***	0.0044	d_{pk1}	0.0208***	0.0054	d_{pk1}	-0.0029	0.0079	d_{pk1}	0.0023	0.0059	d_{pk1}	0.0117**	0.0048
d_{pk2}	0.0214***	0.0046	d_{pk2}	0.0188***	0.0048	d_{pk2}	0.0100	0.0076	d_{pk2}	0.0130**	0.0057	d_{pk2}	0.0097**	0.0041
d_{pk3}	0.0224***	0.0037	d_{pk3}	0.0167***	0.0045	d_{pk3}	0.0130*	0.0066	d_{pk3}	0.0089**	0.0049	d_{pk3}	0.0167***	0.0040
d_{ch1}	0.0224***	0.0048	d_{ch1}	-0.0012	0.0068	d_{ch1}	0.0055	0.0051	d_{ch1}	0.0135**	0.0047	d_{ch1}	0.0240***	0.0060
d_{ch2}	0.0215***	0.0046	d_{ch2}	0.0185**	0.0070	d_{ch2}	0.0130**	0.0050	d_{ch2}	0.0105**	0.0043	d_{ch2}	0.0186***	0.0054
d_{ch3}	0.0292***	0.0039	d_{ch3}	0.0165**	0.0059	d_{ch3}	0.0167**	0.0046	d_{ch3}	0.0192***	0.0037	d_{ch3}	0.0342***	0.0050
$\rho_{bf, bf}$	-0.0399	0.2216	$\rho_{bf, bf}$	-0.1890	0.1907	$\rho_{bf, bf}$	0.0365	0.2278	$\rho_{bf, bf}$	-0.3524*	0.1912	$\rho_{bf, bf}$	-0.3465*	0.1279
$\rho_{bf, ch}$	-1.7719**	0.6197	$\rho_{bf, ch}$	-1.0468**	0.4330	$\rho_{bf, ch}$	-1.3594**	0.5069	$\rho_{bf, ch}$	-0.3311	0.3555	$\rho_{bf, ch}$	-1.1808**	0.4074
$\rho_{bf, pk}$	-1.4225***	0.3796	$\rho_{bf, pk}$	0.8985**	0.3487	$\rho_{bf, pk}$	-2.1678**	0.6258	$\rho_{bf, pk}$	-1.2446***	0.4242	$\rho_{bf, pk}$	-0.7610**	0.2773
$\rho_{ch, bf}$	0.0823	0.1092	$\rho_{ch, bf}$	0.0324	0.1048	$\rho_{ch, bf}$	-0.0679	0.1165	$\rho_{ch, bf}$	0.0447	0.1099	$\rho_{ch, bf}$	0.1234**	0.0621
$\rho_{ch, ch}$	-0.7064**	0.3317	$\rho_{ch, ch}$	-0.7517**	0.2281	$\rho_{ch, ch}$	-0.2997	0.2789	$\rho_{ch, ch}$	-0.4403**	0.1987	$\rho_{ch, ch}$	-0.5161**	0.2073
$\rho_{ch, pk}$	-0.4362**	0.1965	$\rho_{ch, pk}$	-0.1412	0.1892	$\rho_{ch, pk}$	0.0967	0.3486	$\rho_{ch, pk}$	-0.5419**	0.2525	$\rho_{ch, pk}$	-0.2948**	0.1351
$\rho_{pk, bf}$	0.2705**	0.1063	$\rho_{pk, bf}$	0.0174	0.1147	$\rho_{pk, bf}$	0.2410**	0.0897	$\rho_{pk, bf}$	0.1529*	0.0779	$\rho_{pk, bf}$	0.1837**	0.0740
$\rho_{pk, ch}$	-0.3892	0.3089	$\rho_{pk, ch}$	0.7506**	0.2724	$\rho_{pk, ch}$	-0.2452	0.2063	$\rho_{pk, ch}$	0.1390	0.1445	$\rho_{pk, ch}$	0.2972**	0.2353
$\rho_{pk, pk}$	-0.8953***	0.1921	$\rho_{pk, pk}$	-0.1774	0.1988	$\rho_{pk, pk}$	-0.9359**	0.2670	$\rho_{pk, pk}$	-0.9543***	0.1775	$\rho_{pk, pk}$	-0.8412	0.1569
R^2 bf	0.9666		R^2 bf	0.9753		R^2 bf	0.9414		R^2 bf	0.9618		R^2 bf	0.9478	
R^2 pk	0.9780		R^2 pk	0.9741		R^2 pk	0.9720		R^2 pk	0.9734		R^2 pk	0.9674	
R^2 ch	0.9657		R^2 ch	0.9726		R^2 ch	0.9461		R^2 ch	0.9745		R^2 ch	0.9545	
B-P Test bf	40.3600		B-P Test bf	38.5700		B-P Test bf	27.0200		B-P Test bf	35.3500		B-P Test bf	22.3800	
B-P Test pk	39.5000		B-P Test pk	35.3200		B-P Test pk	37.0500		B-P Test pk	31.7800		B-P Test pk	28.4800	
B-P Test ch	32.7100		B-P Test ch	32.9000		B-P Test ch	31.9900		B-P Test ch	27.7600		B-P Test ch	32.7000	

(Table A2.3 continued)

Plains			**South Central**			**Southeast**			**West**		
Diagonal Autocorrelation Correction			Complete Autocorrelation Correction			Complete Autocorrelation Correction			Complete Autocorrelation Correction		
Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err
c_{bf}	-0.5123***	0.0405	c_{bf}	-0.4242***	0.0320	c_{bf}	-0.3820***	0.0278	c_{bf}	-0.3498***	0.0510
$c_{bf, pk}$	0.3727***	0.0244	$c_{bf, pk}$	0.2904***	0.0321	$c_{bf, pk}$	0.2958***	0.0265	$c_{bf, pk}$	0.2329***	0.0200
$c_{bf, ch}$	0.0159	0.0396	$c_{bf, ch}$	-0.0014	0.0203	$c_{bf, ch}$	-0.0048	0.0245	$c_{bf, ch}$	0.0288	0.0508
c_{pk}	-0.4585***	0.0395	c_{pk}	-0.3922***	0.0445	c_{pk}	-0.3766***	0.0389	c_{pk}	-0.3665***	0.0198
$c_{pk, ch}$	0.0682***	0.0241	$c_{pk, ch}$	0.1045***	0.0191	$c_{pk, ch}$	0.0776**	0.0252	$c_{pk, ch}$	0.1145***	0.0191
c_{ch}	-0.1553***	0.0411	c_{ch}	-0.1515***	0.0218	c_{ch}	-0.1328**	0.0342	c_{ch}	-0.2048***	0.0543
β_1	0.4462***	0.0372	β_1	0.5492	0.0246	β_1	0.3869***	0.0242	β_1	0.4710***	0.0251
β_2	0.2109***	0.0198	β_2	0.22246	0.0131	β_2	0.1829***	0.0164	β_2	0.1885***	0.0135
β_3	0.1486***	0.0166	β_3	0.19785	0.0088	β_3	0.2041***	0.0121	β_3	0.1854***	0.0087
a_1	-0.0453***	0.0083	a_1	-0.0438***	0.0056	a_1	-0.0279***	0.0040	a_1	-0.0597***	0.0069
a_2	-0.0238***	0.0051	a_2	-0.0152***	0.0034	a_2	-0.0162***	0.0031	a_2	-0.0190***	0.0042
a_3	-0.0166***	0.0041	a_3	-0.0198***	0.0020	a_3	-0.0224***	0.0028	a_3	-0.0225***	0.0028
$\lambda_{rbe(bf)-0}$	-0.0012	0.0035	$\lambda_{rbe(bf)-0}$	-0.0007	0.0045	$\lambda_{rbe(bf)-0}$	-0.0037**	0.0015	$\lambda_{rbe(bf)-0}$	0.0003	0.0032
$\lambda_{rbe(bf)-1}$	0.0061	0.0041	$\lambda_{rbe(bf)-1}$	-0.0015	0.0066	$\lambda_{rbe(bf)-1}$	-0.0042*	0.0023	$\lambda_{rbe(bf)-1}$	-0.0045	0.0037
$\lambda_{rbe(bf)-2}$	-0.0004	0.0037	$\lambda_{rbe(bf)-2}$	0.0070	0.0062	$\lambda_{rbe(bf)-2}$	-0.0006	0.0023	$\lambda_{rbe(bf)-2}$	-0.0006	0.0032
$\lambda_{rbe(bf)-3}$	0.0008	0.0037	$\lambda_{rbe(bf)-3}$	0.0152**	0.0059	$\lambda_{rbe(bf)-3}$	0.0006	0.0022	$\lambda_{rbe(bf)-3}$	-0.0005	0.0033
$\lambda_{rbe(bf)-4}$	0.0103**	0.0029	$\lambda_{rbe(bf)-4}$	0.0073**	0.0031	$\lambda_{rbe(bf)-4}$	0.0011	0.0021	$\lambda_{rbe(bf)-4}$	0.0004	0.0027
$\lambda_{rbn(bf)-0}$	-0.0034	0.0033	$\lambda_{rbn(bf)-0}$	-0.0023	0.0043	$\lambda_{rbn(bf)-0}$	0.0006	0.0015	$\lambda_{rbn(bf)-0}$	-0.0025	0.0032
$\lambda_{rbn(bf)-1}$	-0.0022	0.0037	$\lambda_{rbn(bf)-1}$	-0.0082	0.0067	$\lambda_{rbn(bf)-1}$	0.0018	0.0022	$\lambda_{rbn(bf)-1}$	0.0013	0.0033
$\lambda_{rbn(bf)-2}$	-0.0071*	0.0035	$\lambda_{rbn(bf)-2}$	-0.0116*	0.0068	$\lambda_{rbn(bf)-2}$	-0.0057*	0.0022	$\lambda_{rbn(bf)-2}$	-0.0019	0.0033
$\lambda_{rbn(bf)-3}$	0.0017	0.0033	$\lambda_{rbn(bf)-3}$	-0.0094	0.0059	$\lambda_{rbn(bf)-3}$	0.0037*	0.0021	$\lambda_{rbn(bf)-3}$	0.0063**	0.0031
$\lambda_{rbn(bf)-4}$	-0.0078**	0.0026	$\lambda_{rbn(bf)-4}$	-0.0070*	0.0029	$\lambda_{rbn(bf)-4}$	-0.0012	0.0019	$\lambda_{rbn(bf)-4}$	-0.0022	0.0025
$\lambda_{rcpk(bf)-0}$	0.0028	0.0042	$\lambda_{rcpk(bf)-0}$	–	–	$\lambda_{rcpk(bf)-0}$	0.0066**	0.0020	$\lambda_{rcpk(bf)-0}$	–	–
$\lambda_{rcpk(bf)-1}$	0.0013	0.0039	$\lambda_{rcpk(bf)-1}$	–	–	$\lambda_{rcpk(bf)-1}$	-0.0023	0.0023	$\lambda_{rcpk(bf)-1}$	–	–
$\lambda_{rcpk(bf)-2}$	-0.0003	0.0031	$\lambda_{rcpk(bf)-2}$	–	–	$\lambda_{rcpk(bf)-2}$	0.0014	0.0025	$\lambda_{rcpk(bf)-2}$	–	–
$\lambda_{rcpk(bf)-3}$	–	–	$\lambda_{rcpk(bf)-3}$	–	–	$\lambda_{rcpk(bf)-3}$	-0.0002	0.0023	$\lambda_{rcpk(bf)-3}$	–	–
$\lambda_{rcpk(bf)-4}$	–	–	$\lambda_{rcpk(bf)-4}$	–	–	$\lambda_{rcpk(bf)-4}$	–	–	$\lambda_{rcpk(bf)-4}$	–	–
$\lambda_{rcpo(bf)-0}$	-0.0018	0.0024	$\lambda_{rcpo(bf)-0}$	-0.0053**	0.0018	$\lambda_{rcpo(bf)-0}$	-0.0004	0.0011	$\lambda_{rcpo(bf)-0}$	–	–
$\lambda_{rcpo(bf)-1}$	-0.0016	0.0042	$\lambda_{rcpo(bf)-1}$	0.0038	0.0050	$\lambda_{rcpo(bf)-1}$	0.0002	0.0021	$\lambda_{rcpo(bf)-1}$	–	–
$\lambda_{rcpo(bf)-2}$	0.0016	0.0043	$\lambda_{rcpo(bf)-2}$	0.0083	0.0060	$\lambda_{rcpo(bf)-2}$	0.0078**	0.0027	$\lambda_{rcpo(bf)-2}$	–	–
$\lambda_{rcpo(bf)-3}$	0.0024	0.0034	$\lambda_{rcpo(bf)-3}$	-0.0010	0.0054	$\lambda_{rcpo(bf)-3}$	0.0005	0.0022	$\lambda_{rcpo(bf)-3}$	–	–
$\lambda_{rcpo(bf)-4}$	-0.0036	0.0023	$\lambda_{rcpo(bf)-4}$	-0.0054*	0.0028	$\lambda_{rcpo(bf)-4}$	-0.0059***	0.0018	$\lambda_{rcpo(bf)-4}$	–	–
$\lambda_{rbe(pk)-0}$	-0.0003	0.0022	$\lambda_{rbe(pk)-0}$	-0.0008	0.0010	$\lambda_{rbe(pk)-0}$	0.0016	0.0013	$\lambda_{rbe(pk)-0}$	0.0025	0.0018
$\lambda_{rbe(pk)-1}$	0.0003	0.0021	$\lambda_{rbe(pk)-1}$	0.0008	0.0027	$\lambda_{rbe(pk)-1}$	0.0006	0.0013	$\lambda_{rbe(pk)-1}$	0.0032*	0.0019
$\lambda_{rbe(pk)-2}$	0.0013	0.0020	$\lambda_{rbe(pk)-2}$	-0.0021	0.0028	$\lambda_{rbe(pk)-2}$	-0.0009	0.0013	$\lambda_{rbe(pk)-2}$	-0.0001	0.0017
$\lambda_{rbe(pk)-3}$	-0.0009	0.0020	$\lambda_{rbe(pk)-3}$	0.0032	0.0028	$\lambda_{rbe(pk)-3}$	-0.0005	0.0013	$\lambda_{rbe(pk)-3}$	0.0006	0.0017
$\lambda_{rbe(pk)-4}$	0.0041**	0.0017	$\lambda_{rbe(pk)-4}$	0.0049**	0.0021	$\lambda_{rbe(pk)-4}$	0.0011	0.0009	$\lambda_{rbe(pk)-4}$	0.0026	0.0015
$\lambda_{rbn(pk)-0}$	-0.0012	0.0020	$\lambda_{rbn(pk)-0}$	0.0001	0.0009	$\lambda_{rbn(pk)-0}$	-0.0007	0.0012	$\lambda_{rbn(pk)-0}$	-0.0044**	0.0017
$\lambda_{rbn(pk)-1}$	-0.0018	0.0020	$\lambda_{rbn(pk)-1}$	-0.0005	0.0026	$\lambda_{rbn(pk)-1}$	0.0006	0.0013	$\lambda_{rbn(pk)-1}$	-0.0014	0.0018
$\lambda_{rbn(pk)-2}$	-0.0033	0.0020	$\lambda_{rbn(pk)-2}$	-0.0034	0.0029	$\lambda_{rbn(pk)-2}$	-0.0017	0.0013	$\lambda_{rbn(pk)-2}$	-0.0017	0.0019
$\lambda_{rbn(pk)-3}$	-0.0002	0.0018	$\lambda_{rbn(pk)-3}$	-0.0028	0.0029	$\lambda_{rbn(pk)-3}$	0.0008	0.0012	$\lambda_{rbn(pk)-3}$	0.0036**	0.0017
$\lambda_{rbn(pk)-4}$	-0.0008	0.0015	$\lambda_{rbn(pk)-4}$	-0.0014	0.0020	$\lambda_{rbn(pk)-4}$	0.0005	0.0009	$\lambda_{rbn(pk)-4}$	-0.0005	0.0014
$\lambda_{rcpk(pk)-0}$	-0.0004	0.0024	$\lambda_{rcpk(pk)-0}$	–	–	$\lambda_{rcpk(pk)-0}$	0.0011	0.0014	$\lambda_{rcpk(pk)-0}$	–	–
$\lambda_{rcpk(pk)-1}$	0.0028	0.0022	$\lambda_{rcpk(pk)-1}$	–	–	$\lambda_{rcpk(pk)-1}$	-0.0009	0.0017	$\lambda_{rcpk(pk)-1}$	–	–
$\lambda_{rcpk(pk)-2}$	0.0020	0.0017	$\lambda_{rcpk(pk)-2}$	–	–	$\lambda_{rcpk(pk)-2}$	-0.0005	0.0015	$\lambda_{rcpk(pk)-2}$	–	–
$\lambda_{rcpk(pk)-3}$	–	–	$\lambda_{rcpk(pk)-3}$	–	–	$\lambda_{rcpk(pk)-3}$	-0.0001	0.0010	$\lambda_{rcpk(pk)-3}$	–	–
$\lambda_{rcpk(pk)-4}$	–	–	$\lambda_{rcpk(pk)-4}$	–	–	$\lambda_{rcpk(pk)-4}$	–	–	$\lambda_{rcpk(pk)-4}$	–	–
$\lambda_{rcpo(pk)-0}$	-0.0028*	0.0015	$\lambda_{rcpo(pk)-0}$	-0.0007	0.0006	$\lambda_{rcpo(pk)-0}$	0.0006	0.0008	$\lambda_{rcpo(pk)-0}$	–	–
$\lambda_{rcpo(pk)-1}$	0.0015	0.0022	$\lambda_{rcpo(pk)-1}$	-0.0024*	0.0013	$\lambda_{rcpo(pk)-1}$	-0.0013	0.0015	$\lambda_{rcpo(pk)-1}$	–	–
$\lambda_{rcpo(pk)-2}$	0.0004	0.0021	$\lambda_{rcpo(pk)-2}$	0.0033	0.0026	$\lambda_{rcpo(pk)-2}$	0.0010	0.0016	$\lambda_{rcpo(pk)-2}$	–	–

$\lambda_{rcpo(pk)-3}$	0.0014	0.0017	$\lambda_{rcpo(pk)-3}$	0.0005	0.0026	$\lambda_{rcpo(pk)-3}$	-0.0007	0.0013	$\lambda_{rcpo(pk)-3}$	–	–
$\lambda_{rcpo(pk)-4}$	-0.0022	0.0013	$\lambda_{rcpo(pk)-4}$	-0.0026	0.0020	$\lambda_{rcpo(pk)-4}$	-0.0013	0.0009	$\lambda_{rcpo(pk)-4}$	–	–
$\lambda_{rbe(ch)-0}$	-0.0011	0.0016	$\lambda_{rbe(ch)-0}$	-0.0007	0.0020	$\lambda_{rbe(ch)-0}$	0.0005	0.0012	$\lambda_{rbe(ch)-0}$	-0.0010	0.0012
$\lambda_{rbe(ch)-1}$	0.0016	0.0017	$\lambda_{rbe(ch)-1}$	-0.0008	0.0024	$\lambda_{rbe(ch)-1}$	0.0008	0.0012	$\lambda_{rbe(ch)-1}$	0.0005	0.0014
$\lambda_{rbe(ch)-2}$	-0.0025*	0.0015	$\lambda_{rbe(ch)-2}$	0.0028	0.0023	$\lambda_{rbe(ch)-2}$	-0.0011	0.0012	$\lambda_{rbe(ch)-2}$	-0.0002	0.0011
$\lambda_{rbe(ch)-3}$	-0.0005	0.0016	$\lambda_{rbe(ch)-3}$	0.0053**	0.0020	$\lambda_{rbe(ch)-3}$	0.0002	0.0012	$\lambda_{rbe(ch)-3}$	-0.0017	0.0013
$\lambda_{rbe(ch)-4}$	0.0022	0.0016	$\lambda_{rbe(ch)-4}$	0.0011	0.0007	$\lambda_{rbe(ch)-4}$	0.0005	0.0009	$\lambda_{rbe(ch)-4}$	0.0011	0.0012
$\lambda_{rbn(ch)-0}$	0.0007	0.0015	$\lambda_{rbn(ch)-0}$	-0.0001	0.0019	$\lambda_{rbn(ch)-0}$	0.0002	0.0012	$\lambda_{rbn(ch)-0}$	0.0007	0.0011
$\lambda_{rbn(ch)-1}$	0.0008	0.0016	$\lambda_{rbn(ch)-1}$	-0.0026	0.0024	$\lambda_{rbn(ch)-1}$	0.0008	0.0013	$\lambda_{rbn(ch)-1}$	-0.00003	0.0013
$\lambda_{rbn(ch)-2}$	-0.0016	0.0015	$\lambda_{rbn(ch)-2}$	-0.0041*	0.0024	$\lambda_{rbn(ch)-2}$	-0.0012	0.0012	$\lambda_{rbn(ch)-2}$	-0.0014	0.0013
$\lambda_{rbn(ch)-3}$	0.0011	0.0015	$\lambda_{rbn(ch)-3}$	-0.0035*	0.0020	$\lambda_{rbn(ch)-3}$	0.0017	0.0011	$\lambda_{rbn(ch)-3}$	0.0018	0.0012
$\lambda_{rbn(ch)-4}$	-0.0015	0.0014	$\lambda_{rbn(ch)-4}$	-0.0022**	0.0006	$\lambda_{rbn(ch)-4}$	0.0007	0.0008	$\lambda_{rbn(ch)-4}$	0.0003	0.0011
$\lambda_{rcpk(ch)-0}$	0.0050**	0.0020	$\lambda_{rcpk(ch)-0}$	–	–	$\lambda_{rcpk(ch)-0}$	0.0035**	0.0013	$\lambda_{rcpk(ch)-0}$	–	–
$\lambda_{rcpk(ch)-1}$	0.0005	0.0018	$\lambda_{rcpk(ch)-1}$	–	–	$\lambda_{rcpk(ch)-1}$	-0.0006	0.0015	$\lambda_{rcpk(ch)-1}$	–	–
$\lambda_{rcpk(ch)-2}$	0.0015	0.0016	$\lambda_{rcpk(ch)-2}$	–	–	$\lambda_{rcpk(ch)-2}$	0.0001	0.0014	$\lambda_{rcpk(ch)-2}$	–	–
$\lambda_{rcpk(ch)-3}$	–	–	$\lambda_{rcpk(ch)-3}$	–	–	$\lambda_{rcpk(ch)-3}$	-0.0007	0.0010	$\lambda_{rcpk(ch)-3}$	–	–
$\lambda_{rcpk(ch)-4}$	–	–	$\lambda_{rcpk(ch)-4}$	–	–	$\lambda_{rcpk(ch)-4}$	–	–	$\lambda_{rcpk(ch)-4}$	–	–
$\lambda_{rcpo(ch)-0}$	-0.0001	0.0011	$\lambda_{rcpo(ch)-0}$	-0.0036***	0.0007	$\lambda_{rcpo(ch)-0}$	-0.0001	0.0008	$\lambda_{rcpo(ch)-0}$	–	–
$\lambda_{rcpo(ch)-1}$	-0.0023	0.0016	$\lambda_{rcpo(ch)-1}$	0.0027	0.0021	$\lambda_{rcpo(ch)-1}$	-0.0018	0.0013	$\lambda_{rcpo(ch)-1}$	–	–
$\lambda_{rcpo(ch)-2}$	0.0027	0.0017	$\lambda_{rcpo(ch)-2}$	0.0016	0.0023	$\lambda_{rcpo(ch)-2}$	0.0018	0.0013	$\lambda_{rcpo(ch)-2}$	–	–
$\lambda_{rcpo(ch)-3}$	-0.0003	0.0015	$\lambda_{rcpo(ch)-3}$	-0.0002	0.0019	$\lambda_{rcpo(ch)-3}$	0.0004	0.0011	$\lambda_{rcpo(ch)-3}$	–	–
$\lambda_{rcpo(ch)-4}$	0.0003	0.0013	$\lambda_{rcpo(ch)-4}$	-0.0027***	0.0006	$\lambda_{rcpo(ch)-4}$	-0.0010	0.0008	$\lambda_{rcpo(ch)-4}$	–	–
d_{bf1}	0.0326**	0.0120	d_{bf1}	-0.0705**	0.0117	d_{bf1}	0.0226***	0.0062	d_{bf1}	0.0463***	0.0106
d_{bf2}	0.0390***	0.0099	d_{bf2}	-0.0236**	0.0111	d_{bf2}	0.0221***	0.0051	d_{bf2}	0.0651***	0.0087
d_{bf3}	0.0492***	0.0100	d_{bf3}	-0.0067	0.0093	d_{bf3}	0.0276***	0.0047	d_{bf3}	0.0605***	0.0089
d_{pk1}	0.0274***	0.0074	d_{pk1}	-0.0129**	0.0058	d_{pk1}	0.0143***	0.0044	d_{pk1}	0.0190**	0.0063
d_{pk2}	0.0250***	0.0064	d_{pk2}	-0.0088*	0.0048	d_{pk2}	0.0200***	0.0039	d_{pk2}	0.0178**	0.0056
d_{pk3}	0.0250***	0.0064	d_{pk3}	0.0009	0.0040	d_{pk3}	0.0168***	0.0039	d_{pk3}	0.0228***	0.0056
d_{ch1}	0.0152**	0.0059	d_{ch1}	-0.0174***	0.0042	d_{ch1}	0.0224***	0.0043	d_{ch1}	0.0200***	0.0043
d_{ch2}	0.0157**	0.0051	d_{ch2}	-0.0073**	0.0040	d_{ch2}	0.0240***	0.0037	d_{ch2}	0.0225***	0.0039
d_{ch3}	0.0188***	0.0051	d_{ch3}	0.0040	0.0032	d_{ch3}	0.0249***	0.0035	d_{ch3}	0.0264***	0.0038
$\rho_{bf, bf}$	-0.1399	0.1841	$\rho_{bf, bf}$	0.1767	0.3675	$\rho_{bf, bf}$	-0.0921	0.1159	$\rho_{bf, bf}$	-0.4770**	0.1851
$\rho_{bf, ch}$	-1.1220**	0.3914	$\rho_{bf, ch}$	-1.6937***	0.4492	$\rho_{bf, ch}$	-0.6604**	0.1954	$\rho_{bf, ch}$	-0.5349	0.4579
$\rho_{bf, pk}$	-1.7658***	0.4139	$\rho_{bf, pk}$	0.8847	0.8090	$\rho_{bf, pk}$	-1.7300***	0.2790	$\rho_{bf, pk}$	-1.5550***	0.3401
$\rho_{ch, bf}$	0.1070	0.0965	$\rho_{ch, bf}$	0.1852**	0.0737	$\rho_{ch, bf}$	0.3109**	0.0994	$\rho_{ch, bf}$	-0.0756	0.0950
$\rho_{ch, ch}$	-0.7764***	0.2234	$\rho_{ch, ch}$	-0.3937***	0.1053	$\rho_{ch, ch}$	-0.8521***	0.1582	$\rho_{ch, ch}$	-0.3883	0.2456
$\rho_{ch, pk}$	-0.4287**	0.2330	$\rho_{ch, pk}$	0.7522***	0.1743	$\rho_{ch, pk}$	-0.8219**	0.2143	$\rho_{ch, pk}$	-0.4158**	0.1880
$\rho_{pk, bf}$	0.2296**	0.0741	$\rho_{pk, bf}$	0.2561	0.1633	$\rho_{pk, bf}$	0.1461	0.0918	$\rho_{pk, bf}$	0.2015**	0.0643
$\rho_{pk, ch}$	-0.1115	0.1616	$\rho_{pk, ch}$	-0.6510**	0.2014	$\rho_{pk, ch}$	0.2107	0.1447	$\rho_{pk, ch}$	-0.1267	0.1625
$\rho_{pk, pk}$	-0.9921**	0.1793	$\rho_{pk, pk}$	-0.4128	0.3601	$\rho_{pk, pk}$	-0.8995***	0.1776	$\rho_{pk, pk}$	-0.6860***	0.1263
R^2 bf	0.9490		R^2 bf	0.8960		R^2 bf	0.9916		R^2 bf	0.9420	
R^2 pk	0.9668		R^2 pk	0.9891		R^2 pk	0.9817		R^2 pk	0.9567	
R^2 ch	0.9414		R^2 ch	0.8437		R^2 ch	0.9755		R^2 ch	0.9535	
B-P Test bf	35.1800		B-P Test bf	18.1900		B-P Test bf	25.3300		B-P Test bf	33.0100	
B-P Test pk	34.3700		B-P Test pk	21.5700		B-P Test pk	29.5600		B-P Test pk	21.1700	
B-P Test ch	26.8200		B-P Test ch	25.6000		B-P Test ch	33.7000		B-P Test ch	18.8000	

Note: bf, pk, ch, and tu indicate beef, pork, chicken, and turkey, respectively. One, double, and triple asterisks (*, **, ***) mean statistical significance at 10%, 5%, and 1% levels. The lambdas are the estimated coefficients of FSIS food recall with lags. For example, $\lambda_{rbe(bf)-0}$ and $\lambda_{rbe(bf)-1}$ indicate the estimated effect of beef *E. coli* recalls on beef demand with lag period zero and one, respectively.

Table A2.4 Estimated Coefficients Meat Separable Model-Ground Beef Specification (Model 2)

	Total US		**California**		**Great Lakes**		**Mid-South**		**Northeast**	
	Diagonal Autocorrelation Correction		Diagonal Autocorrelation Correction		Complete Autocorrelation Correction		Diagonal Autocorrelation Correction		Diagonal Autocorrelation Correction	
Parameters	Coefficients	Std Err	Coefficients	Std Err	Coefficients	Std Err	Coefficients	Std Err	Coefficients	Std Err
c_{gb}	-0.1703***	0.0260	-0.1476***	0.0195	-0.3107***	0.0183	-0.2502***	0.0352	-0.2032***	0.0191
$c_{gb, pk}$	-0.0053	0.0380	0.0230	0.0287	0.1403***	0.0222	-0.0150	0.0386	-0.0061	0.0194
$c_{gb, ch}$	0.0200	0.0290	0.0142	0.0218	-0.0355*	0.0177	0.1018**	0.028	0.0853**	0.0223
c_{ob}	-0.2128**	0.0904	-0.4153***	0.0743	-0.4139***	0.0419	-0.1360**	0.0659	-0.1245*	0.0642
$c_{ob, ch}$	-0.0166	0.0591	0.1562***	0.0471	0.0762**	0.0232	-0.0861**	0.0403	-0.0620	0.0438
c_{ch}	-0.1935***	0.0426	-0.3556***	0.0329	-0.2330***	0.0198	-0.1971***	0.0337	-0.2612***	0.0362
β_1	0.1891***	0.0092	0.1348***	0.0094	0.2160***	0.0074	0.1787***	0.0133	0.1749***	0.0062
β_2	0.3090***	0.0186	0.3507***	0.0275	0.2909***	0.0122	0.2860***	0.0198	0.2871***	0.0212
β_3	0.2394***	0.0121	0.2660***	0.0162	0.1993***	0.0082	0.2197***	0.0131	0.3004***	0.0129
a_1	-0.0065**	0.0022	-0.0056**	0.0025	-0.0058**	0.0024	-0.0064**	0.0028	-0.0090***	0.0016
a_2	-0.0085**	0.0038	-0.0106**	0.0051	-0.0192***	0.0028	-0.0101**	0.0035	-0.0099*	0.0051
a_3	-0.0122***	0.0026	-0.0181***	0.0033	-0.0080***	0.0021	-0.0119***	0.0023	-0.0138***	0.0029
$\lambda_{rbe(gb)-0}$	-0.0008	0.0010	-0.0014	0.0010	-0.0014	0.0009	-0.0015	0.0012	0.0000	0.0007
$\lambda_{rbe(gb)-1}$	-0.0002	0.0010	-0.0009	0.0012	-0.0006	0.0009	-0.0013	0.0013	0.0000	0.0007
$\lambda_{rbe(gb)-2}$	0.0001	0.0009	0.0009	0.0011	–	–	0.0004	0.0011	0.0002	0.0007
$\lambda_{rbe(gb)-3}$	-0.0001	0.0009	0.0004	0.0011	–	–	-0.0003	0.0012	-0.0004	0.0007
$\lambda_{rbe(gb)-4}$	0.00001	0.0009	0.0004	0.0008	–	–	-0.0002	0.0011	0.0004	0.0007
$\lambda_{rbn(gb)-0}$	–	–	0.0008	0.0011	–	–	0.0010	0.0011	–	–
$\lambda_{rbn(gb)-1}$	–	–	-0.0010	0.0013	–	–	-0.0003	0.0013	–	–
$\lambda_{rbn(gb)-2}$	–	–	-0.0012	0.0012	–	–	-0.0007	0.0013	–	–
$\lambda_{rbn(gb)-3}$	–	–	0.0005	0.0012	–	–	0.0008	0.0012	–	–
$\lambda_{rbn(gb)-4}$	–	–	0.0012	0.0008	–	–	0.0006	0.0009	–	–
$\lambda_{rcpk(gb)-0}$	-0.0005	0.0011	-0.0011	0.0013	–	–	-0.0004	0.0014	–	–
$\lambda_{rcpk(gb)-1}$	0.0001	0.0013	-0.0010	0.0015	–	–	-0.0007	0.0016	–	–
$\lambda_{rcpk(gb)-2}$	0.0003	0.0013	-0.0015	0.0016	–	–	0.0004	0.0017	–	–
$\lambda_{rcpk(gb)-3}$	-0.0003	0.0014	-0.0028*	0.0015	–	–	-0.0017	0.0016	–	–
$\lambda_{rcpk(gb)-4}$	-0.0012	0.0010	-0.0029**	0.0009	–	–	-0.0008	0.0011	–	–
$\lambda_{rcpo(gb)-0}$	0.0005	0.0007	0.0003	0.0008	–	–	-0.0001	0.0009	–	–
$\lambda_{rcpo(gb)-1}$	-0.0002	0.0010	0.0011	0.0012	–	–	0.0003	0.0013	–	–
$\lambda_{rcpo(gb)-2}$	0.0006	0.0009	0.0006	0.0011	–	–	0.0017	0.0013	–	–
$\lambda_{rcpo(gb)-3}$	–	–	0.0002	0.0010	–	–	-0.0003	0.0010	–	–
$\lambda_{rcpo(gb)-4}$	–	–	-0.0022**	0.0008	–	–	-0.0009	0.0009	–	–
$\lambda_{rbe(ob)-0}$	-0.0008	0.0018	0.0011	0.0020	0.0013	0.0011	-0.0025	0.0016	0.0007	0.0023
$\lambda_{rbe(ob)-1}$	-0.0048**	0.0018	-0.0032	0.0022	-0.0026*	0.0014	-0.0041**	0.0016	-0.0049**	0.0023
$\lambda_{rbe(ob)-2}$	0.0015	0.0016	0.0024	0.0022	–	–	0.0013	0.0014	0.0013	0.0021
$\lambda_{rbe(ob)-3}$	-0.0001	0.0016	0.0003	0.0022	–	–	0.0004	0.0015	0.0013	0.0021
$\lambda_{rbe(ob)-4}$	-0.0008	0.0017	0.0020	0.0020	–	–	-0.0008	0.0015	-0.0010	0.0022
$\lambda_{rbn(ob)-0}$	–	–	-0.0031	0.0022	–	–	-0.0008	0.0014	–	–
$\lambda_{rbn(ob)-1}$	–	–	-0.0008	0.0022	–	–	-0.0010	0.0016	–	–
$\lambda_{rbn(ob)-2}$	–	–	-0.0009	0.0022	–	–	-0.0009	0.0015	–	–
$\lambda_{rbn(ob)-3}$	–	–	-0.0003	0.0020	–	–	0.0001	0.0014	–	–
$\lambda_{rbn(ob)-4}$	–	–	-0.0014	0.0018	–	–	-0.0006	0.0013	–	–
$\lambda_{rcpk(ob)-0}$	0.0023	0.0021	0.0021	0.0028	–	–	0.0025	0.0019	–	–
$\lambda_{rcpk(ob)-1}$	0.0037*	0.0022	0.0046	0.0028	–	–	0.0031	0.0020	–	–
$\lambda_{rcpk(ob)-2}$	0.0016	0.0023	0.0037	0.0027	–	–	0.0011	0.0020	–	–
$\lambda_{rcpk(ob)-3}$	0.0011	0.0023	0.0034	0.0027	–	–	-0.0012	0.0020	–	–
$\lambda_{rcpk(ob)-4}$	0.0012	0.0019	0.0027	0.0021	–	–	-0.0001	0.0016	–	–
$\lambda_{rcpo(ob)-0}$	-0.0004	0.0014	-0.0006	0.0017	–	–	-0.0007	0.0012	–	–
$\lambda_{rcpo(ob)-1}$	0.0024	0.0018	-0.0002	0.0024	–	–	0.0028	0.0018	–	–
$\lambda_{rcpo(ob)-2}$	0.0026	0.0018	0.0046**	0.0025	–	–	0.0021	0.0017	–	–

$\lambda_{rcpo(ob)-3}$	–	–
$\lambda_{rcpo(ob)-4}$	–	–
$\lambda_{rbe(ch)-0}$	0.0001	0.0013
$\lambda_{rbe(ch)-1}$	0.0014	0.0013
$\lambda_{rbe(ch)-2}$	-0.0009	0.0011
$\lambda_{rbe(ch)-3}$	-0.0002	0.0011
$\lambda_{rbe(ch)-4}$	0.0002	0.0011
$\lambda_{rbn(ch)-0}$	–	–
$\lambda_{rbn(ch)-1}$	–	–
$\lambda_{rbn(ch)-2}$	–	–
$\lambda_{rbn(ch)-3}$	–	–
$\lambda_{rbn(ch)-4}$	–	–
$\lambda_{rcpk(ch)-0}$	-0.0008	0.0015
$\lambda_{rcpk(ch)-1}$	-0.0004	0.0016
$\lambda_{rcpk(ch)-2}$	-0.0010	0.0016
$\lambda_{rcpk(ch)-3}$	-0.0006	0.0016
$\lambda_{rcpk(ch)-4}$	-0.0028**	0.0012
$\lambda_{rcpo(ch)-0}$	-0.0008	0.0015
$\lambda_{rcpo(ch)-1}$	-0.0004	0.0016
$\lambda_{rcpo(ch)-2}$	-0.0010	0.0016
$\lambda_{rcpo(ch)-3}$	–	–
$\lambda_{rcpo(ch)-4}$	–	–
d_{gb1}	0.0009	0.0034
d_{gb2}	0.0090**	0.0038
d_{gb3}	0.0072**	0.0032
d_{ob1}	0.0037	0.0062
d_{ob2}	0.0065	0.0068
d_{ob3}	0.0074	0.0056
d_{ch1}	0.0127***	0.0041
d_{ch2}	0.0129***	0.0047
d_{ch3}	0.0142***	0.0038
$\rho_{gb, gb}$	-0.4037***	0.1071
$\rho_{ob, ob}$	-0.5423***	0.1331
$\rho_{ch, ch}$	-0.6457***	0.0982
R^2 gb	0.9421	
R^2 ob	0.9387	
R^2 ch	0.9369	
B-P Test gbf	25.6600	
B-P Test obf	27.1200	
B-P Test ch	24.8500	

$\lambda_{rcpo(ob)-3}$	-0.0015	0.0019
$\lambda_{rcpo(ob)-4}$	0.0009	0.0017
$\lambda_{rbe(ch)-0}$	0.0000	0.0014
$\lambda_{rbe(ch)-1}$	0.0010	0.0015
$\lambda_{rbe(ch)-2}$	0.0010	0.0016
$\lambda_{rbe(ch)-3}$	-0.0011	0.0016
$\lambda_{rbe(ch)-4}$	0.0006	0.0011
$\lambda_{rbn(ch)-0}$	0.0005	0.0016
$\lambda_{rbn(ch)-1}$	-0.0027	0.0016
$\lambda_{rbn(ch)-2}$	-0.0012	0.0016
$\lambda_{rbn(ch)-3}$	0.0012	0.0015
$\lambda_{rbn(ch)-4}$	0.0010	0.0010
$\lambda_{rcpk(ch)-0}$	-0.0020	0.0020
$\lambda_{rcpk(ch)-1}$	-0.0014	0.0020
$\lambda_{rcpk(ch)-2}$	-0.0043**	0.0019
$\lambda_{rcpk(ch)-3}$	-0.0045**	0.0019
$\lambda_{rcpk(ch)-4}$	-0.0058***	0.0011
$\lambda_{rcpo(ch)-0}$	0.0007	0.0011
$\lambda_{rcpo(ch)-1}$	0.0016	0.0017
$\lambda_{rcpo(ch)-2}$	-0.0014	0.0017
$\lambda_{rcpo(ch)-3}$	0.0009	0.0013
$\lambda_{rcpo(ch)-4}$	-0.0038***	0.0009
d_{gb1}	-0.0013	0.0036
d_{gb2}	0.0074	0.0044
d_{gb3}	0.0065*	0.0033
d_{ob1}	0.0005	0.0082
d_{ob2}	0.0142**	0.0072
d_{ob3}	0.0063	0.0069
d_{ch1}	0.0180***	0.0049
d_{ch2}	0.0160***	0.0051
d_{ch3}	0.0219***	0.0045
$\rho_{gb, gb}$	-0.1833	0.1144
$\rho_{ob, ob}$	-0.6421***	0.1354
$\rho_{ch, ch}$	-0.6357***	0.1019
R^2 gb	0.9514	
R^2 ob	0.9703	
R^2 ch	0.9667	
B-P Test gbf	22.6600	
B-P Test obf	38.2200	
B-P Test ch	23.0400	

$\lambda_{rcpo(ob)-3}$	–	–
$\lambda_{rcpo(ob)-4}$	–	–
$\lambda_{rbe(ch)-0}$	-0.0005	0.0008
$\lambda_{rbe(ch)-1}$	0.0003	0.0009
$\lambda_{rbe(ch)-2}$	–	–
$\lambda_{rbe(ch)-3}$	–	–
$\lambda_{rbe(ch)-4}$	–	–
$\lambda_{rbn(ch)-0}$	–	–
$\lambda_{rbn(ch)-1}$	–	–
$\lambda_{rbn(ch)-2}$	–	–
$\lambda_{rbn(ch)-3}$	–	–
$\lambda_{rbn(ch)-4}$	–	–
$\lambda_{rcpk(ch)-0}$	–	–
$\lambda_{rcpk(ch)-1}$	–	–
$\lambda_{rcpk(ch)-2}$	–	–
$\lambda_{rcpk(ch)-3}$	–	–
$\lambda_{rcpk(ch)-4}$	–	–
$\lambda_{rcpo(ch)-0}$	–	–
$\lambda_{rcpo(ch)-1}$	–	–
$\lambda_{rcpo(ch)-2}$	–	–
$\lambda_{rcpo(ch)-3}$	–	–
$\lambda_{rcpo(ch)-4}$	–	–
d_{gb1}	0.0004	0.0037
d_{gb2}	-0.0031	0.0040
d_{gb3}	0.0142***	0.0032
d_{ob1}	0.0204***	0.0045
d_{ob2}	0.0311***	0.0051
d_{ob3}	0.0095**	0.0039
d_{ch1}	0.0094**	0.0034
d_{ch2}	0.0035	0.0036
d_{ch3}	0.0117***	0.0029
$\rho_{bf, bf}$	-0.2303	0.3187
$\rho_{bf, ch}$	0.2035**	0.0809
$\rho_{bf, pk}$	-0.0681	0.3115
$\rho_{ch, bf}$	-1.3893***	0.3876
$\rho_{ch, ch}$	-0.7869***	0.1040
$\rho_{ch, pk}$	0.6080	0.3707
$\rho_{pk, bf}$	0.1210	0.2889
$\rho_{pk, ch}$	0.2490**	0.0714
$\rho_{pk, pk}$	-0.3933	0.2733
R^2 gb	0.9552	
R^2 ob	0.9687	
R^2 ch	0.9603	
B-P Test gbf	31.3900	
B-P Test obf	12.0200	
B-P Test ch	14.9900	

$\lambda_{rcpo(ob)-3}$	0.0002	0.0013
$\lambda_{rcpo(ob)-4}$	-0.0017	0.0013
$\lambda_{rbe(ch)-0}$	0.00002	0.0011
$\lambda_{rbe(ch)-1}$	0.00001	0.0011
$\lambda_{rbe(ch)-2}$	-0.0011	0.0011
$\lambda_{rbe(ch)-3}$	0.0002	0.0011
$\lambda_{rbe(ch)-4}$	0.0005	0.0010
$\lambda_{rbn(ch)-0}$	0.0015	0.0011
$\lambda_{rbn(ch)-1}$	0.0019*	0.0011
$\lambda_{rbn(ch)-2}$	-0.0001	0.0011
$\lambda_{rbn(ch)-3}$	0.0014	0.0010
$\lambda_{rbn(ch)-4}$	-0.0007	0.0009
$\lambda_{rcpk(ch)-0}$	-0.0001	0.0013
$\lambda_{rcpk(ch)-1}$	-0.0012	0.0014
$\lambda_{rcpk(ch)-2}$	0.0007	0.0013
$\lambda_{rcpk(ch)-3}$	-0.0008	0.0014
$\lambda_{rcpk(ch)-4}$	-0.0019*	0.0009
$\lambda_{rcpo(ch)-0}$	-0.0002	0.0008
$\lambda_{rcpo(ch)-1}$	-0.0019	0.0013
$\lambda_{rcpo(ch)-2}$	0.0007	0.0012
$\lambda_{rcpo(ch)-3}$	-0.0007	0.0009
$\lambda_{rcpo(ch)-4}$	-0.0011	0.0008
d_{gb1}	0.0022	0.0042
d_{gb2}	0.0101**	0.0047
d_{gb3}	0.0064	0.0040
d_{ob1}	0.0065	0.0055
d_{ob2}	0.0045	0.0059
d_{ob3}	0.0115**	0.0051
d_{ch1}	0.0138***	0.0036
d_{ch2}	0.0160***	0.0040
d_{ch3}	0.0098***	0.0032
$\rho_{gb, gb}$	-0.3201**	0.1387
$\rho_{ob, ob}$	-0.4830**	0.1774
$\rho_{ch, ch}$	-0.6836***	0.1440
R^2 gb	0.9712	
R^2 ob	0.9777	
R^2 ch	0.9820	
B-P Test gbf	30.9500	
B-P Test obf	31.5900	
B-P Test ch	33.8400	

$\lambda_{rcpo(ob)-3}$	–	–
$\lambda_{rcpo(ob)-4}$	–	–
$\lambda_{rbe(ch)-0}$	-0.0006	0.0014
$\lambda_{rbe(ch)-1}$	0.0013	0.0014
$\lambda_{rbe(ch)-2}$	-0.0013	0.0013
$\lambda_{rbe(ch)-3}$	-0.0016	0.0013
$\lambda_{rbe(ch)-4}$	0.0004	0.0013
$\lambda_{rbn(ch)-0}$	–	–
$\lambda_{rbn(ch)-1}$	–	–
$\lambda_{rbn(ch)-2}$	–	–
$\lambda_{rbn(ch)-3}$	–	–
$\lambda_{rbn(ch)-4}$	–	–
$\lambda_{rcpk(ch)-0}$	–	–
$\lambda_{rcpk(ch)-1}$	–	–
$\lambda_{rcpk(ch)-2}$	–	–
$\lambda_{rcpk(ch)-3}$	–	–
$\lambda_{rcpk(ch)-4}$	–	–
$\lambda_{rcpo(ch)-0}$	–	–
$\lambda_{rcpo(ch)-1}$	–	–
$\lambda_{rcpo(ch)-2}$	–	–
$\lambda_{rcpo(ch)-3}$	–	–
$\lambda_{rcpo(ch)-4}$	–	–
d_{gb1}	0.0038	0.0027
d_{gb2}	0.0153***	0.0025
d_{gb3}	0.0069***	0.0024
d_{ob1}	0.0104	0.0085
d_{ob2}	0.0049	0.0077
d_{ob3}	0.0086	0.0076
d_{ch1}	0.0092**	0.0050
d_{ch2}	0.0143***	0.0048
d_{ch3}	0.0162***	0.0044
$\rho_{gb, gb}$	-0.4566***	0.0897
$\rho_{ob, ob}$	-0.5865***	0.0835
$\rho_{ch, ch}$	-0.7231***	0.0742
R^2 gb	0.9530	
R^2 ob	0.8641	
R^2 ch	0.9341	
B-P Test gbf	17.0400	
B-P Test obf	29.0700	
B-P Test ch	20.9800	

(Table A2.4 continued)

Plains			South Central			Southeast			West		
Complete Autocorrelation Correction			Diagonal Autocorrelation Correction			Complete Autocorrelation Correction			Complete Autocorrelation Correction		
Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err	Parameters	Coefficients	Std Err
c_{gb}	-0.1540***	0.0261	c_{gb}	-0.1526***	0.0256	c_{gb}	-0.2564***	0.0311	c_{gb}	-0.2112***	0.0241
$c_{gb, pk}$	0.0071	0.0254	$c_{gb, pk}$	0.0030	0.0243	$c_{gb, pk}$	0.0733**	0.0297	$c_{gb, pk}$	0.1007**	0.0384
$c_{gb, ch}$	-0.0406*	0.0236	$c_{gb, ch}$	-0.0002	0.0189	$c_{gb, ch}$	0.0219	0.0233	$c_{gb, ch}$	-0.0162	0.0255
c_{ob}	-0.2641***	0.0463	c_{ob}	-0.2635***	0.0393	c_{ob}	-0.2645***	0.0522	c_{ob}	-0.3421**	0.1004
$c_{ob, ch}$	0.0472	0.0281	$c_{ob, ch}$	0.0043	0.0237	$c_{ob, ch}$	-0.0010	0.0324	$c_{ob, ch}$	0.0702	0.0601
c_{ch}	-0.1620***	0.0266	c_{ch}	-0.1293***	0.0211	c_{ch}	-0.1642***	0.0293	c_{ch}	-0.2164***	0.0408
β_1	0.2288***	0.0119	β_1	0.1834***	0.0113	β_1	0.1887***	0.0113	β_1	0.1860***	0.0070
β_2	0.2889***	0.0153	β_2	0.3205***	0.0154	β_2	0.2697***	0.0171	β_2	0.3564***	0.0152
β_3	0.1944***	0.0095	β_3	0.1802***	0.0100	β_3	0.2102***	0.0137	β_3	0.1995***	0.0102
a_1	-0.0055**	0.0025	a_1	-0.0067**	0.0025	a_1	-0.0045**	0.00184	a_1	-0.0099***	0.0020
a_2	-0.0132***	0.0028	a_2	-0.0064*	0.0032	a_2	-0.0038	0.00296	a_2	-0.0182***	0.0033
a_3	-0.0098***	0.0019	a_3	-0.0099***	0.0018	a_3	-0.0122***	0.0023	a_3	-0.0106***	0.0024
$\lambda_{rbe(gb)-0}$	-0.0011	0.0011	$\lambda_{rbe(gb)-0}$	-0.0016	0.0011	$\lambda_{rbe(gb)-0}$	-0.0022**	0.000822	$\lambda_{rbe(gb)-0}$	-0.0016**	0.0008
$\lambda_{rbe(gb)-1}$	0.0010	0.0011	$\lambda_{rbe(gb)-1}$	-0.0011	0.0012	$\lambda_{rbe(gb)-1}$	-0.0014	0.00088	$\lambda_{rbe(gb)-1}$	-0.0003	0.0011
$\lambda_{rbe(gb)-2}$	0.0007	0.0010	$\lambda_{rbe(gb)-2}$	0.0001	0.0010	$\lambda_{rbe(gb)-2}$	0.0012	0.000813	$\lambda_{rbe(gb)-2}$	0.0002	0.0010
$\lambda_{rbe(gb)-3}$	–	–	$\lambda_{rbe(gb)-3}$	–	–	$\lambda_{rbe(gb)-3}$	-0.0010	0.000823	$\lambda_{rbe(gb)-3}$	-0.0001	0.0011
$\lambda_{rbe(gb)-4}$	–	–	$\lambda_{rbe(gb)-4}$	–	–	$\lambda_{rbe(gb)-4}$	-0.0013	0.000846	$\lambda_{rbe(gb)-4}$	-0.0002	0.0011
$\lambda_{rbn(gb)-0}$	–	–	$\lambda_{rbn(gb)-0}$	0.0014	0.0010	$\lambda_{rbn(gb)-0}$	0.0018**	0.000797	$\lambda_{rbn(gb)-0}$	–	–
$\lambda_{rbn(gb)-1}$	–	–	$\lambda_{rbn(gb)-1}$	-0.0004	0.0013	$\lambda_{rbn(gb)-1}$	-0.0011	0.000879	$\lambda_{rbn(gb)-1}$	–	–
$\lambda_{rbn(gb)-2}$	–	–	$\lambda_{rbn(gb)-2}$	-0.0006	0.0012	$\lambda_{rbn(gb)-2}$	0.0001	0.000866	$\lambda_{rbn(gb)-2}$	–	–
$\lambda_{rbn(gb)-3}$	–	–	$\lambda_{rbn(gb)-3}$	-0.0006	0.0009	$\lambda_{rbn(gb)-3}$	0.0004	0.000802	$\lambda_{rbn(gb)-3}$	–	–
$\lambda_{rbn(gb)-4}$	–	–	$\lambda_{rbn(gb)-4}$	–	–	$\lambda_{rbn(gb)-4}$	0.0010	0.000762	$\lambda_{rbn(gb)-4}$	–	–
$\lambda_{rcpk(gb)-0}$	-0.0013	0.0014	$\lambda_{rcpk(gb)-0}$	-0.0009	0.0010	$\lambda_{rcpk(gb)-0}$	0.0007	0.00111	$\lambda_{rcpk(gb)-0}$	–	–
$\lambda_{rcpk(gb)-1}$	-0.0007	0.0012	$\lambda_{rcpk(gb)-1}$	–	–	$\lambda_{rcpk(gb)-1}$	0.0011	0.0011	$\lambda_{rcpk(gb)-1}$	–	–
$\lambda_{rcpk(gb)-2}$	–	–	$\lambda_{rcpk(gb)-2}$	–	–	$\lambda_{rcpk(gb)-2}$	0.0011	0.00106	$\lambda_{rcpk(gb)-2}$	–	–
$\lambda_{rcpk(gb)-3}$	–	–	$\lambda_{rcpk(gb)-3}$	–	–	$\lambda_{rcpk(gb)-3}$	-2.48E-06	0.00107	$\lambda_{rcpk(gb)-3}$	–	–
$\lambda_{rcpk(gb)-4}$	–	–	$\lambda_{rcpk(gb)-4}$	–	–	$\lambda_{rcpk(gb)-4}$	0.0009	0.000867	$\lambda_{rcpk(gb)-4}$	–	–
$\lambda_{rcpo(gb)-0}$	0.0028***	0.0009	$\lambda_{rcpo(gb)-0}$	0.0005	0.0008	$\lambda_{rcpo(gb)-0}$	-0.0004	0.000638	$\lambda_{rcpo(gb)-0}$	0.0021**	0.0006
$\lambda_{rcpo(gb)-1}$	-0.0004	0.0012	$\lambda_{rcpo(gb)-1}$	0.0003	0.0011	$\lambda_{rcpo(gb)-1}$	0.0029**	0.000964	$\lambda_{rcpo(gb)-1}$	–	–
$\lambda_{rcpo(gb)-2}$	0.0000	0.0011	$\lambda_{rcpo(gb)-2}$	0.0003	0.0011	$\lambda_{rcpo(gb)-2}$	0.0006	0.000964	$\lambda_{rcpo(gb)-2}$	–	–
$\lambda_{rcpo(gb)-3}$	0.0010	0.0011	$\lambda_{rcpo(gb)-3}$	0.0009	0.0010	$\lambda_{rcpo(gb)-3}$	0.0011	0.000782	$\lambda_{rcpo(gb)-3}$	–	–
$\lambda_{rcpo(gb)-4}$	-0.0007	0.0010	$\lambda_{rcpo(gb)-4}$	-0.0018*	0.0009	$\lambda_{rcpo(gb)-4}$	0.0001	0.000756	$\lambda_{rcpo(gb)-4}$	–	–
$\lambda_{rbe(ob)-0}$	0.0004	0.0014	$\lambda_{rbe(ob)-0}$	-0.0002	0.0013	$\lambda_{rbe(ob)-0}$	-0.0020	0.00136	$\lambda_{rbe(ob)-0}$	0.0016	0.0019
$\lambda_{rbe(ob)-1}$	-0.0023*	0.0013	$\lambda_{rbe(ob)-1}$	-0.0016	0.0015	$\lambda_{rbe(ob)-1}$	-0.0035**	0.00155	$\lambda_{rbe(ob)-1}$	-0.0040*	0.0022
$\lambda_{rbe(ob)-2}$	0.0007	0.0012	$\lambda_{rbe(ob)-2}$	0.0016	0.0013	$\lambda_{rbe(ob)-2}$	0.0006	0.00135	$\lambda_{rbe(ob)-2}$	0.0007	0.0021
$\lambda_{rbe(ob)-3}$	–	–	$\lambda_{rbe(ob)-3}$	–	–	$\lambda_{rbe(ob)-3}$	0.0017	0.00143	$\lambda_{rbe(ob)-3}$	-0.0006	0.0020
$\lambda_{rbe(ob)-4}$	–	–	$\lambda_{rbe(ob)-4}$	–	–	$\lambda_{rbe(ob)-4}$	-0.0001	0.00141	$\lambda_{rbe(ob)-4}$	0.0000*	0.0018
$\lambda_{rbn(ob)-0}$	–	–	$\lambda_{rbn(ob)-0}$	-0.0016	0.0013	$\lambda_{rbn(ob)-0}$	-0.0015	0.00138	$\lambda_{rbn(ob)-0}$	–	–
$\lambda_{rbn(ob)-1}$	–	–	$\lambda_{rbn(ob)-1}$	-0.0014	0.0016	$\lambda_{rbn(ob)-1}$	0.0007	0.00158	$\lambda_{rbn(ob)-1}$	–	–
$\lambda_{rbn(ob)-2}$	–	–	$\lambda_{rbn(ob)-2}$	-0.0014	0.0015	$\lambda_{rbn(ob)-2}$	-0.0024	0.00154	$\lambda_{rbn(ob)-2}$	–	–
$\lambda_{rbn(ob)-3}$	–	–	$\lambda_{rbn(ob)-3}$	0.0016	0.0012	$\lambda_{rbn(ob)-3}$	0.0008	0.00149	$\lambda_{rbn(ob)-3}$	–	–
$\lambda_{rbn(ob)-4}$	–	–	$\lambda_{rbn(ob)-4}$	–	–	$\lambda_{rbn(ob)-4}$	-0.0004	0.0013	$\lambda_{rbn(ob)-4}$	–	–
$\lambda_{rcpk(ob)-0}$	0.0009	0.0016	$\lambda_{rcpk(ob)-0}$	0.0024	0.0015	$\lambda_{rcpk(ob)-0}$	0.0021	0.00182	$\lambda_{rcpk(ob)-0}$	–	–
$\lambda_{rcpk(ob)-1}$	0.0013	0.0014	$\lambda_{rcpk(ob)-1}$	–	–	$\lambda_{rcpk(ob)-1}$	-0.0005	0.00189	$\lambda_{rcpk(ob)-1}$	–	–
$\lambda_{rcpk(ob)-2}$	–	–	$\lambda_{rcpk(ob)-2}$	–	–	$\lambda_{rcpk(ob)-2}$	-0.0001	0.00184	$\lambda_{rcpk(ob)-2}$	–	–
$\lambda_{rcpk(ob)-3}$	–	–	$\lambda_{rcpk(ob)-3}$	–	–	$\lambda_{rcpk(ob)-3}$	-0.0017	0.00186	$\lambda_{rcpk(ob)-3}$	–	–
$\lambda_{rcpk(ob)-4}$	–	–	$\lambda_{rcpk(ob)-4}$	–	–	$\lambda_{rcpk(ob)-4}$	-0.0017	0.00147	$\lambda_{rcpk(ob)-4}$	–	–
$\lambda_{rcpo(ob)-0}$	0.0004	0.0012	$\lambda_{rcpo(ob)-0}$	0.0015	0.0011	$\lambda_{rcpo(ob)-0}$	0.0001	0.00106	$\lambda_{rcpo(ob)-0}$	-0.0024*	0.0013
$\lambda_{rcpo(ob)-1}$	0.0000	0.0015	$\lambda_{rcpo(ob)-1}$	0.0010	0.0015	$\lambda_{rcpo(ob)-1}$	0.0004	0.00159	$\lambda_{rcpo(ob)-1}$	–	–
$\lambda_{rcpo(ob)-2}$	0.0021	0.0014	$\lambda_{rcpo(ob)-2}$	0.0023	0.0014	$\lambda_{rcpo(ob)-2}$	0.0042**	0.00164	$\lambda_{rcpo(ob)-2}$	–	–

$\lambda_{rcpo(ob)-3}$	-0.0012	0.0013	$\lambda_{rcpo(ob)-3}$	-0.0010	0.0012	$\lambda_{rcpo(ob)-3}$	-0.0005	0.00142	$\lambda_{rcpo(ob)-3}$	–	–
$\lambda_{rcpo(ob)-4}$	0.0001	0.0012	$\lambda_{rcpo(ob)-4}$	-0.0012	0.0012	$\lambda_{rcpo(ob)-4}$	-0.0042	0.00125	$\lambda_{rcpo(ob)-4}$	–	–
$\lambda_{rbe(ch)-0}$	0.0002	0.0009	$\lambda_{rbe(ch)-0}$	-0.0005	0.0008	$\lambda_{rbe(ch)-0}$	0.0147	0.00299	$\lambda_{rbe(ch)-0}$	-0.0011	0.0011
$\lambda_{rbe(ch)-1}$	0.0012	0.0009	$\lambda_{rbe(ch)-1}$	0.0001	0.0008	$\lambda_{rbe(ch)-1}$	0.0001	0.00102	$\lambda_{rbe(ch)-1}$	0.0007	0.0014
$\lambda_{rbe(ch)-2}$	-0.0014*	0.0008	$\lambda_{rbe(ch)-2}$	-0.0007	0.0007	$\lambda_{rbe(ch)-2}$	0.0011	0.00114	$\lambda_{rbe(ch)-2}$	-0.0001	0.0013
$\lambda_{rbe(ch)-3}$	–	–	$\lambda_{rbe(ch)-3}$	–	–	$\lambda_{rbe(ch)-3}$	-0.0015	0.00101	$\lambda_{rbe(ch)-3}$	-0.0007	0.0013
$\lambda_{rbe(ch)-4}$	–	–	$\lambda_{rbe(ch)-4}$	–	–	$\lambda_{rbe(ch)-4}$	-0.0005	0.00103	$\lambda_{rbe(ch)-4}$	-0.0001	0.0013
$\lambda_{rbn(ch)-0}$	–	–	$\lambda_{rbn(ch)-0}$	0.0017	0.0008	$\lambda_{rbn(ch)-0}$	0.0006	0.00106	$\lambda_{rbn(ch)-0}$	–	–
$\lambda_{rbn(ch)-1}$	–	–	$\lambda_{rbn(ch)-1}$	-0.0001	0.0009	$\lambda_{rbn(ch)-1}$	0.0010	0.00101	$\lambda_{rbn(ch)-1}$	–	–
$\lambda_{rbn(ch)-2}$	–	–	$\lambda_{rbn(ch)-2}$	-0.0005	0.0008	$\lambda_{rbn(ch)-2}$	-0.0002	0.00113	$\lambda_{rbn(ch)-2}$	–	–
$\lambda_{rbn(ch)-3}$	–	–	$\lambda_{rbn(ch)-3}$	-0.0004	0.0007	$\lambda_{rbn(ch)-3}$	0.0001	0.00113	$\lambda_{rbn(ch)-3}$	–	–
$\lambda_{rbn(ch)-4}$	–	–	$\lambda_{rbn(ch)-4}$	–	–	$\lambda_{rbn(ch)-4}$	0.0006	0.00105	$\lambda_{rbn(ch)-4}$	–	–
$\lambda_{rcpk(ch)-0}$	0.0009	0.0011	$\lambda_{rcpk(ch)-0}$	0.0006	0.0008	$\lambda_{rcpk(ch)-0}$	-0.0001	0.000958	$\lambda_{rcpk(ch)-0}$	–	–
$\lambda_{rcpk(ch)-1}$	0.0001	0.0010	$\lambda_{rcpk(ch)-1}$	–	–	$\lambda_{rcpk(ch)-1}$	0.0022	0.0014	$\lambda_{rcpk(ch)-1}$	–	–
$\lambda_{rcpk(ch)-2}$	–	–	$\lambda_{rcpk(ch)-2}$	–	–	$\lambda_{rcpk(ch)-2}$	-0.0008	0.0014	$\lambda_{rcpk(ch)-2}$	–	–
$\lambda_{rcpk(ch)-3}$	–	–	$\lambda_{rcpk(ch)-3}$	–	–	$\lambda_{rcpk(ch)-3}$	0.0005	0.00135	$\lambda_{rcpk(ch)-3}$	–	–
$\lambda_{rcpk(ch)-4}$	–	–	$\lambda_{rcpk(ch)-4}$	–	–	$\lambda_{rcpk(ch)-4}$	-0.0004	0.00136	$\lambda_{rcpk(ch)-4}$	–	–
$\lambda_{rcpo(ch)-0}$	0.0020**	0.0007	$\lambda_{rcpo(ch)-0}$	-0.0003	0.0006	$\lambda_{rcpo(ch)-0}$	-0.0004	0.0011	$\lambda_{rcpo(ch)-0}$	0.0022**	0.0009
$\lambda_{rcpo(ch)-1}$	-0.0009	0.0010	$\lambda_{rcpo(ch)-1}$	-0.0008	0.0009	$\lambda_{rcpo(ch)-1}$	-9.57E-06	0.000799	$\lambda_{rcpo(ch)-1}$	–	–
$\lambda_{rcpo(ch)-2}$	-0.0002	0.0010	$\lambda_{rcpo(ch)-2}$	0.0002	0.0009	$\lambda_{rcpo(ch)-2}$	-0.0015	0.00119	$\lambda_{rcpo(ch)-2}$	–	–
$\lambda_{rcpo(ch)-3}$	0.0009	0.0009	$\lambda_{rcpo(ch)-3}$	0.0009	0.0007	$\lambda_{rcpo(ch)-3}$	0.0003	0.00122	$\lambda_{rcpo(ch)-3}$	–	–
$\lambda_{rcpo(ch)-4}$	-0.0003	0.0008	$\lambda_{rcpo(ch)-4}$	-0.0021	0.0007	$\lambda_{rcpo(ch)-4}$	0.0007	0.00102	$\lambda_{rcpo(ch)-4}$	–	–
d_{gb1}	-0.0049	0.0040	d_{gb1}	0.0048	0.0038	d_{gb1}	0.0008	0.003	d_{gb1}	0.0081**	0.0033
d_{gb2}	0.0052	0.0037	d_{gb2}	0.0053	0.0036	d_{gb2}	0.0050*	0.00269	d_{gb2}	0.0086**	0.0033
d_{gb3}	0.0079	0.0034	d_{gb3}	0.0095**	0.0034	d_{gb3}	0.0060**	0.00236	d_{gb3}	0.0121***	0.0028
d_{ob1}	0.0112	0.0046	d_{ob1}	-0.0011	0.0050	d_{ob1}	0.0003	0.0048	d_{ob1}	0.0132**	0.0060
d_{ob2}	0.0139	0.0047	d_{ob2}	0.0087**	0.0046	d_{ob2}	0.0017	0.0044	d_{ob2}	0.0251***	0.0062
d_{ob3}	0.0135	0.0041	d_{ob3}	0.0045	0.0045	d_{ob3}	0.0009	0.0039	d_{ob3}	0.0135**	0.0050
d_{ch1}	0.0141	0.0031	d_{ch1}	0.0139***	0.0028	d_{ch1}	0.0147***	0.00374	d_{ch1}	0.0120**	0.0041
d_{ch2}	0.0071	0.0031	d_{ch2}	0.0060**	0.0024	d_{ch2}	0.0125***	0.00334	d_{ch2}	0.0094**	0.0040
d_{ch3}	0.0111	0.0027	d_{ch3}	0.0139***	0.0024	d_{ch3}	0.0147***	0.00299	d_{ch3}	0.0136***	0.0035
$\rho_{gb, gb}$	-0.9821***	0.2266	$\rho_{gb, gb}$	-0.3047**	0.1131	$\rho_{gb, gb}$	-1.1878***	0.1963	$\rho_{bf, bf}$	0.2733	0.2550
$\rho_{gb, ob}$	0.1897	0.1143	$\rho_{ob, ob}$	-0.2212	0.1701	$\rho_{gb, ob}$	-0.0420	0.0893	$\rho_{bf, ch}$	0.1694**	0.0713
$\rho_{gb, ch}$	0.9327***	0.2255	$\rho_{ch, ch}$	-0.6743***	0.1061	$\rho_{gb, ch}$	0.5737***	0.1688	$\rho_{bf, pk}$	-0.4792**	0.2024
$\rho_{ob, gb}$	0.2450	0.2878				$\rho_{ob, gb}$	1.4612***	0.3548	$\rho_{ch, bf}$	-1.8613**	0.5627
$\rho_{ob, ob}$	-0.8276***	0.1408				$\rho_{ob, ob}$	-0.5624***	0.157	$\rho_{ch, ch}$	-0.9429***	0.1614
$\rho_{ob, ch}$	-0.7246**	0.2818				$\rho_{ob, ch}$	-1.4608***	0.2985	$\rho_{ch, pk}$	0.5364	0.4542
$\rho_{ch, gb}$	-0.5922**	0.1873				$\rho_{ch, gb}$	-0.8282**	0.2487	$\rho_{pk, bf}$	1.1412***	0.3270
$\rho_{ch, ob}$	0.3241**	0.0943				$\rho_{ch, ob}$	0.2212*	0.1121	$\rho_{pk, ch}$	0.2780***	0.0946
$\rho_{ch, ch}$	0.1531	0.1877				$\rho_{ch, ch}$	0.0466	0.2172	$\rho_{pk, pk}$	-1.0119***	0.2650
R^2 gb	0.9643		R^2 gb	0.9510		R^2 gb	0.9830		R^2 gb	0.9686	
R^2 ob	0.9660		R^2 ob	0.9792		R^2 ob	0.9845		R^2 ob	0.9604	
R^2 ch	0.9546		R^2 ch	0.9681		R^2 ch	0.9860		R^2 ch	0.9559	
B-P Test gbf	17.8400		B-P Test gbf	20.8400		B-P Test gbf	24.8600		B-P Test gbf	16.6400	
B-P Test obf	12.2000		B-P Test obf	21.4800		B-P Test obf	31.8100		B-P Test obf	20.8600	
B-P Test ch	13.8800		B-P Test ch	23.0900		B-P Test ch	26.5500		B-P Test ch	9.0400	

Note: gbf, obf, ch, and om indicate ground beef, other beef, chicken, and other meat, respectively. One, double, and triple asterisks (*, **, ***) mean statistical significance at 10%, 5%, and 1% levels.The lambdas are the estimated coefficients of FSIS food recall lags. For example, $\lambda_{rbe(gbf)-0}$ and $\lambda_{rbe(gbf)-1}$ indicate the estimated effect of beef *E. coli* recalls on ground beef demand with lag period zero and one, respectively.

Table A2.5 Summary of the Pairwise Hypothesis Tests and Key Findings

A: Meat Separable Model (Model 1)

Tests for Model 1	Key findings
	H_0: the effects of food Safety recall do not have regional heterogeneity
CA vs GL	Pork recalls have different effects on the demand of beef, pork, and turkey between CA and GL in the short run; Poultry recalls have different effects on beef demand in the long run
CA vs MS	Pork recalls have different effects on beef, pork, and turkey demand between CA and MS in the short run
CA vs NE	Pork recalls have different effects on pork demand between CA and NE in the short run
CA vs PL	Poultry recalls have different effects on pork demand between CA and PL in the short run
CA vs SC	Poultry recalls have different effect on all meat demand in the short run between CA and SC; Beef *E. coli* Recalls have different effects on beef, chicken, and turkey demand in the long run
CA vs SE	Pork recalls have different effects on beef, pork, and turkey demand between CA and SE in the short run; Beef *E. coli* recalls have different short run effects on chicken demand
CA vs WT	Beef non-*E. coli* recalls have different effects on pork demand between CA and WT in the short run
GL vs MS	Pork recalls have different effects on chicken demand between GL and MS in the short run
GL vs NE	Pork recalls have different effects on turkey demand between GL and NE in both short and long run
GL vs PL	Pork recalls have different effects on beef demand in the short run and different effect on pork demand in the long run between GL and PL
GL vs SC	Beef *E. coli* recalls have different effects on beef demand between GL and SC in the short run; Beef non-*E. coli* recalls have different effects on the demand for beef, chicken and turkey in the long run.
GL vs SE	Beef *E. coli* recalls have different effects on beef demand between GL and SE
GL vs WT	The null hypothesis cannot be rejected. No regional differences between GL and WT
MS vs NE	Beef non-*E. coli* recalls have different effects on chicken demand between MS and NE
MS vs PL	Pork recalls have different effects on chicken demand in the short run between MS and PL; Beef non-*E. coli* recalls have different effects on beef demand in the long run
MS vs SC	Beef non-*E. coli* recalls have different effects on the demand of beef, chicken and turkey between MS and SC in the long run
MS vs SE	Pork recalls have different long-run effects on the demand for pork and turkey between MS and SE in the long run
MS vs WT	Beef non-*E. coli* recalls have different effects on pork demand between MS and WT in the short run
NE vs PL	Poultry recalls have different effects on pork demand between NE and PL in both short- and long-run
NE vs SC	Beef non-*E. coli* recalls have different effects on the demand for beef, chicken, and turkey between NE and SC in the long run
NE vs SE	Beef non-*E. coli* recalls have different effects on the demand for beef and turkey between NE and SE in both short- and long-run
NE vs WT	The long-run effects of beef non-*E. coli* recall on beef are different between NE and WT
PL vs SC	Beef non-*E. coli* recalls have different long-run effects on chicken demand between PL and SC
PL vs SE	The short-run Beef *E. coli* recalls effects are different on chicken demand between PL and SE
PL vs WT	The long-run effects of beef non-*E. coli* recalls on beef demand are different between PL and WT
SC vs SE	The long-run effects of beef *E. coli* recalls on beef demand are different between SC and SE
SC vs WT	Beef *E. coli* recalls have different effects on beef demand between SC and WT in the long run
SE vs WT	The long-run effects of beef non-*E. coli* recalls on pork demand are different between SE and WT
	H_0: the effects of food safety recalls are same in both short- and long run(SR vs LR) in the same region
Beef *E. coli* recalls	Reject same SR and LR effects on the demand for beef, chicken, and turkey in PL and SC
Beef non-*E. coli* recalls	Reject same SR and LR effects on beef demand in PL and SC; Reject same SR and LR effects on turkey demand in NE, PL, and SC
Pork recalls	Reject same SR and LR effects on pork demand in CA, GL, and NE
Poultry recalls	Reject same SR and LR effects on turkey demand in NE

(Table A2.5 continued)

B: Meat Separable Model with Ground Beef Specification (Model 2)

Tests for Model 2	Key findings
	***H_0*: the effects of food Safety recall do not have regional heterogeneity**
CA vs GL	The null hypothesis cannot be rejected. No regional differences between CA and GL
CA vs MS	Beef *E. coli* recalls have different effects on other beef demand between CA and MS in the short run
CA vs NE	The null hypothesis cannot be rejected. No regional differences between CA and NE
CA vs PL	Poultry recalls have different effects on poultry demand between CA and PL in the short run; Pork recall have different long-run effects on demand for ground beef, other beef, and chicken
CA vs SC	The null hypothesis cannot be rejected. No regional differences between CA and SC
CA vs SE	Beef *E. coli* recalls have different effects on other beef demand between CA and SE in the short run; Pork recalls have different long-run effects on ground beef, other beef, and chicken demand
CA vs WT	Poultry recalls have different effects on ground beef and chicken demand between CA and WT in the short run
GL vs MS	Beef *E. coli* recalls have different effects on other beef demand between GL and MS in the short run
GL vs NE	The null hypothesis cannot be rejected. No regional differences between GL and NE
GL vs PL	The null hypothesis cannot be rejected. No regional differences between GL and PL
GL vs SC	The null hypothesis cannot be rejected. No regional differences between GL and SC
GL vs SE	Beef *E. coli* recalls have different effects on other beef and other meat demand between GL and SE
GL vs WT	The null hypothesis cannot be rejected. No regional differences between GL and WT
MS vs NE	Beef *E. coli* recalls have different effects on other meat demand between MS and NE in the short run
MS vs PL	Beef *E. coli* recalls have different effects on other beef demand between MS and PL in the short run
MS vs SC	Poultry recalls have different effects on other beef demand between MS and SC in the long run
MS vs SE	The null hypothesis cannot be rejected. No regional differences between MS and SE
MS vs WT	Beef *E. coli* recalls have different effects on other beef demand between MS and WT in the short run
NE vs PL	The null hypothesis cannot be rejected. No regional differences between NE and PL
NE vs SC	The null hypothesis cannot be rejected. No regional differences between NE and SC
NE vs SE	Beef *E. coli* recalls have different effects, respectively, on the demand for ground beef between NE and SE in the short- and long-run
NE vs WT	The short-run effects of beef *E. coli* recall on ground beef are different between NE and WT
PL vs SC	Poultry recalls have different long-run effects on the demand for ground beef, chicken, and other meat between PL and SC
PL vs SE	The long-run Beef *E. coli* recalls effects are different on ground beef demand between PL and SC
PL vs WT	The short-run effects of poultry recalls on the demand for other beef and other meat are different between PL and WT
SC vs SE	The null hypothesis cannot be rejected. No regional differences between SC and SE
SC vs WT	Poultry recalls have different effects on the demand for ground beef, other beef, and chicken between SC and WT in the short run
SE vs WT	Beef *E. coli* recalls have different effects on other beef demand between NE and SE in the short run
	***H_0*: the effects of food safety recalls are same in both short- and long run(SR vs LR) in the same region**
Beef *E. coli* recalls	Cannot reject the null hypothesis
Beef non-*E. coli* recalls	Reject same SR and LR effects on chicken demand in MS
Pork recalls	Reject same SR and LR effects on the demand for ground beef, other beef, and chicken in CA
Poultry recalls	Reject same SR and LR effects on chicken demand in MS; Reject same SR and LR effects on ground beef demand in SE

Chapter 3 - Determinants of Red Meat Trade: the Role of SPS Measures

Section 1 Introduction

1.1 Situation

Global red meat consumption has been gradually increasing for decades, driven by rising incomes and populations as well as productivity growth of meat production (Jones *et al*., 2013). Emerging markets such as China and other developing countries have growing demand and great purchasing power in the global red meat market. For example, the United States Department of Agriculture (USDA) indicates that the continuation of China's economic growth and urbanization will raise the per capita meat consumptions to 65 kilograms by 2023/24. Correspondingly, Chinese meat imports like pork are projected to rise from 750,000 metric tons to 1.2 million metric tons (Hansen and Fred, 2014). Such escalated demands in international red meat and livestock markets provide meat exporters with great opportunities to expand their livestock and meat production.

However, extraordinary changes also continue in international red meat markets. Food safety issues have increased consumers' and producers' awareness of external effects associated with trade in agricultural products (Schlueter *et al*., 2009). Various sanitary and phytosanitary (SPS) measures often with food safety stated goals have been widely applied by members of the World Trade Organization (WTO) to ensure food safety and to prevent the spread of diseases and pests among animals, animal products, and plants. Since the condition of food safety hazard and preferences differ for each exporting and importing country, the desired level and the benchmark of SPS measures may also vary across countries (Li, 2014). As a consequence, meat exporters might have difficulties in meeting the diverse safety regimes in both domestic and international markets. Such differences in food safety standards and regulations can be substantial across different importers and exporters (Baylis *et al*., 2011).

Despite the substantial body of studies analyzing the impacts of SPS measures on agricultural and food trade, little is known about the determinants of red meat international market as well as the impacts of SPS regulations on trade values. Research about SPS measures on meat trade is essential. On one side, these measures may be necessary for importers to improve the market benefits of consumer confidence in safer products by providing desired health and safety levels (Wilson and Anton, 2006). On the other hand, red meat trade can be affected by SPS measures by increasing costs for both importers and exporters potentially. For example, the imposition of SPS standards may raise the costs of foreign supplies and prohibit imports from countries which lack adequate regulatory infrastructure (Li, 2004). However, a substantial knowledge gap still exists on the specific trade impacts of different regulatory instruments on red meat trade.

Although SPS standards and regulations raise the costs of foreign supplies relative to domestic production and conventionally act as “trade barriers” in the literature, the trade impacts of those regulations are not always negative (Anders and Caswell, 2009; Schlueter *et al*., 2009). Strict food safety restrictions on exports may push meat suppliers to implement high standard inspection systems and update production facilities with advanced food safety standards, which increase producer efficiency and maintain consumer confidence in the long run. Under this condition, such safe and healthy efforts could behave like “catalysts” and result in positive trade impacts (Schlueter *et al*., 2009). It is the balance of these trade costs and the potential “catalysts” of red meat products among countries that makes the estimations of SPS measures controversial in empirical studies.

Meat products are exposed to a great number of market failures (Schlueter *et al*., 2009), which could be a good example of market intervention (Koo *et al*. 1994). This research examines the impacts of SPS measures on trade flows and investigate the determinants of red meat trade. We examine how different SPS regulations imposed to achieve a desired level of SPS goals in a country have diverse trade effects. This provides necessary information to the meat industry and policy makers. Manually counted frequency data on SPS measures from 1997 to 2013 is compiled and used in multiple empirical models in this study. Also, unlike previous literature (Koo *et al*. 1994; Schlueter *et al*., 2009), we estimate the effects of SPS regulations on both aggregated meat products and specific meat products respectively and examine the robustness across models.

The potential spillover effects on red meat trade are another focus in this study. Considering the diverse SPS regulations across beef and pork, such spillover effects can be classified into two categories: the effects of the different SPS regulations across different meat products (beef and pork), and the product-specific spillovers on industry level. For instance, it is hypothesized that the imposition of SPS on pork (or beef) may have positive or negative effects on aggregated beef (or pork) trade flows. We conduct a myriad of tests via multiple estimations and detect if the corresponding spillover effects exist in the empirical models.

Gravity equation models are widely used to provide evidence for agricultural products on the trade impacts of distance, importer and exporter production, free trade agreements, and other regulatory measures (Orden *et al*., 2002; Disdier *et al*., 2008; Anders and Caswell, 2009; Schlueter *et al*., 2009; Jayasnghe *et al*., 2010; Sun and Reed, 2010; Xiong and Beghin; 2012).

Following previous research, the current study adopts a series of gravity equations and evaluate relevant SPS instruments applied in the red meat sector. To be specific, by disaggregating the SPS regulations into specific goals, we examine various effects of SPS measures related to animal health, human health, and maximum residue limits (MRLs) on red meat trade values. In addition, since econometric problems such as heteroscedasticity and the presence of zero usually are associated with gravity equation models, we concentrate on several econometric estimators and compare the sensitivity of the related gravity equation parameters across different model specifications.

1.2 Objectives

The overall objective of this study is to provide an *ex post* econometric examination of SPS measures and their influences on the trade of red meat. Meanwhile, the specific objectives are fourfold. First, we determine and classify the reasonable estimators for the regression of gravity equations. Second, we compare and identify the appropriate model specifications for multiple red meat gravity equations grouped by Harmonized System (HS) codes. Third, we check the robustness of certain estimators with diverse percentage of zeros in dependent variables. Fourth, we test the potential spillover effects across red meat products and industries.

The current study fills several knowledge gaps and addresses the following questions: 1) which factors determine the red meat international trade from among a presumably relevant factors including importer's GDP per capita, importer's production, exporter's production, transportation cost, free trade agreements, and SPS regulations; 2) do the spillover effects of SPS regulations and meat supply really exist across the trade of red meat products (between beef and pork) and industry levels?. One important feature of our model set-up is that the model is red meat in intermediate demand rather than final demand. Red meat data in this study is at the level of HS four-digit data (HS 0201, HS 0202, and HS 0203).

1.3 Organization of This Chapter

This chapter is organized into the following sections. The second section outlines the background information about red meat trade and SPS agreements. The literature and methodology reviews of relevant trade studies are organized in the third section. The fourth section specifies the research methods as well as the data description. Within this section, the strategies of model specification and model selection are also discussed. The fifth section reports the associated results from different model specifications and examines the robustness of the main results. The sixth section estimates and discusses the spillover effects across the industry levels and examines the SPS impacts on the U.S. red meat exports.

Section 2 Background of Red Meat Market

This section provides an overview of the background information about red meat trade and SPS measures. Red meat in the current study refers to beef and pork. In this section, the development and forecasting of red meat production, imports, and exports are discussed based on historical data from 1997 to 2013. Also, the history and roles of SPS measures are covered in the last subsection.

2.1 International Beef Market and Trade

Table 3.1 (A and B) lists the top fifteen beef producers in the world from 1997 to 2013, based on volume data from USDA Foreign Agricultural Service (USDA/FAS) and Food and Agriculture Organization of the United Nations (FAOSTAT). The total volume of beef production from these top fifteen countries accounts for 80%-85% of world total beef production (Table 3.1 B). So it is obvious that these fifteen countries dominate world total beef production. As shown in Figure 3.1, both the world and the top fifteen beef producers' productions have expanded steadily over the past decades. World beef production increased from 54.6 million metric tons in 1997 to 63.98 million metric tons in 2013. Correspondingly, the beef production of the top fifteen producers increased from 45.49 million metric tons in 1997 to 52.96 million metric tons in 2013. Specifically, although U.S. beef production significantly decreased after the outbreak of BSE (Bovine Spongiform Encephalopathy) in December 2003, the U.S. is still the world's largest beef producer, accounting for almost 20% of total world beef production on average. According to USDA Foreign Agricultural Services (USDA/FAS), the U.S. production is expected to rise in 2016 as cattle inventories recover on improved pasture conditions and lower feed costs (USDA/FAS, 2015). Brazil is the second-largest beef producer during the same period. The USDA/FAS forecasts that continuing herd expansion will drive beef production higher for major traders, particularly the U.S., India, Argentina, and Brazil (USDA/FAS, 2015).

International beef exports have a different condition. Within the top fifteen beef producers, the countries like China, Colombia, Kazakhstan, and Russia are not major beef exporters. This suggest that most of their beef production are for domestic consumption. Table 3.2 (A and B) shows export volume of the eleven selected major beef exporters in the world market, using the data from USDA/FAS and the Global Trade Atlas® (GTA). In general, the total volume of beef exports from the eleven major exporters constitutes over 90% of total beef exports in the world market. Figure 3.2 demonstrates the trends of world beef exports versus the exports from the eleven major beef exporters. Although the volumes declined in 2008 and 2009, beef exports overall keep an upward tendency. Australia was the largest beef exporter before 2004 and accounted for over 20% of total beef exports in the world. However, Brazil then was ranked as the number one beef exporter after 2004, except 2011, and covered about 22.6% of total volume on average. The volume of India beef (meat from water buffalo[15]) exports expands rapidly with about 14% annual rate (Table 3.2 A and Figure 3.3) between 2000 and 2013, where the share of total world exports raises from only 3.7% in 1997 to 19.3% in 2013. India has moved ahead of Brazil to become the world's largest beef exporter in 2014, and are expected to lead major exporters with about 6% annual growth during 2015 to 2025 (Westcott and Hansen, 2015). Because India beef (water buffalo meat) is chewier and cheaper, developing regions like Southeast Asia, the Middle East, and North Africa will remain huge demand centers for India beef (USDA/FAS, 2015). The outbreak of BSE made the U.S. beef exports hit the historical low

[15] USDA classifies water buffalo (a member of the bovine family) meat as beef. Cows are revered in Hindu culture and the restrictions on cattle slaughter apply in most states in India.

and altered the U.S. beef export patterns in 2004. After that, U.S. beef exports started to rebound as the reopening of the Japanese and Korean markets in 2008. In 2014, the volume of Japan beef imports represented over 20% of all U.S. beef exports (Muhammad *et al*., 2016). So far, however, U.S beef are still banned in some countries like China (BSE) and European Union (beef hormones).

Table 3.3 (A and B) lists the eleven selected major beef importers in the world beef market from 1997 to 2013. Generally speaking, these eleven countries and regions absorb 70%-80% of these worldwide imports (Table 3.3 B). As shown in Figure 3.4, the volume of the eleven importers had significant variation during this period which may be based on many factors such as income, domestic and international beef prices, SPS regulations imposed by importers, and other related policies. While the U.S., Russia, and Japan (Table 3.3 B and Figure 3.5) are the top three importers for beef on average, they have diverse import sources. For example, according to USDA/ERS, Canada, Australia, and New Zealand remains the most important suppliers of beef to the United States. Most of the beef imported from Australia and New Zealand goes into processed products such as ground beef (USDA/ERS). Russia beef imports have been uneven during the same period with Brazil, Paraguay, and the countries of Eastern Europe being the major beef suppliers. In 2014, in response to geopolitical dispute centering on Ukraine, Russia banned agricultural and food imports from many countries including the U.S., European Union, Norway, Canada, and Australia (Liefert and Liefert, 2015). Japan is the third largest beef importer in the world. Its primary sources of imported beef are the U.S. and Australia, which accounted for nearly 90% of beef imports in both quantity and value (Muhammad *et al*., 2016). The U.S. covered 38.2% of quantity in 2014, which has steadily rebounded since 2004 to 2006 when Japan banned imports of U.S. beef in response to BSE outbreak (Muhammad *et al*., 2016).

Japan resumed its position as the largest U.S. beef importers in 2014 (USDA/FAS, 2015). Overall, world beef imports are expected to continue expanding with the growing appetite for beef in developing countries. In this research, we capture the trade values of major beef importers and other important traders which account for over 80% beef imports worldwide.

Figure 3.1: World and Top 15 Beef Producers' Production, 1997-2013

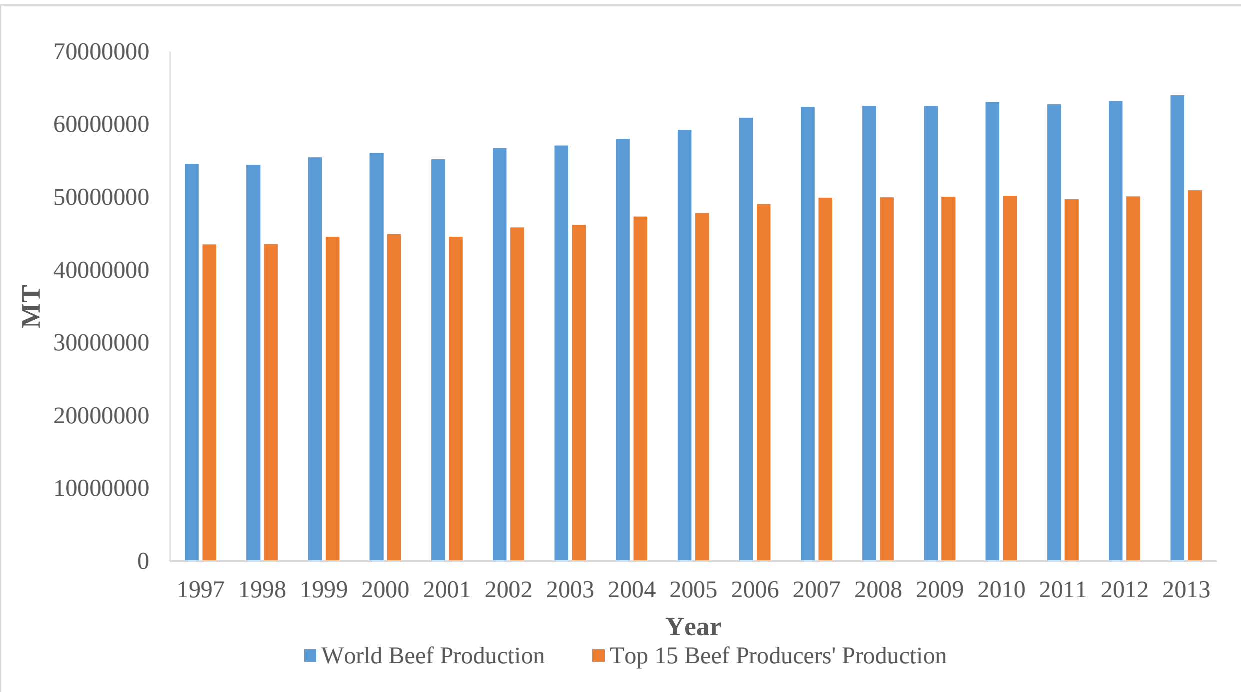

Figure 3.2: World and Eleven Major Beef Exporters' Exports, 1997-2013

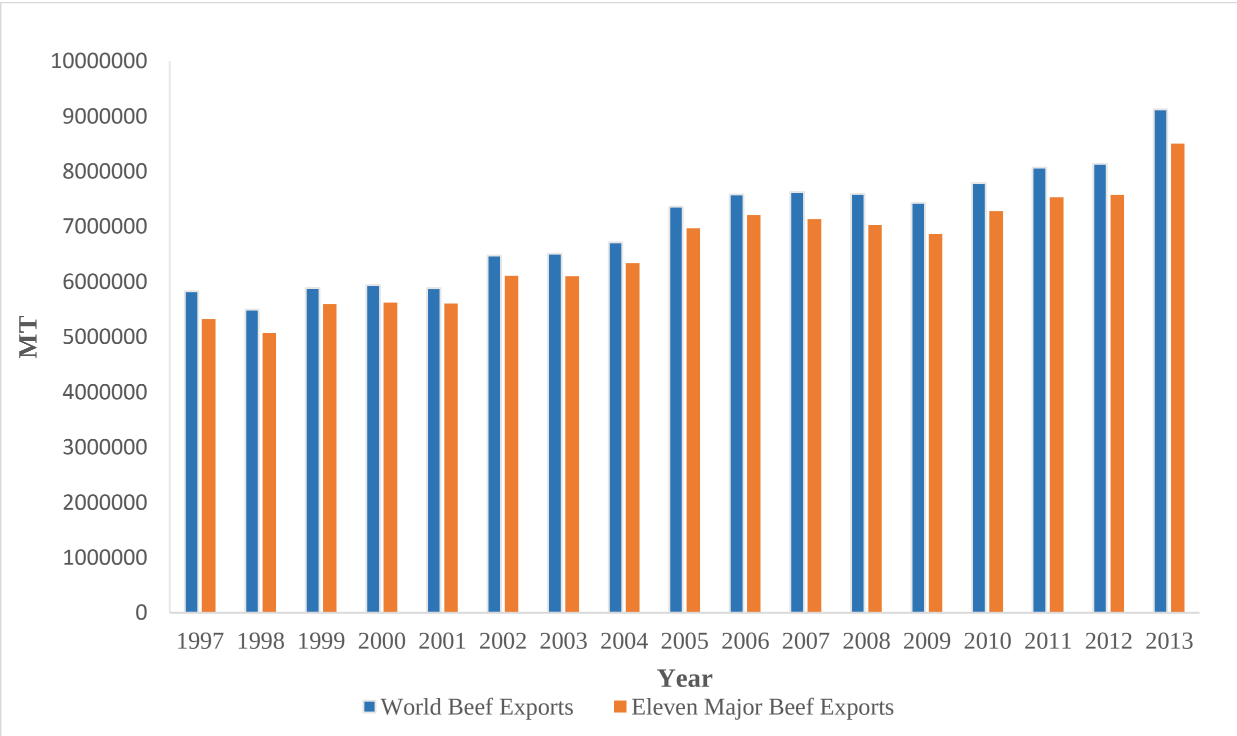

Figure 3.3: Eleven Major Beef Exporters' Exports (Country Specific Exports), 1997-2013

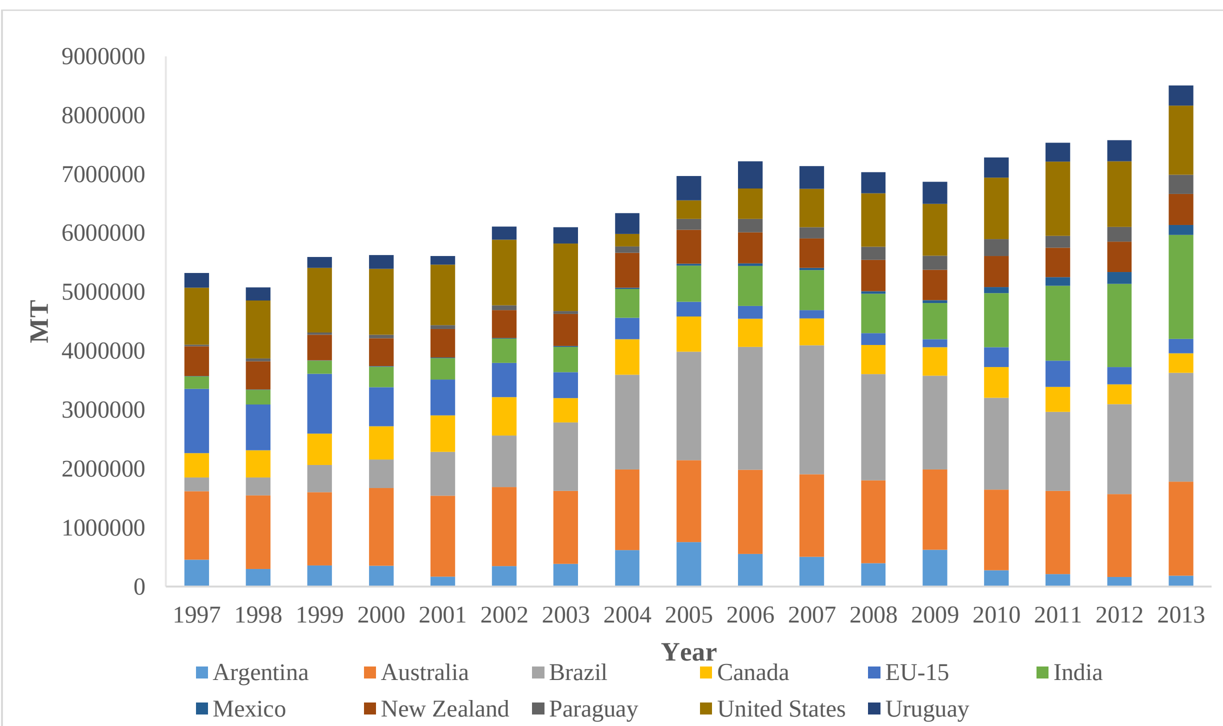

Figure 3.4: World and Eleven Major Beef Importers' Imports, 1997-2013

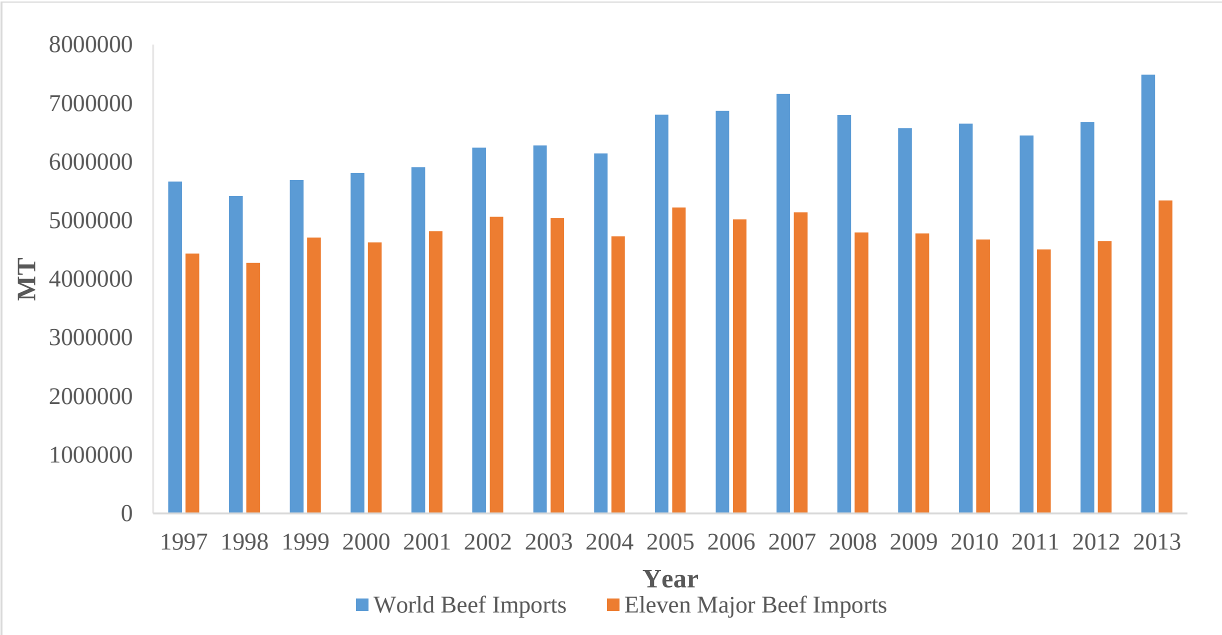

Figure 3.5: Eleven Major Beef Importers' Imports (Country Specific Exports, 1997-2013)

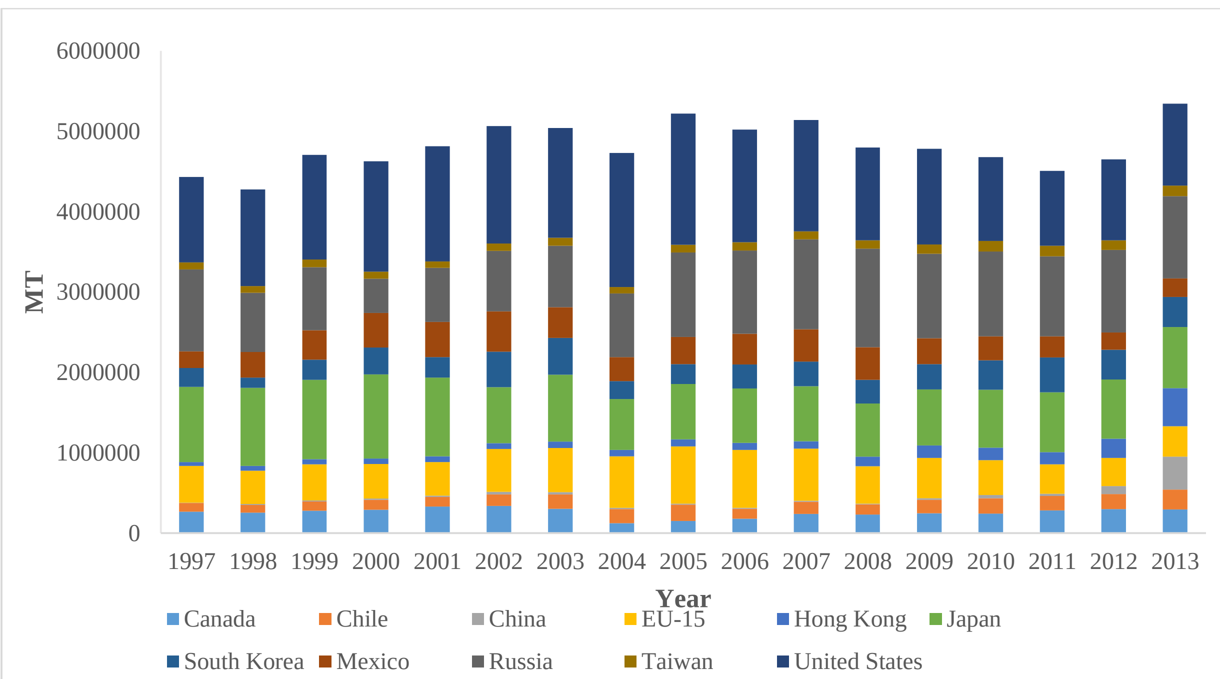

Table 3.1: Top 15 Major Beef Producers and Production, 1997-2013

Table 3.1 (A): Beef Production of Top 15 Major Producers (Unit: 1000 Metric Tons)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Argentina	2975	2600	2840	2880	2640	2700	2800	3130	3200	3100	3300	3150	3380	2620	2530	2620	2850
Australia	1942	1989	1956	2053	2079	2090	1998	2113	2090	2188	2169	2138	2106	2129	2129	2152	2359
Brazil	6050	6140	6270	6520	6895	7240	7385	7975	8592	9025	9303	9024	8935	9115	9030	9307	9675
Canada	1089	1182	1264	1263	1262	1298	1204	1500	1470	1329	1278	1304	1239	1276	1141	1060	1049
China	4409	4799	5054	5131	5086	5219	5425	5604	5681	5767	6134	6132	6355	6531	6475	6623	6730
Colombia	680	745	705	734	682	638	642	717	792	827	856	917	810	767	821	854	848
EU15	7889	7624	7679	7432	7360	7473	7366	7430	7235	7293	7338	7237	7106	7302	7234	6935	6654
India	1100	1350	1450	1525	1650	1810	1960	2170	2225	2450	2490	2700	2950	3125	3308	3491	3800
Kazakhstan	493	348	344	306	288	296	312	330	345	370	384	400	400	407	393	374	384
Mexico	1795	1800	1900	1900	1925	1725	1950	1900	1725	1550	1600	1667	1705	1745	1804	1821	1807
New Zealand	651	605	570	581	577	588	681	697	661	648	607	644	623	642	601	624	620
Paraguay	226	231	246	239	242	262	285	325	370	400	380	450	500	490	380	460	510
Russia	2010	1890	1740	1595	1580	1650	1680	1640	1520	1450	1430	1490	1460	1435	1360	1380	1380
United States	11714	11804	12124	12298	11983	12427	12039	11261	11318	11980	12097	12163	11891	12046	11983	11848	11751
Uruguay	468	454	425	440	317	425	450	544	600	640	560	535	580	530	510	530	525
Top 15 Total	45489	45560	46567	46898	46568	47844	48181	49341	49830	51024	51934	51960	52050	52171	51711	52092	52956
World Total	54580	54428	55437	56066	55178	56740	57096	58015	59246	60923	62408	62518	62525	63071	62746	63177	63984

Source: USDA/FAS and FAOSTAT

Notes: “Top 15 Total” refers to the total amount of beef production from the top 15 beef producers; “World Total” refers to the total amount of beef production in the world.

Table 3.1 (B): The Global Shares of Beef Production of Top 15 Major Producers

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Argentina	0.055	0.048	0.051	0.051	0.048	0.048	0.049	0.054	0.054	0.051	0.053	0.050	0.054	0.042	0.040	0.041	0.045
Australia	0.036	0.037	0.035	0.037	0.038	0.037	0.035	0.036	0.035	0.036	0.035	0.034	0.034	0.034	0.034	0.034	0.037
Brazil	0.111	0.113	0.113	0.116	0.125	0.128	0.129	0.137	0.145	0.148	0.149	0.144	0.143	0.145	0.144	0.147	0.151
Canada	0.020	0.022	0.023	0.023	0.023	0.023	0.021	0.026	0.025	0.022	0.020	0.021	0.020	0.020	0.018	0.017	0.016
China	0.081	0.088	0.091	0.092	0.092	0.092	0.095	0.097	0.096	0.095	0.098	0.098	0.102	0.104	0.103	0.105	0.105
Colombia	0.012	0.014	0.013	0.013	0.012	0.011	0.011	0.012	0.013	0.014	0.014	0.015	0.013	0.012	0.013	0.014	0.013
EU15	0.145	0.140	0.139	0.133	0.133	0.132	0.129	0.128	0.122	0.120	0.118	0.116	0.114	0.116	0.115	0.110	0.104
India	0.020	0.025	0.026	0.027	0.030	0.032	0.034	0.037	0.038	0.040	0.040	0.043	0.047	0.050	0.053	0.055	0.059
Kazakhstan	0.009	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Mexico	0.033	0.033	0.034	0.034	0.035	0.030	0.034	0.033	0.029	0.025	0.026	0.027	0.027	0.028	0.029	0.029	0.028
New Zealand	0.012	0.011	0.010	0.010	0.010	0.010	0.012	0.012	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Paraguay	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.006	0.006	0.007	0.006	0.007	0.008	0.008	0.006	0.007	0.008
Russia	0.037	0.035	0.031	0.028	0.029	0.029	0.029	0.028	0.026	0.024	0.023	0.024	0.023	0.023	0.022	0.022	0.022
United States	0.215	0.217	0.219	0.219	0.217	0.219	0.211	0.194	0.191	0.197	0.194	0.195	0.190	0.191	0.191	0.188	0.184
Uruguay	0.009	0.008	0.008	0.008	0.006	0.007	0.008	0.009	0.010	0.011	0.009	0.009	0.009	0.008	0.008	0.008	0.008
Top 15 Total	0.833	0.837	0.840	0.836	0.844	0.843	0.844	0.850	0.841	0.838	0.832	0.831	0.832	0.827	0.824	0.825	0.828

Source: Author's calculations

Table 3.2: Eleven Major Beef Exporters and Exports, 1997-2013

Table 3.2 (A): Beef Exports of Eleven Major Exporters (Unit: 1000 Metric Tons)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Argentina	454	300	355	354	168	345	382	616	754	552	505	396	621	277	213	164	186
Australia	1165	1247	1249	1316	1376	1343	1241	1369	1388	1430	1400	1407	1364	1368	1410	1407	1593
Brazil	231	304	461	488	741	872	1162	1610	1845	2084	2189	1801	1596	1558	1340	1524	1849
Canada	412	461	530	563	619	657	413	603	596	477	457	494	480	523	426	335	332
EU-15	1092	780	1018	663	610	581	439	361	248	220	140	201	139	336	445	296	244
India	215	245	220	344	365	411	432	492	617	681	678	672	609	917	1268	1411	1765
Mexico	6	6	8	12	10	10	12	19	32	39	42	42	51	103	148	200	166
New Zealand	501	479	434	473	483	475	548	594	577	530	496	533	514	530	503	517	529
Paraguay	28	50	37	58	62	80	48	109	180	224	194	222	243	283	197	251	326
United States	969	985	1094	1120	1029	1110	1142	209	316	519	650	905	878	1043	1263	1112	1174
Uruguay	251	218	189	236	145	225	282	354	417	460	385	361	376	347	320	360	340
Major Total	5324	5075	5595	5627	5608	6109	6101	6336	6970	7216	7136	7034	6871	7285	7533	7577	8504
World Total	5825	5497	5889	5941	5888	6476	6513	6717	7364	7586	7630	7594	7433	7794	8072	8138	9126

Source: USDA/FAS and Global Trade Atlas® (GTA)

Notes: "Major Total" refers to the total volume of beef exports from the eleven major beef exporters; "World Total" refers to the total amount of beef exports in the world.

Table 3.2 (B): The Shares of Beef Exports of Eleven Major Exporters

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Argentina	0.078	0.055	0.060	0.060	0.029	0.053	0.059	0.092	0.102	0.073	0.066	0.052	0.084	0.036	0.026	0.020	0.020
Australia	0.200	0.227	0.212	0.222	0.234	0.207	0.191	0.204	0.188	0.189	0.183	0.185	0.184	0.176	0.175	0.173	0.175
Brazil	0.040	0.055	0.078	0.082	0.126	0.135	0.178	0.240	0.251	0.275	0.287	0.237	0.215	0.200	0.166	0.187	0.203
Canada	0.071	0.084	0.090	0.095	0.105	0.101	0.063	0.090	0.081	0.063	0.060	0.065	0.065	0.067	0.053	0.041	0.036
EU-15	0.187	0.142	0.173	0.112	0.104	0.090	0.067	0.054	0.034	0.029	0.018	0.026	0.019	0.043	0.055	0.036	0.027
India	0.037	0.045	0.037	0.058	0.062	0.063	0.066	0.073	0.084	0.090	0.089	0.088	0.082	0.118	0.157	0.173	0.193
Mexico	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.003	0.004	0.005	0.006	0.006	0.007	0.013	0.018	0.025	0.018
New Zealand	0.086	0.087	0.074	0.080	0.082	0.073	0.084	0.088	0.078	0.070	0.065	0.070	0.069	0.068	0.062	0.064	0.058
Paraguay	0.005	0.009	0.006	0.010	0.011	0.012	0.007	0.016	0.024	0.030	0.025	0.029	0.033	0.036	0.024	0.031	0.036
United States	0.166	0.179	0.186	0.189	0.175	0.171	0.175	0.031	0.043	0.068	0.085	0.119	0.118	0.134	0.156	0.137	0.129
Uruguay	0.043	0.040	0.032	0.040	0.025	0.035	0.043	0.053	0.057	0.061	0.050	0.048	0.051	0.045	0.040	0.044	0.037
Major Total	0.914	0.923	0.950	0.947	0.952	0.943	0.937	0.943	0.946	0.951	0.935	0.926	0.924	0.935	0.933	0.931	0.932

Source: Author’s calculations

Table 3.3: Eleven Major Beef Importers and Imports, 1997-2013

Table 3.3 (A): Beef Imports of Eleven Major Importers (Unit: 1000 Metric Tons)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Canada	267	256	280	290	330	340	304	123	151	180	241	230	247	243	282	301	296
Chile	108	96	114	124	119	143	180	178	205	124	151	129	166	190	180	187	245
China	4	12	13	16	19	32	26	14	9	10	12	6	23	40	29	99	412
EU-15	459	414	449	429	417	533	549	641	715	720	647	469	500	437	365	348	376
Hong Kong	48	60	66	71	70	71	79	79	88	89	90	118	154	154	152	241	473
Japan	935	969	986	1045	982	697	833	634	686	678	686	659	697	721	745	737	760
South Korea	233	129	249	333	253	442	457	224	250	298	308	295	315	366	431	370	375
Mexico	209	316	369	433	438	503	381	296	335	383	403	408	322	296	265	215	232
Russia	1018	738	782	425	671	751	766	791	1054	1033	1115	1227	1053	1058	994	1027	1023
Taiwan	88	85	96	85	80	91	101	82	95	104	102	103	112	130	130	116	130
United States	1063	1199	1303	1375	1435	1459	1363	1669	1632	1399	1384	1151	1191	1042	933	1007	1020
Major Total	4432	4274	4707	4626	4814	5062	5039	4731	5220	5018	5139	4795	4780	4677	4506	4648	5342
World Total	5661	5418	5692	5808	5907	6241	6281	6145	6803	6872	7160	6800	6575	6649	6451	6679	7489

Source: USDA/FAS and Global Trade Atlas® (GTA)

Notes: "Major Total" refers to the total amount of beef imports from the eleven major beef importers; "World Total" refers to the total amount of beef imports in the world.

Table 3.3 (B): The Shares of Beef Imports of Eleven Major Importers

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Canada	0.047	0.047	0.049	0.050	0.056	0.054	0.048	0.020	0.022	0.026	0.034	0.034	0.038	0.037	0.044	0.045	0.040
Chile	0.019	0.018	0.020	0.021	0.020	0.023	0.029	0.029	0.030	0.018	0.021	0.019	0.025	0.029	0.028	0.028	0.033
China	0.001	0.002	0.002	0.003	0.003	0.005	0.004	0.002	0.001	0.001	0.002	0.001	0.003	0.006	0.004	0.015	0.055
EU-15	0.081	0.076	0.079	0.074	0.071	0.085	0.087	0.104	0.105	0.105	0.090	0.069	0.076	0.066	0.057	0.052	0.050
Hong Kong	0.008	0.011	0.012	0.012	0.012	0.011	0.013	0.013	0.013	0.013	0.013	0.017	0.023	0.023	0.024	0.036	0.063
Japan	0.165	0.179	0.173	0.180	0.166	0.112	0.133	0.103	0.101	0.099	0.096	0.097	0.106	0.108	0.115	0.110	0.101
South Korea	0.041	0.024	0.044	0.057	0.043	0.071	0.073	0.036	0.037	0.043	0.043	0.043	0.048	0.055	0.067	0.055	0.050
Mexico	0.037	0.058	0.065	0.075	0.074	0.081	0.061	0.048	0.049	0.056	0.056	0.060	0.049	0.045	0.041	0.032	0.031
Russia	0.180	0.136	0.137	0.073	0.114	0.120	0.122	0.129	0.155	0.150	0.156	0.180	0.160	0.159	0.154	0.154	0.137
Taiwan	0.016	0.016	0.017	0.015	0.014	0.015	0.016	0.013	0.014	0.015	0.014	0.015	0.017	0.020	0.020	0.017	0.017
United States	0.188	0.221	0.229	0.237	0.243	0.234	0.217	0.272	0.240	0.204	0.193	0.169	0.181	0.157	0.145	0.151	0.136
Major Total	0.783	0.789	0.827	0.796	0.815	0.811	0.802	0.770	0.767	0.730	0.718	0.705	0.727	0.703	0.698	0.696	0.713

Source: Author's calculations

2.2 International Pork Market and Trade

Table 3.4 (A and B) lists the top twelve pork producers in the world from 1997 to 2013, based on the data from USDA/FAS and FAOSTAT. In general, these twelve countries dominate the world pork production and account for over 90% of total pork production (Table 3.4 B). As shown in Figure 3.6, worldwide pork production has increased steadily over time. During this period, pork productions on both sides kept an annually increasing rate of 2% on average. Correspondingly, the total pork production of the top twelve producers shifted from 69.93 million metric tons in 1997 to 100.56 million metric tons in 2013. China is the world's largest pork producer and covers nearly half of total world pork production on average (Table 3.4 B). Pork production in China had been keeping a significant increasing rate during these seventeen years. Its annual pork output is more than four times that of the U.S. and more than two time that of the European Union (Gale *et al*., 2012; also as shown in Table 3.4 A). China generally produces pork for domestic consumption and pork accounts for about 65% of animal protein consumption for Chinese consumers (Koopman and Laney, 2014). USDA projections indicate that China will continue to increase its production of pork as lower feed costs and higher pork prices spur a slight increase in breeding sow inventories and improved efficiency (USDA/FAS, 2015). The European Union and the U.S. are the second- and third-largest pork producers during the same period (Table 3.4 A). Pork production in the EU is heavily concentrated in the fifteen countries[16] that were already member states in 1995 (Koopman and Laney, 2014). Pork production in the EU-15 has maintained an increasing trend since 2007. In spite of slightly

[16] The EU-15 members are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

falling of U.S. pork production between 2008 and 2010 because of the hog cycle, the U.S. still accounts for about 10% of global pork production throughout this period (Table 3.4 B).

Table 3.5 (A and B) shows the seven selected major pork exporters in the world from 1997 to 2013, based on the rankings of pork export volume. The total volume of pork exports from the seven major exporters covered over 90% of worldwide pork exports after 1998. Pork exports of these seven regions in 2013 is more than three times that of exports in 1997. Figure 3.7 demonstrates the trends of worldwide pork exports versus exports from the seven major pork exporters. Overall, the volume of pork exports in the world market increases rapidly with annual rate of 9.6% (Table 3.5 A). Specifically, the EU-15 was the largest pork exporter before 2004, which accounted for over 30% of total pork exports in the world on average. After 2004 however, the U.S. pork exports has increased nearly two-fold compared to 1997 and surpassed the EU-15 as the top pork exporter (Table 3.5 B and Figure 3.8). Japan was consistently the largest export destination market for U.S. pork before 2013, followed by the U.S.'s North American Free Trade Agreement (NAFTA) partners, Mexico and Canada (Koopman and Laney, 2014). China is also an important market for U.S. pork which provides enormous long-run potential for the U.S. pork industry (Hayes, 2010). From Table 3.5 A, Canada is the third-largest pork exporter whose major export markets include the U.S., Mexico, Japan, China, and South Korea. In addition, Canada's pork exports to Japan are at higher average unit values than the other markets (Koopman and Laney, 2014).

Table 3.6 (A and B) lists the eleven selected major pork importers in the world pork market from 1997 to 2013. On average, these eleven countries and regions absorb about 85% of worldwide volume of imports (Table 3.6 B). As show in Figure 3.9, the import volumes of the eleven importers as well as the worldwide imports increased rapidly with annual rate of 6.5% on average, which may be contributed by the increasing demand for pork. Japan, Russia, and the U.S. (Table 3.6 B and Figure 3.10) are the top three pork importers before 2009. According to USDA/ERS, Japan remains the largest pork importer in the world in terms of both volume and value. The U.S. is the leading supplier to the Japanese pork market followed by Canada, the EU-15, and Mexico (Koopman and Laney, 2014). Similar to beef imports, Russia pork imports have been uneven during the period of 1997 to 2013. Before 2014, Brazil was the largest supplier with about 40% pork market share, followed by the EU, the U.S., and Canada. However, as the consequence of the dispute centering on Ukraine, Russia banned pork imports from the EU, the U.S., and Canada which makes its pork imports reach to the record lows (Liefert and Liefert, 2015). For the U.S., pork imports account for a small share of U.S. consumption and the primary sources of imported pork are Canada, Mexico, and the EU-15. Pork imported from Canada and Mexico are often driven by transportation costs and proximity of production to population centers (Koopman and Laney, 2014). China's imports for pork started to expand tremendously in 2008 with nearly seven times compared to 2007 (Table 3.6 A). The outbreaks of Porcine Reproductive and Respiratory Syndrome (PRRS) virus or "swine blue ear disease" in 2006 in China increased the demand for imports which was majorly filled by U.S. pork (Koopman and Laney, 2014). In the long run, China is still considered as a major pork importer which provides opportunities for hog farmers, business leaders, and investors around the world (Gale *et al*., 2012).

Figure 3.6: World and Top 12 Pork Producers' Production, 1997-2013

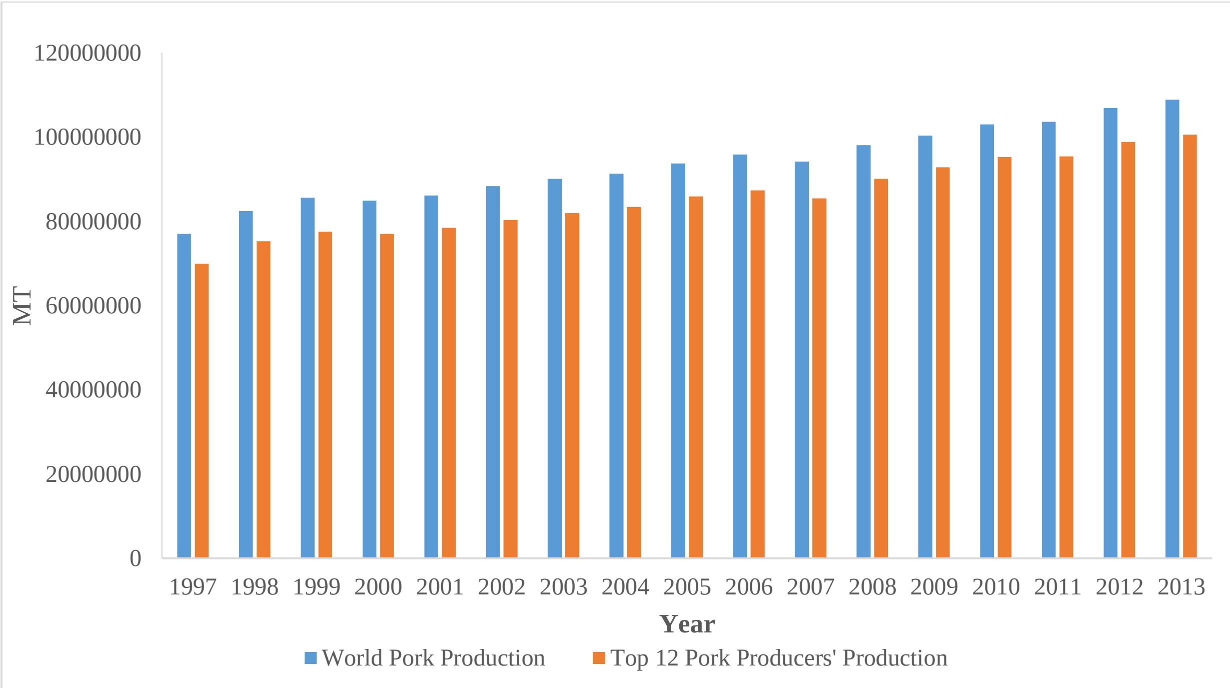

Figure 3.7: World and Seven Major Pork Exporters' Exports, 1997-2013

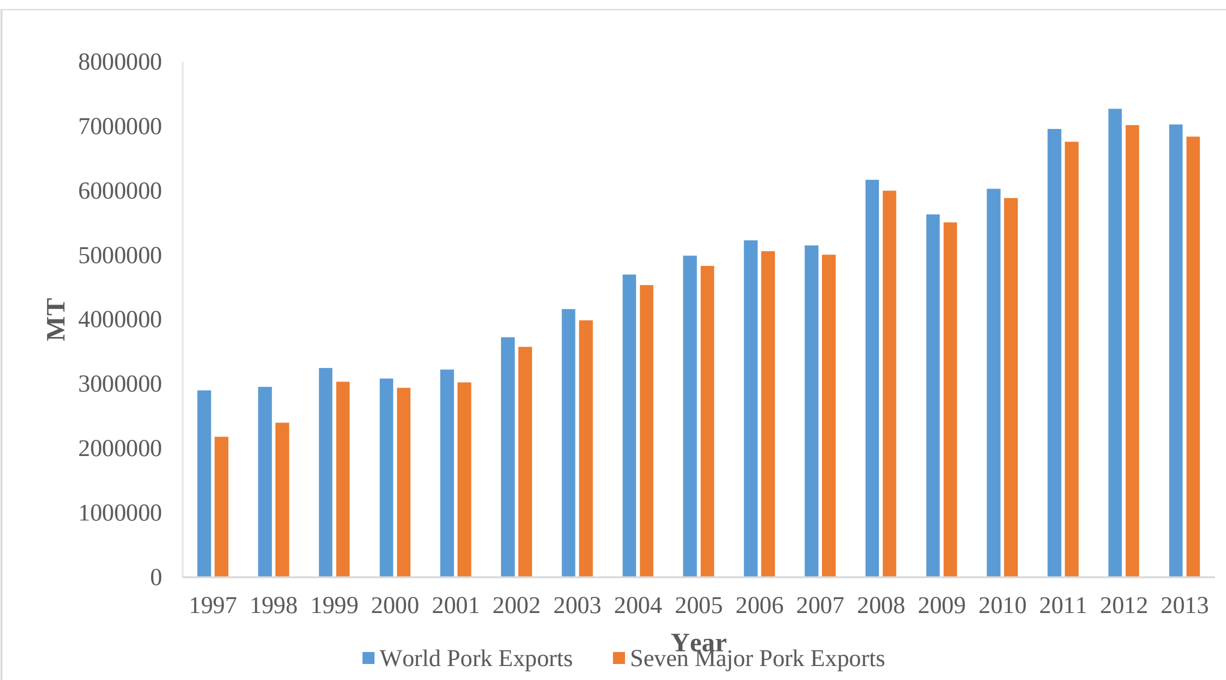

Figure 3.8: Seven Major Pork Exporters' Exports (Country Specific Exports), 1997-2013

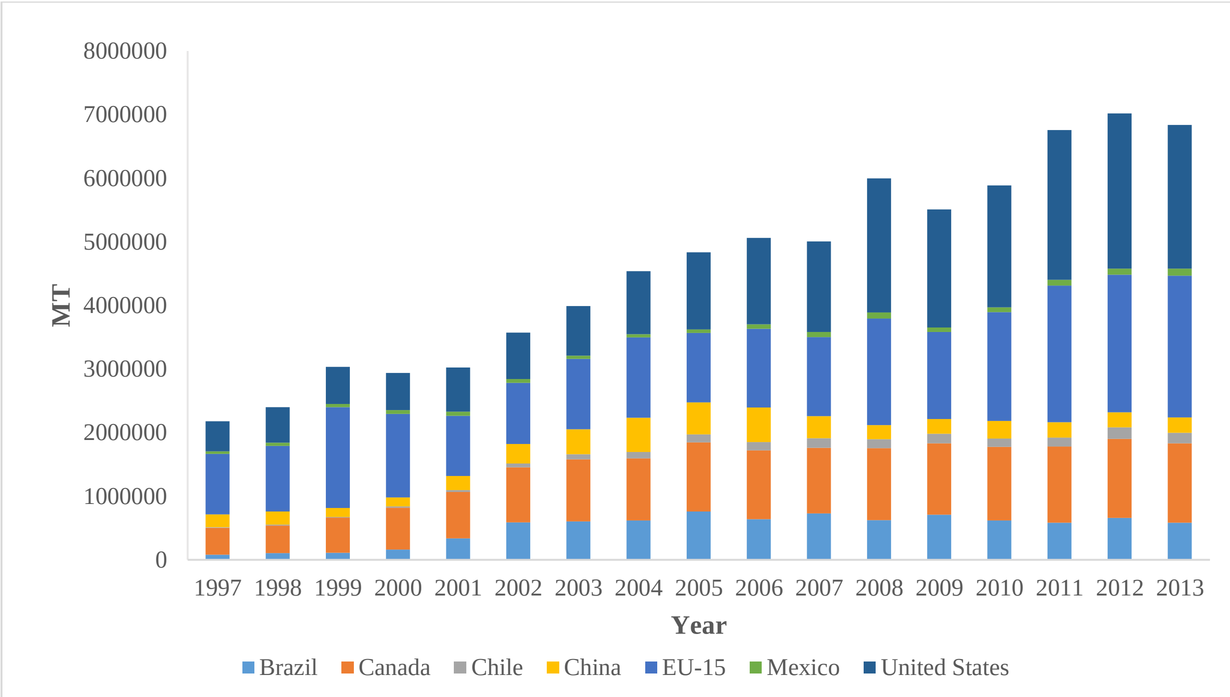

Figure 3.9: World and Eleven Major Pork Importers' Imports, 1997-2013

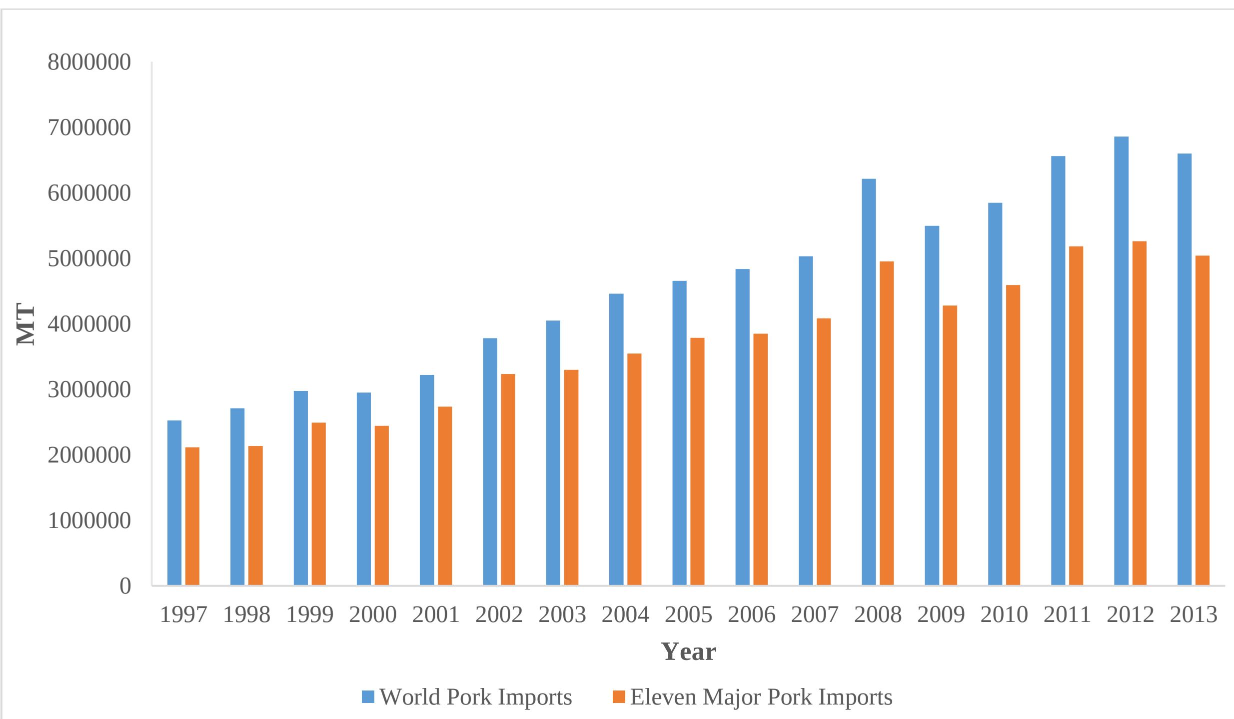

Figure 3.10: Eleven Major Pork Importers' Imports (Country Specific Exports), 1997-2013

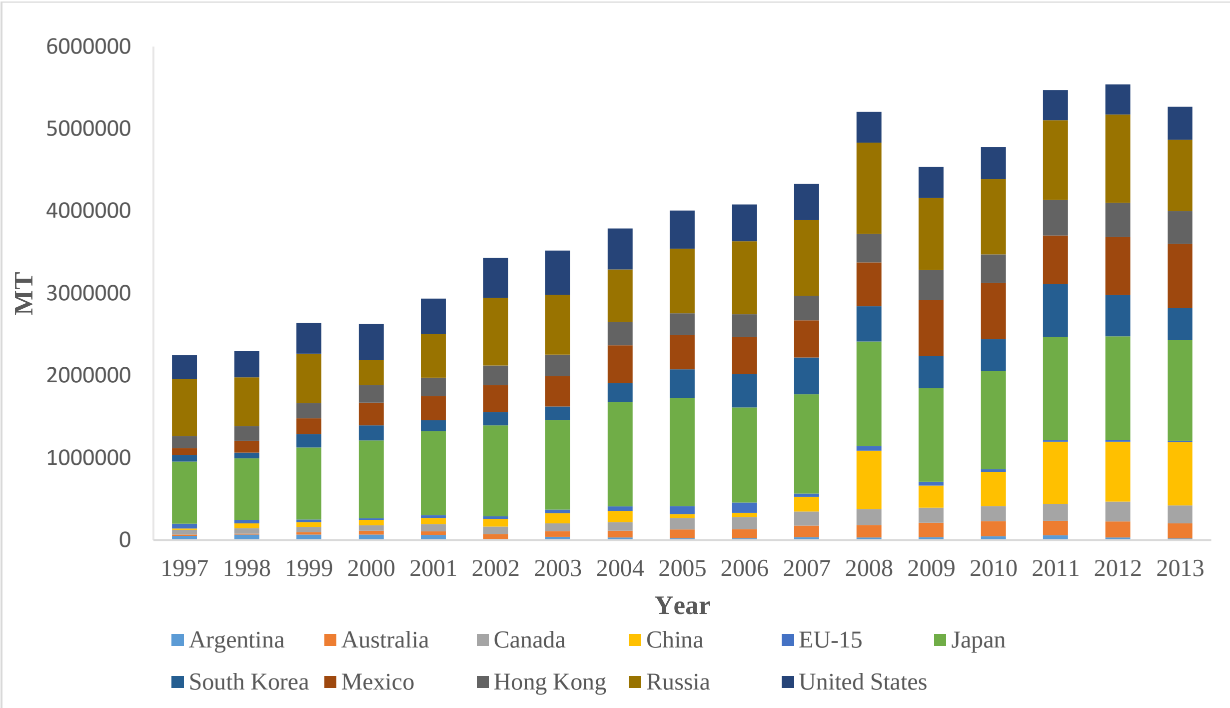

Table 3.4: Top 12 Major Pork Producers and Production, 1997-2013

Table 3.4 (A): Pork Production of Top 12 Major Producers (Unit: 1000 Metric Tons)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Brazil	1540	1690	1835	2010	2230	2565	2560	2600	2710	2830	2990	3015	3130	3195	3227	3330	3335
Canada	1156	1282	1439	1509	1593	1709	1730	1780	1765	1748	1746	1786	1794	1783	1817	1844	1822
China	35963	38837	40056	39660	40517	41231	42386	43410	45553	46505	42878	46205	48908	50712	50604	53427	54930
EU-15	16250	17581	18145	17649	17646	17816	17927	17940	18039	17961	18781	19162	18929	19481	19618	19360	19161
Japan	1283	1285	1277	1269	1245	1236	1260	1272	1245	1247	1250	1249	1310	1292	1267	1297	1309
South Korea	873	992	950	1004	1077	1153	1149	1100	1036	1000	1043	1056	1062	1110	837	1086	1252
Mexico	940	950	994	1030	1058	1070	1035	1064	1103	1109	1152	1161	1162	1175	1202	1239	1284
Philippines	901	933	973	1008	1064	1095	1145	1145	1175	1215	1250	1232	1246	1260	1288	1310	1340
Russia	1314	1279	1310	1341	1287	1367	1481	1433	1334	1444	1640	1736	1844	1981	2064	2175	2400
Taiwan	1030	892	822	921	962	935	893	898	911	931	914	862	857	845	865	878	855
United States	7835	8623	8758	8596	8691	8929	9056	9313	9392	9559	9962	10599	10442	10186	10331	10554	10525
Vietnam	843	896	962	1029	1106	1207	1311	1469	1670	1829	1864	2023	2140	2217	2262	2307	2349
Top 12 Total	69928	75240	77521	77026	78476	80313	81933	83424	85933	87378	85470	90086	92824	95237	95382	98807	100562
World Total	77015	82373	85570	84884	86102	88362	90104	91306	93766	95826	94206	98041	100308	102998	103581	106868	108823

Source: USDA/FAS and FAOSTAT

Notes: "Top 12 Total" refers to the total amount of pork production from the top 12 pork producers; "World Total" refers to the total amount of pork production in the world.

Table 3.4 (B): The Shares of Pork Production of Top 12 Major Producers

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Brazil	0.020	0.021	0.021	0.024	0.026	0.029	0.028	0.028	0.029	0.030	0.032	0.031	0.031	0.031	0.031	0.031	0.031
Canada	0.015	0.016	0.017	0.018	0.019	0.019	0.019	0.019	0.019	0.018	0.019	0.018	0.018	0.017	0.018	0.017	0.017
China	0.467	0.471	0.468	0.467	0.471	0.467	0.470	0.475	0.486	0.485	0.455	0.471	0.488	0.492	0.489	0.500	0.505
EU-15	0.211	0.213	0.212	0.208	0.205	0.202	0.199	0.196	0.192	0.187	0.199	0.195	0.189	0.189	0.189	0.181	0.176
Japan	0.017	0.016	0.015	0.015	0.014	0.014	0.014	0.014	0.013	0.013	0.013	0.013	0.013	0.013	0.012	0.012	0.012
South Korea	0.011	0.012	0.011	0.012	0.013	0.013	0.013	0.012	0.011	0.010	0.011	0.011	0.011	0.011	0.008	0.010	0.012
Mexico	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.012	0.012	0.012
Philippines	0.012	0.011	0.011	0.012	0.012	0.012	0.013	0.013	0.013	0.013	0.013	0.013	0.012	0.012	0.012	0.012	0.012
Russia	0.017	0.016	0.015	0.016	0.015	0.015	0.016	0.016	0.014	0.015	0.017	0.018	0.018	0.019	0.020	0.020	0.022
Taiwan	0.013	0.011	0.010	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.009	0.009	0.008	0.008	0.008	0.008
United States	0.102	0.105	0.102	0.101	0.101	0.101	0.101	0.102	0.100	0.100	0.106	0.108	0.104	0.099	0.100	0.099	0.097
Vietnam	0.011	0.011	0.011	0.012	0.013	0.014	0.015	0.016	0.018	0.019	0.020	0.021	0.021	0.022	0.022	0.022	0.022
Top 12 Total	0.908	0.913	0.906	0.907	0.911	0.909	0.909	0.914	0.916	0.912	0.907	0.919	0.925	0.925	0.921	0.925	0.924

Source: Author’s calculations

Table 3.5: Seven Major Pork Exporters and Exports, 1997-2013

Table 3.5 (A): Pork Exports of Seven Major Exporters (Unit: 1000 Metric Tons)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Brazil	82	105	109	162	337	590	603	621	761	639	730	625	707	619	584	661	585
Canada	420	433	554	660	728	864	975	972	1084	1081	1033	1129	1123	1159	1197	1243	1246
Chile	13	17	10	17	32	59	80	103	128	130	148	142	152	130	139	180	164
China	201	203	143	144	223	307	397	537	502	544	350	223	232	278	244	235	244
EU-15	949	1034	1582	1311	946	961	1107	1262	1091	1241	1241	1677	1367	1706	2150	2165	2227
Mexico	39	49	53	59	61	61	48	52	59	66	80	91	70	78	86	95	111
United States	473	558	582	584	698	731	779	989	1209	1359	1425	2110	1857	1915	2357	2440	2262
Major Total	2177	2399	3033	2937	3025	3573	3989	4536	4834	5060	5007	5997	5508	5885	6757	7019	6839
World Total	2901	2955	3246	3084	3224	3726	4163	4697	4989	5227	5148	6167	5629	6029	6955	7268	7027

Source: USDA/FAS and Global Trade Atlas® (GTA)

Notes: "Major Total" refers to the total amount of pork exports from the seven major beef exporters; "World Total" refers to the total amount of pork exports in the world.

Table 3.5 (B): The Shares of Pork Exports of Seven Major Exporters

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Brazil	0.028	0.036	0.034	0.053	0.105	0.158	0.145	0.132	0.153	0.122	0.142	0.101	0.126	0.103	0.084	0.091	0.083
Canada	0.145	0.147	0.171	0.214	0.226	0.232	0.234	0.207	0.217	0.207	0.201	0.183	0.200	0.192	0.172	0.171	0.177
Chile	0.004	0.006	0.003	0.006	0.010	0.016	0.019	0.022	0.026	0.025	0.029	0.023	0.027	0.022	0.020	0.025	0.023
China	0.069	0.069	0.044	0.047	0.069	0.082	0.095	0.114	0.101	0.104	0.068	0.036	0.041	0.046	0.035	0.032	0.035
EU-15	0.327	0.350	0.487	0.425	0.293	0.258	0.266	0.269	0.219	0.237	0.241	0.272	0.243	0.283	0.309	0.298	0.317
Mexico	0.013	0.017	0.016	0.019	0.019	0.016	0.012	0.011	0.012	0.013	0.016	0.015	0.012	0.013	0.012	0.013	0.016
United States	0.163	0.189	0.179	0.189	0.217	0.196	0.187	0.211	0.242	0.260	0.277	0.342	0.330	0.318	0.339	0.336	0.322
Major Total	0.750	0.812	0.934	0.952	0.938	0.959	0.958	0.966	0.969	0.968	0.973	0.972	0.979	0.976	0.972	0.966	0.973

Source: Author's calculations

Table 3.6: Eleven Major Pork Importers and Imports, 1997-2013

Table 3.6 (A): Pork Imports of Eleven Major Importers (Unit: 1000 Metric Tons)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Argentina	51	66	64	65	61	13	38	31	23	24	33	31	35	48	59	32	18
Australia	14	12	32	47	42	60	72	82	105	109	141	152	176	183	175	194	183
Canada	59	64	65	68	91	91	91	105	139	146	171	194	180	183	204	240	220
China	14	60	57	65	76	91	124	137	48	53	182	709	270	415	758	730	770
EU-15	62	44	31	19	32	31	44	52	99	125	36	59	47	30	19	21	15
Japan	752	746	875	947	1022	1108	1091	1269	1314	1154	1210	1267	1138	1198	1254	1259	1223
South Korea	84	71	164	184	132	164	163	233	345	410	447	430	390	382	640	502	388
Mexico	82	144	190	276	294	325	371	458	420	446	451	535	678	687	594	706	783
Hong Kong	147	178	187	212	224	237	260	285	263	277	301	346	369	347	432	414	399
Russia	694	592	600	307	529	822	728	637	785	889	917	1107	876	916	971	1077	868
United States	288	320	375	438	431	486	538	499	464	449	439	377	378	390	364	364	399
Major Total	2115	2133	2489	2444	2735	3233	3297	3546	3784	3849	4082	4954	4279	4591	5183	5263	5039
World Total	2526	2713	2975	2950	3217	3780	4051	4459	4653	4834	5032	6213	5497	5846	6558	6858	6597

Source: USDA/FAS and Global Trade Atlas® (GTA)

Notes: “Major Total” refers to the total amount of pork exports from the seven major beef exporters; “World Total” refers to the total amount of pork exports in the world.

Table 3.6 (B): The Shares of Pork Imports of Eleven Major Importers

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Argentina	0.020	0.024	0.022	0.022	0.019	0.003	0.009	0.007	0.005	0.005	0.007	0.005	0.006	0.008	0.009	0.005	0.003
Australia	0.006	0.004	0.011	0.016	0.013	0.016	0.018	0.018	0.023	0.023	0.028	0.024	0.032	0.031	0.027	0.028	0.028
Canada	0.023	0.024	0.022	0.023	0.028	0.024	0.022	0.024	0.030	0.030	0.034	0.031	0.033	0.031	0.031	0.035	0.033
China	0.006	0.022	0.019	0.022	0.024	0.024	0.031	0.031	0.010	0.011	0.036	0.114	0.049	0.071	0.116	0.106	0.117
EU-15	0.025	0.016	0.010	0.006	0.010	0.008	0.011	0.012	0.021	0.026	0.007	0.009	0.009	0.005	0.003	0.003	0.002
Japan	0.298	0.275	0.294	0.321	0.318	0.293	0.269	0.285	0.282	0.239	0.240	0.204	0.207	0.205	0.191	0.184	0.185
South Korea	0.033	0.026	0.055	0.062	0.041	0.043	0.040	0.052	0.074	0.085	0.089	0.069	0.071	0.065	0.098	0.073	0.059
Mexico	0.032	0.053	0.064	0.094	0.091	0.086	0.092	0.103	0.090	0.092	0.090	0.086	0.123	0.118	0.091	0.103	0.119
Hong Kong	0.058	0.066	0.063	0.072	0.070	0.063	0.064	0.064	0.057	0.057	0.060	0.056	0.067	0.059	0.066	0.060	0.060
Russia	0.275	0.218	0.202	0.104	0.164	0.217	0.180	0.143	0.169	0.184	0.182	0.178	0.159	0.157	0.148	0.157	0.132
United States	0.114	0.118	0.126	0.148	0.134	0.129	0.133	0.112	0.100	0.093	0.087	0.061	0.069	0.067	0.056	0.053	0.060
Major Total	0.890	0.847	0.887	0.891	0.912	0.907	0.869	0.850	0.861	0.844	0.860	0.838	0.825	0.817	0.834	0.808	0.798

Source: Author’s calculations

2.3 SPS Agreement

Traditional trade instruments such as tariff and quota barriers have been decreasing in the world agricultural trade as the use of non-tariff measures and technical regulations of commercial policy continue to rise (Jayasinghe *et al*., 2010; Grant *et al*., 2015). Among the list of non-tariff and technical barriers to trade (TBTs), sanitary and phytosanitary (SPS) measures are increasingly important to agricultural trade (Disdier et al., 2008). The Agreement on Application of Sanitary and Phytosanitary Measures (SPS Agreement) was negotiated during the 1986 to 1994 Uruguay Round and entered into force with the establishment of the World Trade Organization in 1995 (WTO, 1998). The SPS agreements provides guidelines for WTO members in implementing SPS measures to protect human, animal, and plant life or health within its territory form certain risks and hazards associated with the trade of agricultural commodities. Those risks and hazards include:

- The entry or the spread of diseases, disease-carrying organisms or disease-causing organisms;
- Additives, contaminations, pesticide and veterinary drug residues, toxins or disease-causing organisms in feedstuffs;
- The entry or spread of pests, disease-carrying animals, plants, and their products (WTO, 1998).

The basic aims of the SPS agreement is to maintain the sovereign right to any government to provide the level of health protection it deems appropriate. So the agreement allows participating countries to adopt their own SPS standards based on the risk assessment and justifications (Grant *et al*., 2015). However, to ensure that the sovereign right are not misused for protectionism and do not results in unnecessary barriers, the WTO members need to recognize and following several principles under the SPS Agreement to impose the regulations they desired, which include: 1) harmonization principle: “member nations shall base their measures on international standards, guidelines or recommendations” (Article 3); 2) equivalence: “member nations shall accept and not discriminate the measures of another countries with similar conditions” (Article 4); 3) scientific principle: “measures shall be on the basis of an examination and evaluation of available scientific information, including relevant processes and production methods, relevant inspections, sampling and testing methods” (Article 4) ; 4) transparency principle: “member nations shall ensure that all measures which have been adopted are published promptly which enable interested members to become acquainted with them” (Article 5).

SPS measures have been considered as important issues in negotiations on agricultural trades among the members of WTO because of the sensitive nature such as food safety and animal health (Grant *et al*., 2015). Despite variety in SPS measures that importing countries impose on exporting countries has contributed to numbers of disputed raised to the WTO SPS Committee (Orden *et al*, 2002), SPS measures are still considered as a minimally trade distorting mechanism to prevent the use of protectionism (Josling *et al*. 2004; Schlueter *et al*., 2009). Since 1995, almost 320 official complaints and disputes related to SPS measures have been lodged by WTO members (Grant *et al*., 2015). Among these cases related to red meat products, the notable disputes include a European Union ban on U.S. meat treated with growth-promoting hormones, BSE-related U.S. beef bans from Japan, South Korea, Mexico, and Canada, and the complaints and disputes from Canada and Mexico to the U.S. about certain country of origin labeling requirements (Bureau *et al*., 1998; Jin and Koo, 2003; Rude *et al*., 2006).

In summary, the SPS Agreement explicitly ensures the rights of each WTO member to take SPS measures to protect human, animal, or plant life or health. Measuring and economic impacts of SPS on agricultural and food trade are important which may offer guidelines to policy makers on how to make use of regulatory instruments managing and governing agri-food trade (Schlueter *et al*., 2009). This study attempts to use detailed information to better understand the impacts of SPS measures and other relevant determinants on red meat trade.

Section 3 Literature and Methodology Reviews

This section provides an overview of relevant literature in agricultural trade with SPS measures and research methodology. Overall, a number of studies have investigated the impacts of SPS measures on agricultural trade, which provide good instruction for the currently study. We also explore the history and development of two widely used modeling approaches for empirical trade study: the price-wedge approach and the gravity equation. Their features and limitations are also discussed in this section.

3.1 Literature Review of SPS Measures on Agricultural Trade

As one of the most important non-tariff measures, a growing body of research has emerged to quantify the trade effects of SPS measures on agricultural commodities (Grant *et al*., 2015; Peterson *et al*., 2013; Xiong and Beghin, 2012; Jayasinghe *et al*., 2010; Schlueter *et al*., 2009; Anders and Caswell 2009; Peterson and Orden, 2008; Disdier *et al*., 2008; Otsuki *et al*., 2001; Beghin and Bureau, 2001). On the one hand, some studies focused on the trade impacts of SPS measures at the aggregated level of agricultural trade. For example, Disdier *et al*. (2008) analyzed the impacts of SPS and TBT agreement on agricultural trade and suggested that SPS measures significantly reduced developing countries' exports to OECD (Economic Cooperation and Development) countries but did not affect the internal trade between OECD members. Fontagne *et al*. (2005) estimated the effects of environmental SPS and TBT on international trade and found negative effects of SPS measures for sixty-one product groups. On the other hand, most of prior research departed from the aggregated products and focused instead on the trade effects of SPS measures on a particular product. For instance, Peterson *et al*. (2013) evaluated the trade restrictiveness of SPS measures on U.S. fresh fruits and vegetable imports and found that while the SPS treatments generally reduce trade, the actually restrictiveness diminished dramatically as exporter accumulate experience. Grant *et al*. (2015) found similar results for assessing the impact of SPS regulations on U.S. fresh fruit and vegetable exports. Xiong and Beghin (2012) provided an *ex post* econometric evaluation of the tightening policy of European Union maximum residue limit (MRL) on aflatoxins in 2002 and its impact on African groundnut exports. They found no evidence of the EU MRL having a significantly impact on groundnut exports from Africa.

Empirical studies about trade impacts of SPS measures in the meat sector are limited. Most of them narrowly focused on either a specific food safety issue like maximum residue limits (Wilson *et al*. 2003) or an animal disease outbreak such as foot-and-mouth disease (FMD) (Yang and Saghaian, 2010). Schlueter *et al*. (2009) departed from the impact of specific events or diseases and estimated the SPS regulatory policies in meat trade. They disaggregated the SPS instruments into classes/groups based on the desired level of SPS health and analyzed the trade effects of different measures that are imposed in the meat sector. Their results indicated that there are specific measures that have a substantial positive impact and others with a significant negative impact, which could offset each other within a class/group. They also showed that, SPS measures ensuring animal health were identified as a significant meat trade enhancing factor in the estimation. They did not have a further disaggregation of the meat sector or compare the potential spillover effects across species which we will elaborate on our study.

SPS measures as well as other related standards can be either barrier to impede trade or catalysts to improve trade (Schlueter *et al*., 2009; Liu and Yue, 2011). The imposition of SPS measures on exporters can increase the production and trade costs in order to comply with the safety requirements and thus reduce the export competitiveness (Otsuki *et al*., 2001; Disdier *et* *al*., 2008; Jayasinghe *et al*., 2010; Liu and Yue, 2011; Peterson *et al*., 2013; Grant *et al*., 2015), especially for the developing countries. Otsuki *et al*. (2001) indicated that the EU standards on aflatoxins are the main barriers to imports of African groundnuts. Jayasinghe *et al*. (2010) analyzed the effects of SPS measures on U.S. seed exports and concluded seed exports decrease as foreign SPS standards required increase.

From another perspective, SPS standards can deal with the externalities including imperfect information and increase consumer confidence in safer products which stimulate consumer demand in the long run (Beghin and Bureau, 2001; Jaffee and Henson, 2004; Anders and Caswell 2009). The cost of implementing with food safety standards may provide incentives for the modernization of export supply chains in the developing countries and such costs may be offset by benefits, which potentially create new forms of competitive advantage (Henson and Jaffee, 2008). Maertens and Swinnen (2008) critically reviewed the arguments and empirical evidence on the link between increasing food standards and developing country's exports. They used a survey-based evidence and presented case-studies show that with increasing food standards it was possible for poor countries to develop and maintain their competitive capacity in exports markets. Anders and Caswell estimated the impact of the implementation of HACCP in the U.S. on seafood imports in 1997. Their study indicated that the mandatory HACCP standard plays as a 'catalyst' for developed countries to the U.S. and a 'barrier' for seafood exports from developing countries. In addition, larger seafood exporting countries benefited more from the implementation of SPS regulations.

3.2 Methodology Review

Different strategies have been suggested in the literature for identifying and quantifying SPS measures and their impacts. Within these strategies, two major approaches have been widely used for estimating the impacts on agricultural commodity trade, which include the price-wedge approach (Calvin and Krissoff, 1998; Otsuki *et al*., 2001; Bradford 2003; Calvin and Krissoff, 2005; Dean et al., 2006; Yue *et al*., 2006) and the gravity equation model (Anders and Caswell, 2009; Schlueter *et al*., 2009; Peterson and Orden, 2008; Jayasinghe *et al*., 2010; Xiong and Beghin, 2011; Peterson *et al*., 2013; Grant *et al*., 2015). A brief review of the two models and their implications are discussed next.

3.2.1 Price-wedge Approach

The Price-wedge approach is aimed to detect the effects of trade barriers on domestic processing of imported goods by comparing these prices with some reference prices (Disdier *et al*., 2008). The idea of price-wedge method is that non-tariff trade barriers (e.g. SPS measures) can be gauged in terms of their impacts on the domestic price in comparison to a reference price. Differences between prices of domestic goods and those of corresponding imported goods may come from tariffs and non-tariff barriers. Therefore, the price effect or "price wedge" is computable and commonly computed by comparing domestic and import price in the presence of SPS measures (Disdier *et al*., 2008). The price-wedge estimators usually rely on the assumptions of homogeneous commodities and a price arbitrage condition in most of previous studies (Yue *et al*., 2006).

Among articles implementing a price-wedge approach, Calvin and Krissoff (1998) estimated the tariff rate equivalents of the technical regulations in U.S. apples by calculating the price wedge, with the assumption that the price gap consists of the tariff and technical barrier tariff rate are equivalent. They used monthly data and compared CIF (cost insurance and freight) prices of U.S. apples in a foreign country with wholesale prices in the foreign market. Once the difference in price between the U.S. apples delivered in the foreign country and the wholesale price for a similar apple in the foreign wholesale market was known, the monthly price wedge was calculated. The monthly price wedge was divided into the known tariff rate and the technical barrier tariff rate equivalent, which was the estimation residual in the model. Their research found the price-wedge method can provide useful estimates of the tariff equivalent of technical barriers. Other papers like Yue *et al*. (2006) provided an extension of the price-wedge method which accounts for imperfect substitution between domestic and imported goods. They relaxed the homogeneous assumption and accounted explicitly for commodity heterogeneity and perceived quality of substitutes by investigating the Japan-U.S. apple trade dispute. Their study indicated that removing the Japanese technical barriers would yield limited export gains to the United States.

Beghin and Bureau (2001) discussed the limitations of price-wedge method, which include the difficulty to distinguish between the different barriers and the limitation of available data. The data available are too aggregate to reflect differences in the quality of goods (Beghin and Bureau 2001). In addition, the price-wedge approach can only have reliable estimation on a particular product that is relatively standardized. In addition, this method applied to a level of detail such as two-digit level of Harmonized System cannot reflect the true effects of non-tariff trade barriers (Beghin and Bureau 2001).

3.2.2 Gravity Model Approach

The gravity model approach is another effective trade model for empirical international trade analysis. The gravitational concept was adapted in physics and advanced by Newton in

1686 (Dascal *et al*., 2002). Tinbergen (1962) first performed the gravity model on international trade independently. Then the gravity model has inspired many researchers to explain bilateral trade flows. The basic idea behind the gravity model of international trade is that the bilateral trade volumes from one country to another can be explained by factors that capture the potentials of a country to export and import goods. Generally speaking, gravity equation simply shows that the trade flows is a function of the relevant variables. Tinbergen (1962) had determined the normal and standard patterns of international trade that would prevail among forty-two counties without trade barriers using gravity concepts. His study also made a great contribution on introducing dummy variables for trade agreement and the presence of a common border among trading partners into the empirical gravity model. Pëyhënen (1963) analyzed the trade volumes of ten European countries in a single year and introduced country GDP and transportation cost to represent incomes and distance variables. After Tinbergen (1962) and Pëyhënen (1963), subsequent researchers increasingly applied gravity model in international trade studies, adjusting and revising the models for their specific needs. For example, Linneman (1966) introduced population as an additional measure of country size, and Helpman *et al*. (2008) introduced fixed effects across countries. Now, gravity models are widely used to infer trade flow effects of distance, trade agreements, common borders, tariffs, non-tariff barriers, and fixed cost between countries (Xiong and Beghin, 2010).

Among great number of prior studies, the research by Koo *et al*. (1994), Dascal *et al*. (2002), Peterson and Orden (2008), Schlueter *et al*. (2009), Villoria (2009), Sun and Reed (2010), Yang *et al*. (2010), Jayasinghe *et al*. (2010), Xiong and Beghin (2011), Peterson *et al*. (2013), and Grant *et al*. (2015) discussed and applied the gravity model on agricultural commodities to provide evidence on the trade impacts of tariff and non-tariff measures at various levels of details. For applications of gravity model on meat trade, Koo *et al*. (1994) revised the gravity model and made the model fit for a single agricultural commodity effectively by using panel data. Their simulation showed that the modified gravity model is applicable to single commodity (like beef) trade flows. Their study revealed that trade policies, meat production capacity in countries, and long-term agreement are important in determining trade flows of meat significantly. However, their analysis has two limitations. First, they failed to mention and solve the problems of zero trade flows which may cause biased estimation and heteroscedasticity in the empirical model. Second, the country-level multilateral resistance terms which are captured by the importer and exporter fixed effects were not included in their study.

Despite the success in empirical studies of trade patterns in the history, the gravity model had been a target of criticism because of its lack of theoretical foundations (Anderson and van Wincoop, 2003). Many researchers have worked on connecting international trade theories with a gravity model specification. Anderson (1979) derived a gravity model using an expenditure function in countries while assuming the homothetic preferences across regions. He assumed that goods are differentiable by country of origin and concluded that the gravity equation can be derived from the properties of expenditure system. Bergstrand (1985) indicated that the gravity model is a reduced form of a general equilibrium trade model, where the trade flows can be defined as a function of available resources, transport cost, and barriers to trade. Deardorff (1998) built the link between the Heckscher-Ohlin (H-O) model and gravity equation by deriving gravity model from two separate type of H-O.

More recently, Anderson and van Wincoop (2003) derived a full specification of the gravity equation by maximizing the utility function with constant elasticity of substitution (CES) preferences using cross sectional data. Most importantly, they emphasized the structural shortcomings of the traditional gravity model. They claimed that the “multilateral resistance” term, which can be captured by importer and exporter fixed effects, should not be omitted in the gravity equation. Baldwin and Taglioni (2006) generalized Anderson and van Wincoop’s multilateral resistance term to allow for panel data application. They argued that the multilateral resistance term need to be time-variant in order to eliminate the misspecification and unobserved trade costs. Silva and Tenreyro (2006) stated that the parameters of a log-linearized gravity equation cannot be interpreted as the true elasticities because of Jensen’s inequality. They estimated the gravity equation in the multiplicative form in levels using a Poisson Pseudo-maximum Likelihood (PPML) method and concluded that the PPML is an appealing approach to deal with heteroscedasticity and measurement errors. Fally (2015) supported the use of PPML and found that the estimation of a gravity equation with PPML and exporter and importer fixed effects is consistent with the introduction of multilateral resistance as in Anderson and van Wincoop (2003). To sum up, all of these studies made significant contributions in providing a solid theoretical foundation for the gravity model to overwhelm the earlier criticisms, which make the gravity approach the most widely used method in empirical trade studies.

Section 4 Research Methods

The research process contains multiple steps best described in sequence. Figure 3.11 illustrates the roadmap for the current research procedures. The start point is to discuss the econometric problems as well as the structure shortcomings associated with gravity equations. Second, multiple gravity equations of red meat trade values incorporating with multilateral resistance term are constructed following the recommendation of Anderson and van Wincoop (2003) and Baldwin and Taglioni (2006). Three estimation alternatives include OLS, Heckman selection model, and Poisson Pseudo-maximum likelihood (PPML) estimator are considered for the model estimations. In the context of data description, the selection of HS four-digit (HS 0201, HS 0202, and HS 0203) levels of red meat (includes beef and pork) data from Global Trade Atlas[8] (GTA) and the frequency data of SPS measures from WTO SPS information system are discussed throughout detailed illustration. Furthermore, multiple product-specific and pooled products models have been included. To compare and better understand the robustness of each estimation alternative with different percentages of zero trade flows, we also evaluate two scenarios of unbalanced and unbalanced exporters datasets on each product-level gravity equation.

4.1 Econometric Issues of Gravity Equation Model

In the process of model estimation, two econometric issues related to gravity equation model and trade data are widely discussed in previous literature: sample selection bias and heteroscedasticity. A common feature of sample selection bias in bilateral trade data is that zero trade volumes are frequent across country pairs and products. One reason is that some country pairs simply do not trade in certain products. This problem is more likely to occur when small countries are taken into consideration (Silva and Tenreyro, 2006). The other reason is that it is not profitable for the potential exporters to bear the fixed costs of trade in some specific markets (Helpman *et al*., 2008). At the same time, rounding errors may also be an additional source of zeros if trade flow is measure by big units (like thousands of dollars) (Silva and Tenreyro, 2006). As a consequence, the existence of zero trade observations creates problems for the use of the log-linear form of the gravity equation. Also, such zeros cannot be simply omitted because it may delete some important information on the zero level of trade and cause biased estimates and inconsistency. Although several procedures have been developed to deal with this problem, such as replacing zero trade values by a small (arbitrary) number, these methods are still inconsistent (Silva and Tenreyro, 2006). A natural and effective way suggested by Helpman *et al*. (2008), advocated that the zeros should be modeled in a sample selection process by estimating the two-stage Heckman selection model (Heckman, 1979).

Heteroscedasticity is another econometric issue associated with gravity model estimation. Since the data sample of a gravity equation usually consists of trade volumes from different sources and countries with diverse productivities, the varying of data can lead to heteroscedasticity (Xiong and Chen, 2014). Under these conditions, the ordinary least squares and nonlinear least squares estimators cannot be efficient, as they require the conditional variance to be constant. At the same time, all estimators of logarithm form gravity models are generally inconsistent because of the Jensen's Inequality (Silva and Tenreyro, 2006). To accommodate the potential problems, a Poisson Pseudo-maximum likelihood (PPML) estimators which was originally introduced by Silva and Tenreyre (2006) has been widely used in empirical trade analyses of agricultural products (Schlueter *et al*., 2009; Sun and Reed, 2010; Jayasinghe *et al*., 2010; Xiong and Beghin, 2011; Peterson *et al*., 2013; Grant *et al*., 2015). Silva and Tenreyro

(2006) used Monte Carlo simulation to show that the PPML estimator is relatively robust to heteroscedasticity and well behaved over other estimators including ordinary least square (OLS), Tobit, and non-linear least square (NLS). Moreover, the PPML estimates trade data in levels, which allows zeros to exist in the dependent variable. Next, we discuss model specifications and selection and then move into the data description.

4.2 Model Specifications

Based on the modeling frameworks of Anderson and van Wincoop (2003) and Baldwin and Taglioni (2006), multiple product-level gravity models are conducted for estimating the effects of SPS measures on red meat trade. Three estimation procedures have been considered for the empirical gravity equation model: OLS, Heckman selection model (or HMR model proposed by Helpman, Melitz, and Rubinstein, 2008), and Poisson Pseudo-maximum Likelihood (PPML).

4.2.1 OLS

The log-linearized OLS estimator is used in our study simply as a “baseline” to compare with other two model specifications. The dependent variable is the log of 1 plus the value of bilateral imports so that zero trade flows are retained (Silva and Tenreyro, 2006). The OLS estimator cannot solve heteroscedasticity which cause biased estimates. In addition, since the expected value of the log-linearized error depends on the covariates, OLS will be inconsistent even if all observations of dependent variable are strictly positive (Silva and Tenreyro, 2006). These limitations and concerns motivate us to move to the Heckman selection model and the PPML.

4.2.2 Heckman Selection Model (or HMR Model)

Helpman *et al*. (2008) presented a rich theoretical model to study the bilateral trade across countries using a Heckman selection approach. They extended the Heckman selection model by introducing the inverse Mills ratio to capture entry and exit behavior of firms. This new Heckman selection model, or HMR model, not only helps to explain zero trade flows, but also addresses the sample selection bias via a two-stage procedure. First, the selection equation (first stage) accounts for whether or not the analyst observes bilateral trade between two countries in the sample. It is a binary choice model explaining why bilateral trade happens. Second, the outcome equation (second stage) which is based on the gravity equation with firm level heterogeneity in productivity, determines the potential size of bilateral trade conditioned on the first stage. In addition, the HMR model is appealing in explaining the asymmetry in bilateral trade flows between country pairs and the high prevalence of zeros (Silva and Tenreyro, 2015). The HMR model with two-stage procedures in the application of red meat is specified as follows:

(3.1)

$$\Pr\left(T_{ijt}^{k} > 0\right) = \gamma_0^k + \gamma_1^k \ln(GDP_{it}) + \gamma_2^k \ln(IProd_{it}^{m}) + \gamma_3^k \ln\left(EProd_{jt}^{m}\right) + \gamma_4^k \ln\left(Dist_{ij}\right) + r_5^k DFta_{ij} + r_6^k DLan_{ij} + \sum_n \eta_n^k \, Ln\left(SPS_{ijt}^{k}\right) + \pi_i + \pi_j + \pi_t + \epsilon_{ijt}$$

(3.2)

$$Ln\left(T_{ijt}^{k} \middle| T_{ijt}^{k} > 0\right) = \beta_0^k + \beta_1^k \ln(GDP_{it}) + \beta_2^k \ln(IProd_{it}^{m}) + \beta_3^k \ln\left(EProd_{jt}^{m}\right) + \beta_4^k \ln\left(Dist_{ij}\right) + \beta_5^k DFta_{ij} + \sum_n \lambda_n^k \, Ln\left(SPS_{ijt}^{k}\right) + \mu^k IMR_{ijt}^{k} + \pi_i + \pi_j + \pi_t + \varepsilon_{ijt}$$

where equation 3.1 is a standard probit binary choice model representing the selection equation with standard normal distribution, and equation 3.2 is the outcome equation conditioned on equation 3.1. For the explanatory variables, T_{ijt}^{k} refers to the trade values (in US Dollars) of red meat *k* imported from exporter *j* to importer *i* in year *t*; GDP_{it} is the GDP per capita (in current US dollars) of importer *i* in year *t*; $IProd_{it}^{m}$ and $EProd_{jt}^{m}$ are the total production of red meat *m* in importing country *i* and exporting country *j* in year *t*, respectively. Note that both superscripts *k* and *m* refer to red meat products. The differences are that *k* represents the category of three red meat products disaggregated by the HS codes whereas *m* only refers to the meat production grouped by beef and pork. This is because the production definition in FAOSTAT does not match the HS system's products definition contained in the trade data. For example, "meat of bovine animal, fresh or chilled" and "meat of bovine animal, frozen" are two separate commodities in trade data, but they belongs to one product category in FAOSTAT. In this case, we apply the same production data to both fresh (HS 0201) and frozen beef (HS 0202) as proxies for importer and exporter production[17].

The geographic distances between importer *i* and exporter *j* are captured by $Dist_{ij}$; $DFta_{ij}$ and $DLan_{ij}$ indicate the dummy variables for free trade agreement (FTA) and common language between importer *i* and exporter *j*, respectively. The free trade agreement dummy variables in this study do not distinguish specific commodities. The effects of FTAs on specific

[17] Due to the data availability, the original production data from the FAOSTAT is not grouped by the HS system. Thus, when we individually estimate the trade values of HS 0201 (*k* = HS 0201, "meat of bovine animal, fresh and chilled") and HS 0202 (*k* = HS 0202, "meat of bovine animal, frozen"), the two equations share the same explanatory variables of beef (*m* = beef) production. The estimation of HS 0203 (*k* = HS 0203, "meat of swine, fresh, chilled or frozen") is not affected and has the explanatory variable of about pork (*m* = pork) production.

goods are not considered. SPS_{ijt}^{k} represents a series of SPS measures with different arrangements imposed from importer *i* to exporter *j* on meat *k* in time *t*. π_i, π_j, and π_t are importer, exporter, and year fixed effects following the suggestions of Schlueter *et al*. (2009), Xiong and Beghin (2012), Peterson *et al*. (2013), and Grant *et al*. (2015).

To deal with the issues of identification, the explanatory variable of common language included in the selection equation (equation 3.1) is dropped from the outcome equation (equation 3.2). This reflects an assumption that the common language affects the fixed costs but not the variable costs of trade between country pairs (Helpman *et al*., 2008). The inverse Mills ratio (IMR_{ijt}^{k}) which is computed from the selection equation, controls for the standard sample selection errors in model specification (Heckman, 1979). The effect of tariff which is captured by time fixed effects, is not included in the model specification. For empirical estimation, equation 3.1 and is estimated through maximum-likelihood method in the first stage. The non-linear least squares are used to estimate equation 3.2 which measure the sizes of import values and the effects of SPS's.

4.2.3 Poisson Pseudo-maximum Likelihood (PPML)

The PPML is another estimation method applied in this study. The PPML estimator is able to accommodate the inefficiency and inconsistency caused by heteroscedasticity. The bias in elasticity estimates of the log-linearized gravity equation can also be addressed by the PPML because the dependent variable of PPML estimator is estimated in levels without the practice of log-linearization. Meanwhile, the PPML provides a more feasible format on the data set. The estimations of PPML do not actually require the data to follow a Poisson distribution, which is the reason why the estimation is a "pseudo-maximum likelihood". The PPML estimator is robust and consistent as long as the conditional mean of the variate of interest is correctly specified (Silva and Tenreyro, 2006).

Martin and Pham (2008) and Burger *et al*. (2009) argued that other estimators may be superior to PPML because they allow for a greater proportion of zeros in the trade matrix. However, Silva and Tenreyro (2011) provided further evidence and confirmed that the PPML estimator is generally well behaved, even when the conditional variance is far from being proportional to the conditional mean. Furthermore, when the dependent variable has a large proportion of zeros and the data suffers from over-dispersion, the PPML estimator is not impacted in empirical studies (Silva and Tenreyro, 2011). Fally (2015) further supported Silva and Tenreyro (2011) and emphasized that estimating gravity equation using PPML with fixed effects automatically satisfies the "adding-up" constraints and it is perfectly match the observed outputs and expenditures, respectively.

With these points in mind, the specification of a product-level gravity equation with PPML estimator in this study is presented as follows:

(3.3)

$$T_{ijt}^{k} = \exp\{\beta_0^k + \beta_1^k \ln(GDP_{it}) + \beta_2^k \ln(IProd_{it}^m) + \beta_3^k \ln\left(EProd_{jt}^m\right) + \beta_4^k \ln\left(Dist_{ij}\right) + \beta_5^k DFta_{ij} + \beta_6^k DLan_{ij} + \sum_n \lambda_n^k \, Ln\left(SPS_{ijt}^k\right) + \pi_i + \pi_j + \pi_t\}\varepsilon_{ijt}$$

where "exp" refers to the exponential function and the definitions of variable are similar to equation 3.2. As we said, the trade value T_{ijt}^k is measured in levels and SPS_{ijt}^k also represents a series of SPS measures with different arrangements imposed from importer *i* to exporter *j* on meat *k* in time *t*. Multiple SPS measures with different policy goals can be explained separately throughout this setting.

Table 3.7 briefly summarizes the advantages and disadvantages of each estimator for the gravity equation. Notably, the log-linearized OLS estimator is inferior to the alternatives because of zero trade flows and heteroscedasticity. Thus, both the Heckman selection approach (HMR model) and the PPML estimator are two primary methods used for estimating multiple gravity equations in the current study. We also conduct specification tests to compare these estimators econometrically.

4.3 Data Description

The data for red meat trade values utilized in this study were obtained from the Global Trade Atlas® (GTA) of Global Trade Information Services from 1997 through 2013. The GTA data set, which are commonly used by government officials and organizations (e.g. USDA, USITC, and U.S. Meat Export Foundations), can allow users to track imports and exports of products grouped by Harmonized System (HS) codes from the most general to the most detailed levels. Due to data availability, HS four-digit products include HS 0201 (meat of bovine animals, fresh or chilled), HS 0202 (meat of bovine animals, frozen), and HS 0203 (meat of swine, fresh, chilled, or frozen) have been selected to represent "red meat" in this study. Fifteen countries/regions which account for over 80% of red meat trade worldwide (Argentina, Australia, Brazil, Canada, Chile, China, EU-15, Hong Kong, Japan, South Korea, Mexico, New Zealand, Russia, Taiwan, and the United States) [18] are included over the sample period in the current study. Because the major destinations of Indian beef are the developing regions like Southeast Asia, the Middle East, and North Africa, these fifteen countries do not have significant demands for Indian beef. To accurately reflect the real trade flows between country pairs, we

[18] See Table 3.1 to 3.6 for the detailed production, import, and export data for beef and pork.

select the annual trade values (import values) reported by the side of importers[19] and also include the zero trade flows.

For SPS measures, following the suggestion of Schlueter *et al*. (2009), data on SPS regulations is extracted from the World Trade Organization SPS information Management System (SPS-IMS)[20]. We manually search and gather the information of SPS regulations on red meat sector grouped by HS four-digit code. Using SAS SQL language, the variable of SPS regulations imposed from importer *i* on exporter *j* in time *t* about meat *k* are specified in our data set. Using manually selected data is better than the information available from the traditionally used Trade Analysis and Information System (TRAINS) on two points: 1) it contains the bilateral dimension of SPS regulation between countries; 2) the data specify the reasons/goals why an importer issued regulations on the specific meat products. The variables of SPS measures in our study are arranged into aggregated SPS, SPS with policy goals, SPS related to BSE (bovine spongiform encephalopathy), and SPS related to FMD (foot-and-mouth disease). The effects of the SPS variables are estimated separately in our study which help to understand the relationship between trade flows and SPS measures in more detail. Because of systematic data limitations, the closing dates of specific SPS regulations are unknown in WTO SPS-IMS. Thus, following Schlueter *et al*. (2009), SPS regulations are treated as being imposed in a given year if the effective date was in the first half of the year; otherwise, it is assumed that the SPS's took effect in the following year. The frequency[21] of SPS is aggregated by the issuing dates and such number calculated in the first year will not be accumulated in the next year. The data for SPS

[19] Because of the asymmetric information such as meat smuggling and transportation loss, the import values reported by importers and the export values reported by exporters are not exactly matching.

[20] SPS information Management System Data Available online at http://spsims.wto.org/

[21] See Appendix for more information.

measures is not summed up over the 1997-2013 period cumulatively for each country pair in the empirical models.

For exporting countries, unlike previous literature, this study applies two scenarios in formatting the data sets: unbalanced and balanced. For the data set with unbalanced exporters, each importer may have different trading partners on a specific meat product. For example, the U.S. did not import beef from the Eastern European countries over the sample period, whereas the EU-15 did. Therefore if any importers have different trading partners, the corresponding exporters in the data set are called "unbalanced" exporters. The factors such as transportation cost, regional trade agreements, and trade regulations may contribute to such unbalances among exporters. For the data set with balanced exporters, we manually imposed the condition that each importer shares the same trading partners excluding itself over the sample period. These forty-nine "balanced exporters" were chosen based on the union (∪) of existing exporters in the unbalanced data. Consequently, the data set with balanced exporters for any single red meat (e.g. HS 0201) has the total number of observations[22] n=12,257. Table 3.8 list the importing countries and the countries which were selected in the group as the balanced exporters. Two features of the data set with balanced exporters are necessary. First, the balanced exporters increase the total number of zero observations for a single meat product, which may contain more relevant information about the underlying trade costs and help to explain why specific country pairs did not trade between each other. Second, the balanced data can be used to check the robustness of certain estimators with extensive zeros econometrically, and see how the results of model specifications change when data contains larger portion of zeros.

[22] 721 country pairs × 17 years = 12257 observations.

The additional variables in gravity equations are also obtained from multiple sources. The income impact on the consumer demand for red meat is captured by the GDP per capita expressed in the current US dollars, which was collected from the World Bank Databank for any given year with the exception of Taiwan. The data about Taiwan (Chinese Taipei) was obtained from the International Macroeconomics Data Set of USDA ERS[23]. The annual production/supply quantities of beef and pork for both importers and exporters are extracted from the Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). The distance data, which originates from CEPII[24], measures the geographic distances between the centers of country pairs, where the EU-15 is centered on Germany geographically (Schlueter *et al*., 2009). The dummy variable for bilateral or regional free trade agreements (FTA) applied in this study is based on those agreements notified to the WTO and obtained from the Regional Trade Agreements Information System[25] (Table 3.9). A common language dummy that equals to 1 if a language is spoken by most of the population in both countries are also included in the empirical models. Table 3.10 presents the summary statistics for the selected variables in our empirical models.

[23] Available online at: http://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx

[24] Available online at: http://www.cepii.fr/cepii/en/bdd_modele/presentation.asp?id=6

[25] Available online at: http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx

Figure 3.11: Map of the Research Procedures

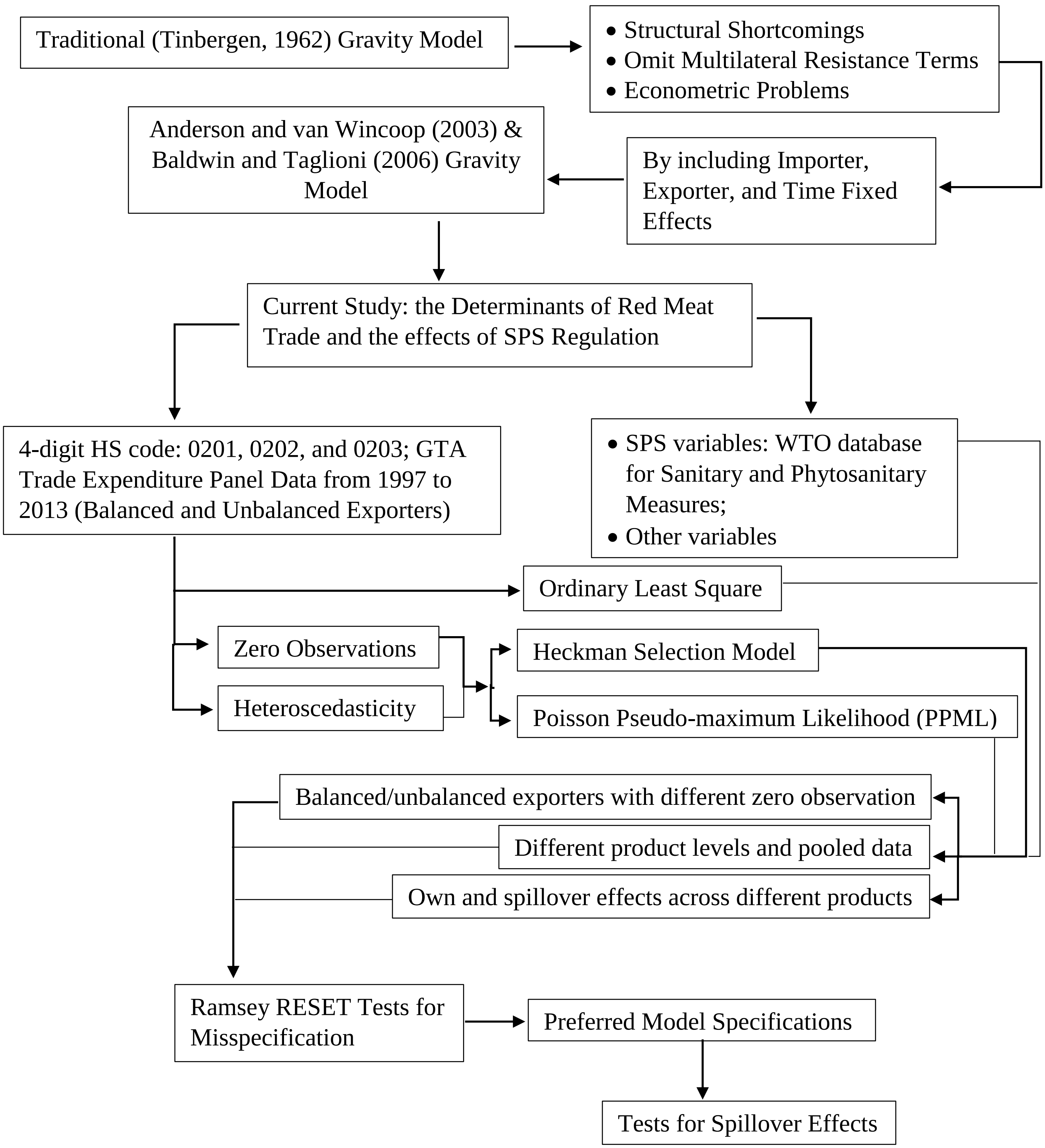

Table 3.7: Features of Different Estimators for the Gravity Equation

Estimator	Zero Trade Flow	Log-linearization	Robustness to Heteroscedasticity
OLS	No	Yes	No
Heckman (HMR)	Yes	Yes	No
PPML	Yes	No	Yes

Table 3.8: List of Countries

Importers	Balanced Exporters			
Argentina	Argentina	EU15	Panama	Uruguay
Australia	Australia	Honduras	Paraguay	Vanuatu
Brazil	Belarus	Hungary	Poland	Vietnam
Canada	Botswana	India	Romania	Zimbabwe
Chile	Brazil	Japan	Russia	
China	Bulgaria	Kazakhstan	Serbia	
EU15	Canada	Latvia	Slovakia	
Hong Kong	Chile	Lithuania	Slovenia	
Japan	China	Mexico	South Korea	
South Korea	Colombia	Moldova	Swaziland	
Mexico	Costa Rica	Mongolia	Switzerland	
New Zealand	Croatia	Namibia	Taiwan	
Russia	Cyprus	New Zealand	Thailand	
Taiwan	Czech Republic	Nicaragua	Ukraine	
United States	Estonia	Norway	United States	

Table 3.9: List of Bilateral and Regional FTA and the Effective Dates

ASEAN - Australia - New Zealand	1/1/2010	EU - Central America	8/1/2013
ASEAN - China	1/1/2005	EU - Chile	2/1/2003
ASEAN - India	1/1/2010	EU - South Korea	7/1/2011
ASEAN - Japan	12/1/2008	EU - Mexico	7/1/2000
ASEAN - South Korea	1/1/2010	EU - Norway	7/1/1973
Australia - Chile	3/6/2009	EU - Serbia	2/1/2010
Australia - New Zealand (ANZCERTA)	1/1/1983	Hong Kong, China - New Zealand	1/1/2011
Canada - Chile	7/5/1997	India - Japan	8/1/2011
Canada - Colombia	8/15/2011	South Korea - Chile	4/1/2004
Canada - Costa Rica	11/1/2002	South Korea - US	3/15/2012
Chile - China	10/1/2006	New Zealand - Chinese Taipei	12/1/2013
Chile - Colombia	5/8/2009	Nicaragua - Chinese Taipei	1/1/2008
Chile - Costa Rica (Chile - Central America)	2/15/2002	North American Free Trade Agreement (NAFTA)	1/1/1994
Chile - Japan	9/3/2007	Russian Federation - Belarus	4/20/1993
Chile - Mexico	8/1/1999	Russian Federation - Kazakhstan	6/7/1993
China - Costa Rica	8/1/2011	Russian Federation - Republic of Moldova	3/30/1993
China - Hong Kong, China	6/29/2003	Russian Federation - Serbia	6/3/2006
China - New Zealand	10/1/2008	Thailand - Australia	1/1/2005
Colombia - Mexico	1/1/1995	Thailand - New Zealand	7/1/2005
EFTA - Canada	7/1/2009	Ukraine - Russian Federation	2/21/1994
EFTA - Chile	12/1/2004	US - Australia	1/1/2005
EFTA - Colombia	7/1/2011	US - Chile	1/1/2004
EFTA - South Korea	9/1/2006	US - Colombia	5/15/2012

Table 3.10: Summary Statistics of Selected Variables

Groups	HS 0201				HS 0202				HS 0203			
Data Types	Unbalanced Exporters		Balanced Exporters		Unbalanced Exporters		Balanced Exporters		Unbalanced Exporters		Balanced Exporters	
Variables	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Trade Values	327.48	1302.16	82.21	667.63	247.42	978.15	79.96	567.92	413.78	1635.20	121.09	904.32
GDP per capita	22026.72	14795.43	21037.95	15166.33	21651.05	14572.47	21037.95	15166.33	21801.57	14567.36	21037.95	15166.33
Importer Production	34.69	36.80	29.11	34.89	31.16	34.67	29.11	34.89	72.71	119.70	54.76	110.61
Exporter Production	21.93	34.24	9.71	22.67	20.08	32.80	9.71	22.67	38.85	86.61	18.00	64.37
Distance (miles)	7850.05	5542.95	9743.68	4763.65	8203.37	5500.46	9743.68	4763.65	7617.29	5111.17	9743.68	4763.65
Language Dummy	0.20	0.40	0.11	0.31	0.17	0.37	0.11	0.31	0.13	0.34	0.11	0.31
FTA Dummy	0.22	0.41	0.07	0.26	0.18	0.38	0.07	0.26	0.17	0.38	0.07	0.26
Aggregated SPS's	1.27	2.49	0.83	1.94	1.18	2.43	0.83	1.94	0.86	2.21	0.56	1.77
SPS for Policy Goals												
SPS(Animal Health)	0.22	0.61	0.21	0.56	0.21	0.60	0.21	0.56	0.07	0.27	0.06	0.25
SPS(Human Health)	1.18	2.44	0.74	1.89	1.10	2.37	0.74	1.89	0.81	2.18	0.51	1.74
SPS(Residue)	0.86	2.33	0.45	1.75	0.80	2.26	0.45	1.75	0.73	2.15	0.44	1.72
SPS for Diseases												
SPS(BSE)	0.16	0.50	0.17	0.53	0.15	0.50	0.17	0.53	0.02	0.14	0.02	0.16
SPS(FMD)	0.03	0.20	0.04	0.21	0.03	0.19	0.04	0.21	0.02	0.17	0.03	0.20
No. of Observation	3077		12257		3961		12257		3587		12257	
Percentage of Zero	47.38%		86.79%		49.10%		83.55%		48.87%		85.04%	

Notes: Trade values are expressed as import values in $100,000 USD. GDP per capita is expressed in current US dollars. Quantities of importer and exporter production are in 100,000 metric tons. It is possible that the mean of importers' production are relatively larger than the mean of exporters' production. This is because we have fifteen countries as importers and some importers are both larger meat producers and importers (See Table 3.1 to 3.6 for detailed production and import data)

Section 5 Model Results and Discussions

This section reports the estimated results of the specified gravity models for different red meat products using three estimators including OLS, Heckman selection model (HMR model), and the PPML. The results are reported by different HS codes (HS 0201, HS 0202, and HS 0203) under separate subsections. All five SPS scenarios (differentiations of SPS measures) are examined by all three estimators. Specifically, the OLS estimator uses $\mathrm{Ln}(\mathrm{T_{ij}} + 1)$ as dependent variable as a way of dealing with zeros, whereas the dependent variable of each PPML estimator is measured in levels. We also apply the term of $Ln(SPS_{ijt}^{k} + 1)$ if a particular country did not issue any SPS measure (SPS = 0) in a given year.

Overall, Table 3.11 to Table 3.16 present the outcomes of ninety product-level gravity equations[26]. For each table, columns (1) to (4) report the results of gravity equations using three estimators without the treatment of SPS measures (HMR model results require two columns). Columns (5) to (8) reports the results of gravity equations with SPS measures included in an aggregated level. Columns (9) to (12) captures the parameter estimates of models with SPS measures specific to three policy goals, which consider the SPS measures by three different safety objectives. Models with SPS measures with an emphasis of BSE treatment are reported in columns (13) to (16) while columns (17) to (20) present model results when SPS measures with special focus on FMD are included. Within each subsection, the robustness check to extensive zeros and the tests of misspecification are employed for each estimator.

[26] 90 gravity equations = 3 estimators (OLS, HMR, and PPML) × 5 SPS scenarios × 3 HS-digit products (HS 0201, HS 0202, and HS 0203) × 2 data formations (unbalanced and balanced exporters).

In addition, the pooled data over the three HS-digit products (thirty gravity equations)[27] are investigated using the similar methods (Table 3.18) in order to have an understanding of aggregate red meat trade and to compare with existing meat trade studies. Following the suggestion of Silva and Tenreyro (2006), all models and estimators are tested by the Ramsey's Regression Equation Specification Error Test (RESET), which helps to detect whether the gravity equations are correctly specified. The RESET tests the null hypothesis that additional regressors $(x\hat{\beta})^2$ and $(x\hat{\beta})^3$ cannot help to interpret the dependent variables by running the auxiliary regression as additional independent variables (Silva and Tenreyro, 2006; Schlueter et al., 2009). In other words, it tests the hypothesis that the coefficients on the test variables are zero.

Further discussions about the spillover effects across red meat (beef and pork) industries using PPML are also specified in this section. Lastly, the effects of SPS measures on U.S. red meat exports (the U.S. only case), are also discussed.

5.1 HS 0201 Meat of Bovine Animals, Fresh or Chilled (Fresh/Chilled Beef)

5.1.1 HS 0201-Unbalanced Exporters

Table 3.11 shows the estimated fresh/chilled beef trade effects using three estimators for the data set of unbalanced exporters whose percentage of zeros is 47.38%. The HMR results are reported via two columns (e.g. columns 2 and 3) under each SPS scenario, which includes the results of the probit (selection) equation in the first stage and the results of the outcome equation

[27] 30 gravity equations = 3 estimators (OLS, HMR, and PPML) × 5 SPS scenarios × 1 pooled data (stack HS 0201, HS 0202, and HS 0203) × 2 data formations (unbalanced and balanced exporters)

in the second stage. For all HMR estimators, the sample selection terms, represented by the inverse Mills ratios, are not statistically significant for all five SPS scenarios, which indicate that the issue of self-selection bias is not severe in this particular data set. As we discussed, the OLS estimator is the baseline to compare the other two estimation alternatives and we focus on the estimations of HMR and PPML. Within this table, the results of Ramsey's RESET tests, the total number of observations, and the percentage of zeros are also included.

Generally speaking, the parameter estimates of the gravity equations under the five SPS scenarios are similar. The signs of estimated coefficients for GDP per capita, beef production from importers and exporters, geographic distance, and free trade agreement (FTAs) are as expected. Importers' beef production and distance negatively affects trade values, while the income effects, exporters' production, and FTAs foster trade values of fresh/chilled beef. About the estimated results of PPML estimator, the sizes of importers' GDP effect range from 1.721 (column 8) to 1.932 (column 4), which indicate that if GDP per capita increases 1%, the corresponding import values also raise within the range of 1.721% to 1.932%. The coefficients of FTAs under five scenarios are around 0.94 on average. This implies that country pairs with FTAs are more likely to have 155 % ((exp(0.94)-1) × 100) more fresh/chilled beef trade flows compared with other country pairs do not sign the free trade agreements. Surprisingly, countries with common language are not more likely to trade with each other, indicating that language may not be as important as expected once other trade determinants are accounted for. The impacts of SPS measures are not statistically significant in most of SPS scenarios except the probit equations of HMR models with BSE and policy objectives, which mean an increase in BSE regulation decreases the predicted probability of international trade for fresh/chilled beef.

However, the results of RESET tests reject the hypothesis that the coefficients on the test variables are zero for all three estimators with five SPS scenarios. The tests suggest that the OLS, HMR, and PPML estimators are inappropriate in this case.

5.1.2 HS 0201-Balanced Exporters

We now turn to the model specification of HS 0201 with balanced data. In this case, we manually imposed the condition that each importer shares the same trading partners excluding itself. Table 3.12 presents the estimation outcomes resulting from various techniques for the gravity equations with five different SPS scenarios. The number of observation increases to 12,257 and the percentage of zeros raises to 86.79%. The estimated OLS coefficients present notable differences compared to the results from Table 3.11 due to the increasing number of zero observations. This suggests that different percentages of zero observations and heteroscedasticity together make OLS estimators significantly inconsistent and biased. However, most coefficients from HMR and PPML with extensive zeros are rather close to those obtained from the data set with unbalanced exporters. This indicates that both HMR and PPML are effective for dealing with extensive zeros in this case.

Table 3.12 also reveals that both HMR and PPML have the expected signs for the covariates of GDP per capita, the beef production from importers and exporters, geographic distance, and free trade agreements. To be specific, high incomes on a per capita basis in importing countries generate an increase in fresh/chilled beef imports. Importers that produce more beef import less fresh/chilled beef from other countries while increased exporter beef production encourages more fresh/chilled beef exports. Members of regional free trade agreements appear to increase trade. Similar to Table 3.11, the current results do not support the notion that SPS measures (no matter which scenario considered) generally reduce trade in a statistically significant way.

Similarly, employment of Ramsey RESET test on all models excludes all three estimators for each SPS scenario because of the potential misspecifications. The null hypotheses of RESET are rejected for all gravity equations, which indicate that we fail to obtain a correct model specification even with larger number of observations in the data set.

Table 3.11: Parameter Estimates of Gravity Equations—HS 0201 Meat of Bovine Animals, Fresh or Chilled (*Unbalanced Exporters*)

0201 Meat of Bovine Animals, Fresh or Chilled (Unbalanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	1.511***	0.349***	0.861***	1.932***	1.543***	0.351***	0.878***	1.721***	1.781***	0.430***	0.864***	1.742***
	(0.388)	(0.109)	(0.244)	(0.284)	(0.390)	(0.110)	(0.244)	(0.252)	(0.403)	(0.114)	(0.252)	(0.254)
Log Importer Production	-2.224***	-0.529**	-0.641	-0.951***	-2.218***	-0.529**	-0.642	-1.196***	-2.326***	-0.564***	-0.634	-1.187***
	(0.765)	(0.213)	(0.411)	(0.295)	(0.765)	(0.213)	(0.411)	(0.292)	(0.766)	(0.214)	(0.412)	(0.290)
Log Exporter Production	-0.997	-0.213	-0.143	1.485***	-0.954	-0.209	-0.122	1.417***	-0.791	-0.154	-0.104	1.415***
	(0.642)	(0.178)	(0.374)	(0.306)	(0.645)	(0.179)	(0.375)	(0.297)	(0.647)	(0.181)	(0.376)	(0.296)
Log Distance	-3.384***	-0.810***	-1.787***	-1.698***	-3.385***	-0.810***	-1.787***	-1.710***	-3.385***	-0.813***	-1.779***	-1.710***
	(0.159)	(0.051)	(0.133)	(0.090)	(0.159)	(0.051)	(0.133)	(0.089)	(0.159)	(0.051)	(0.133)	(0.089)
Free Trade Agreement	1.243***	0.288***	0.950***	0.932***	1.243***	0.289***	0.955***	0.943***	1.232***	0.289***	0.945***	0.944***
	(0.338)	(0.096)	(0.198)	(0.175)	(0.338)	(0.096)	(0.198)	(0.168)	(0.337)	(0.096)	(0.198)	(0.169)
Common Language	-0.689*	0.015		-1.385***	-0.690*	0.015		-1.392***	-0.685*	0.020		-1.392***
	(0.365)	(0.113)		(0.189)	(0.365)	(0.113)		(0.187)	(0.365)	(0.113)		(0.188)
Log Aggregated SPS					0.140	0.013	0.096	-0.031				
					(0.195)	(0.056)	(0.101)	(0.050)				
Log SPS_Animal Health									-0.042	-0.076	0.180	-0.0249
									(0.411)	(0.117)	(0.210)	(0.124)
Log SPS_Human Health									-0.574	-0.127	-0.086	-0.016
									(0.432)	(0.123)	(0.222)	(0.110)
Log SPS_Maximum Residue									1.061**	0.254*	0.185	-0.002
									(0.461)	(0.134)	(0.234)	(0.124)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			0.166				0.169				0.139	
			(0.304)				(0.304)				(0.303)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Reject	Reject	N/A	Reject	Reject	Reject	N/A	Reject	Reject
Observations	3,077	3,077	1,619	3,077	3,077	3,077	1,619	3,077	3,077	3,077	1,619	3,077
Percentage of Zeros	47.38%	47.38%	0.00%	47.38%	47.38%	47.38%	0.00%	47.38%	47.38%	47.38%	0.00%	47.38%

(Table 3.11 continues)

0201 Meat of Bovine Animals, Fresh or Chilled (Unbalanced)	**SPS BSE**				**SPS FMD**			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	1.546***	0.365***	0.858***	1.771***	1.512***	0.863***	0.863***	1.773***
	(0.388)	(0.109)	(0.245)	(0.250)	(0.388)	(0.244)	(0.244)	(0.252)
Log Importer Production	-2.358***	-0.579***	-0.634	-1.195***	-2.214***	-0.641	-0.641	-1.168***
	(0.768)	(0.214)	(0.413)	(0.288)	(0.765)	(0.411)	(0.411)	(0.289)
Log Exporter Production	-0.968	-0.203	-0.152	1.437***	-0.997	-0.133	-0.133	1.408***
	(0.642)	(0.178)	(0.375)	(0.301)	(0.642)	(0.375)	(0.375)	(0.294)
Log Distance	-3.384***	-0.812***	-1.793***	-1.710***	-3.384***	-1.785***	-1.785***	-1.709***
	(0.159)	(0.051)	(0.133)	(0.089)	(0.159)	(0.133)	(0.133)	(0.089)
Free Trade Agreement	1.245***	0.292***	0.953***	0.944***	1.242***	0.948***	0.948***	0.943***
	(0.337)	(0.096)	(0.198)	(0.169)	(0.338)	(0.198)	(0.198)	(0.169)
Common Language	-0.682*	0.021		-1.391***	-0.687*			-1.391***
	(0.365)	(0.113)		(0.187)	(0.365)			(0.188)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	-0.743*	-0.275**	0.082	-0.079				
	(0.396)	(0.114)	(0.215)	(0.106)				
Log SPS_FMD					-0.669	0.288	0.288	0.002
					(0.812)	(0.444)	(0.444)	(0.265)
Inverse Mills Ratio			0.189				0.161	
			(0.303)				(0.304)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Reject	Reject	N/A	Reject	Reject
Observations	3,077	3,077	1,619	3,077	3,077	3,077	1,619	3,077
Percentage of Zeros	47.38%	47.38%	0.00%	47.38%	47.38%	47.38%	0.00%	47.38%

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels; "Yes" denotes that the fixed effects have been included in estimation.

Table 3.12: Parameter Estimates of Gravity Equations—HS 0201 Meat of Bovine Animals, Fresh or Chilled (*Balanced Exporters*)

0201 Meat of Bovine Animals, Fresh or Chilled (Balanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.466***	0.328***	0.807***	1.776***	0.489***	0.333***	0.823***	1.725***	0.542***	0.379***	0.808***	1.743***
	(0.139)	(0.095)	(0.240)	(0.270)	(0.140)	(0.096)	(0.241)	(0.271)	(0.143)	(0.098)	(0.247)	(0.274)
Log Importer Production	-0.848***	-0.445**	-0.573	-1.157***	-0.833***	-0.444**	-0.573	-1.184***	-0.838***	-0.474***	-0.568	-1.181***
	(0.249)	(0.175)	(0.408)	(0.296)	(0.250)	(0.175)	(0.408)	(0.299)	(0.250)	(0.176)	(0.408)	(0.298)
Log Exporter Production	-0.354**	-0.157	-0.087	1.486***	-0.354**	-0.152	-0.066	1.494***	-0.354**	-0.129	-0.058	1.492***
	(0.158)	(0.140)	(0.373)	(0.299)	(0.158)	(0.141)	(0.374)	(0.302)	(0.158)	(0.141)	(0.376)	(0.299)
Log Distance	-1.504***	-1.021***	-1.654***	-1.910***	-1.504***	-1.021***	-1.653***	-1.911***	-1.504***	-1.023***	-1.656***	-1.911***
	(0.055)	(0.041)	(0.131)	(0.096)	(0.055)	(0.041)	(0.131)	(0.096)	(0.055)	(0.041)	(0.131)	(0.096)
Free Trade Agreement	2.863***	0.845***	0.873***	1.102***	2.863***	0.846***	0.877***	1.103***	2.857***	0.847***	0.870***	1.103***
	(0.147)	(0.081)	(0.210)	(0.211)	(0.147)	(0.081)	(0.210)	(0.211)	(0.147)	(0.081)	(0.210)	(0.211)
Common Language	0.263**	0.372***		-1.557***	0.262**	0.372***		-1.557***	0.263**	0.373***		-1.557***
	(0.128)	(0.085)		(0.199)	(0.128)	(0.085)		(0.198)	(0.128)	(0.085)		(0.198)
Log Aggregated SPS					0.096	0.029	0.091	-0.030				
					(0.072)	(0.047)	(0.101)	(0.052)				
Log SPS_Animal Health									0.103	-0.0283	0.180	0.001
									(0.141)	(0.0973)	(0.210)	(0.132)
Log SPS_Human Health									-0.172	-0.0776	-0.069	-0.036
									(0.137)	(0.102)	(0.222)	(0.114)
Log SPS_Maximum Residue									0.427***	0.176	0.154	0.017
									(0.161)	(0.110)	(0.233)	(0.130)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-0.189				-0.190				-0.186	
			(0.222)				(0.222)				(0.222)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Reject	Reject	N/A	Reject	Reject	Reject	N/A	Reject	Reject
Observations	12,257	12,257	1,619	12,257	12,257	12,257	1,619	12,257	12,257	12,257	1,619	12,257
Percentage of Zeros	86.79%	86.79%	0.00%	86.79%	86.79%	86.79%	0.00%	86.79%	86.79%	86.79%	0.00%	86.79%

(Table 3.12 continues)

0201 Meat of Bovine Animals, Fresh or Chilled (Balanced)	**SPS BSE**				**SPS FMD**			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}
Log GDP Per Capita	0.463***	0.342***	0.800***	1.775***	0.465***	0.328***	0.811***	1.774***
	(0.139)	(0.096)	(0.241)	(0.268)	(0.139)	(0.095)	(0.240)	(0.269)
Log Importer Production	-0.884***	-0.484***	-0.558	-1.184***	-0.851***	-0.445**	-0.574	-1.161***
	(0.251)	(0.177)	(0.409)	(0.294)	(0.249)	(0.175)	(0.408)	(0.296)
Log Exporter Production	-0.353**	-0.149	-0.097	1.518***	-0.354**	-0.157	-0.0780	1.482***
	(0.158)	(0.140)	(0.373)	(0.307)	(0.158)	(0.140)	(0.373)	(0.298)
Log Distance	-1.503***	-1.022***	-1.659***	-1.911***	-1.503***	-1.021***	-1.655***	-1.911***
	(0.054)	(0.041)	(0.131)	(0.096)	(0.055)	(0.041)	(0.131)	(0.096)
Free Trade Agreement	2.863***	0.847***	0.878***	1.103***	2.864***	0.845***	0.872***	1.104***
	(0.147)	(0.081)	(0.210)	(0.211)	(0.147)	(0.081)	(0.210)	(0.212)
Common Language	0.263**	0.375***		-1.556***	0.262**	0.373***		-1.555***
	(0.128)	(0.085)		(0.198)	(0.128)	(0.085)		(0.199)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	-0.169	-0.197**	0.113	-0.080				
	(0.126)	(0.0977)	(0.213)	(0.113)				
Log SPS_FMD					0.230	-0.0814	0.303	0.107
					(0.254)	(0.198)	(0.443)	(0.293)
Inverse Mills Ratio			-0.175				-0.187	
			(0.222)				(0.222)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Reject	Reject	N/A	Reject	Reject
Observations	12,257	12,257	1,619	12,257	12,257	12,257	1,619	12,257
Percentage of Zeros	86.79%	86.79%	0.00%	86.79%	86.79%	86.79%	0.00%	86.79%

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels; "Yes" denotes that the fixed effects have been included in estimation.

5.2 HS 0202 Meat of Bovine Animals, Frozen (Frozen Beef)

5.2.1 HS 0202-Unbalanced Exporters

Table 3.13 presents the estimation outcomes resulting from three techniques for the product-level gravity equations of frozen beef with unbalanced exporters. A total of 3,961 observations and 49.1% of the samples associated with zero frozen beef imports have been specified. For all HMR estimators, the sample selection terms, represented by the inverse Mills ratios, are statistically significant for all five SPS scenarios, which indicate that the issue of self-selection bias is important and the applications of two-stage selection model are essential. However, the results of RESET test reject the hypothesis that the coefficients on the test variables are zero for the OLS and HMR estimators with five SPS scenarios. The tests suggest that the models estimated using the OLS and Heckman selection are inappropriate in this frozen beef case, whereas the PPML estimators for all models are correctly specified.

The parameter estimates of the gravity equations using PPML estimators are rather similar across multiple SPS scenarios. The PPML estimates reveal that the estimated coefficients for GDP per capita in the destination market, importers' and exporters' production, and geographic distance have the expected signs and are statistically significant. Higher incomes on a per capita basis in importing countries result in more frozen beef imports. More beef produced by importers generate less frozen beef imports while increased exporters' beef production improve more export values. Notice that the estimated elasticities of exporter production are all around 3.2 for all SPS scenarios, indicating that 1% increase in beef production will expand exporter values by 3.2% on frozen beef exports. Such elasticities are five time larger than the elasticities of importer production, suggesting that exporter production has a larger impact on frozen beef trade. In addition, the estimates from the PPML also indicate that two countries sharing a common language and regional FTAs do not influence frozen beef trade flows significantly.

Now we turn to a discussion of the trade effects of SPS measures on frozen beef import values. Traditionally, because SPS treatments can increase exporters' cost of accessing the import market, these measures have been expected to reduce frozen beef imports and decrease import values if the cost of applying SPS measures is greater than the additional profit that might be obtained by exporting (Grant *et al*., 2015). Column (12) of Table 3.13 shows that only animal health is significant among the policy goals potentially underlying SPS measures. The negative sign of the corresponding parameter estimate confirms that SPS measures on animal health reduce the overall trade flow and decrease import values by 0.3% at 10% confidence level. The sixteenth column of Table 3.13 additionally reports the estimates for SPS measures about BSE. The PPML estimates indicate that even treat BSE as an individual SPS regulation in model specification, the outbreak of BSE does not significantly influence the trade values of frozen beef in the global market with fairly larger number of exporters. Referring to Figure 3.4 and 3.5, despite the outbreak of BSE in Canada and the U.S. in 2003, overall beef imports and production in the world market still maintain in a fairly consistent tendency. The other measures including the aggregated SPS and FMD-related SPS also do not impact trade values significantly. Perhaps the trade costs provided by SPS measures are offset by trade benefits from increasing beef demand in the world market.

5.2.2 HS 0202-Balanced Exporters

By imposing the condition that each importer shares the same trading partners excluding itself, we specify a data set with a total of 12,257 observations and 83.55% of zeros in this case. Table 3.14 reports the estimated coefficients of gravity equations for frozen beef products with balanced exporters. Comparing with the results in Table 3.13, it is notable that the estimates from the HMR and PPML do not present significant differences from the results with unbalanced exporters. The data with balanced exporters, which may contain detailed information why particular countries do not trade with each other, make the OLS estimator inconsistent. In contrast, the HMR and PPML have fairly robust performances even if zero observations are extensive. Furthermore, although the significant coefficients of inverse Mills ratio affirm the necessity of sample selection model, the heteroscedasticity with extensive zero let the RESET test reject the null hypothesis that the coefficients on the test variables are zero. This means that the gravity equations using HMR are inappropriately specified.

The PPML estimators present appropriate model specifications of gravity equations for each SPS scenario. Also, with the imposition of balanced exporters, the estimates of GDP per capita in the importing market, production of importers and exporters, geographic distance, and common language have the correct signs and are statistically significant. The regional FTAs still do not influence frozen beef trade flows significantly. The overall sizes of these parameters are similar to these results in Table 3.13. Likewise, higher incomes on a per capita basis in importing countries correspond with more frozen beef imports. More beef produced in importing countries leads to less frozen beef imports but increased exporters' beef production expands export values. On average, the coefficients of common language dummies under the five SPS scenarios are about 0.75. This implies that countries with same language have 112 % ($(\exp(0.75)-1) \times 100$) more frozen beef trade flows compared with other countries not sharing a common language. While informative, the results in Table 3.14 also say little about the effects of SPS measures except the SPS with policy goals. The negative sign of the parameter estimate in column (12) indicates that the 1% increase of SPS measures on animal health may reduce frozen beef trade values by 0.33%.

Table 3.13: Parameter Estimates of Gravity Equations Gravity Equations—HS 0202 Meat of Bovine Animals, Frozen (*Unbalanced Exporters*)

0202 Meat of Bovine Animals, Frozen (Unbalanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.190	-0.121	0.925***	0.741***	0.186	-0.123	0.908***	0.718***	0.380	-0.066	0.987***	0.804***
	(0.345)	(0.090)	(0.193)	(0.179)	(0.348)	(0.0909)	(0.194)	(0.175)	(0.360)	(0.095)	(0.201)	(0.184)
Log Importer Production	-2.068***	-0.738***	0.739*	-0.561*	-2.068***	-0.738***	0.745*	-0.589*	-2.202***	-0.784***	0.706*	-0.681**
	(0.653)	(0.171)	(0.380)	(0.329)	(0.653)	(0.171)	(0.381)	(0.318)	(0.656)	(0.173)	(0.383)	(0.325)
Log Exporter Production	1.122*	0.215	0.760**	3.181***	1.119*	0.214	0.740**	3.220***	1.210**	0.242	0.769**	3.194***
	(0.578)	(0.150)	(0.350)	(0.358)	(0.579)	(0.150)	(0.351)	(0.356)	(0.580)	(0.150)	(0.352)	(0.353)
Log Distance	-2.268***	-0.627***	-0.344**	-0.498***	-2.268***	-0.627***	-0.342**	-0.504***	-2.266***	-0.629***	-0.349***	-0.506***
	(0.141)	(0.043)	(0.134)	(0.073)	(0.141)	(0.043)	(0.134)	(0.0715)	(0.141)	(0.043)	(0.133)	(0.072)
Free Trade Agreement	2.328***	0.621***	0.087	-0.104	2.327***	0.621***	0.079	-0.143	2.331***	0.624***	0.077	-0.133
	(0.313)	(0.086)	(0.198)	(0.134)	(0.314)	(0.086)	(0.198)	(0.134)	(0.313)	(0.086)	(0.198)	(0.136)
Common Language	0.207	0.249**		0.101	0.207	0.249**		0.120	0.212	0.251**		0.109
	(0.339)	(0.104)		(0.170)	(0.339)	(0.104)		(0.167)	(0.339)	(0.104)		(0.166)
Log Aggregated SPS					-0.0173	-0.008	-0.083	-0.112				
					(0.182)	(0.048)	(0.099)	(0.0732)				
Log SPS_Animal Health									-0.408	-0.099	-0.237	-0.304*
									(0.397)	(0.106)	(0.217)	(0.156)
Log SPS_Human Health									-0.247	-0.086	-0.126	-0.006
									(0.415)	(0.113)	(0.230)	(0.126)
Log SPS_Maximum Residue									0.498	0.155	0.121	-0.035
									(0.441)	(0.119)	(0.245)	(0.158)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-1.653***				-1.666***				-1.637***	
			(0.338)				(0.338)				(0.337)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	3,961	3,961	2,016	3,961	3,961	3,961	2,016	3,961	3,961	3,961	2,016	3,961
Percentage of Zeros	49.10%	49.10%	0.00%	49.10%	49.10%	49.10%	0.00%	49.10%	49.10%	49.10%	0.00%	49.10%

(Table 3.13 continues)

0202 Meat of Bovine Animals, Frozen (Unbalanced)	**SPS BSE**				**SPS FMD**			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}
Log GDP Per Capita	0.203	-0.115	0.932***	0.751***	0.192	-0.120	0.930***	0.746***
	(0.345)	(0.090)	(0.193)	(0.179)	(0.345)	(0.090)	(0.193)	(0.177)
Log Importer Production	-2.152***	-0.767***	0.718*	-0.604*	-2.067***	-0.738***	0.748**	-0.551*
	(0.656)	(0.173)	(0.383)	(0.336)	(0.653)	(0.171)	(0.381)	(0.324)
Log Exporter Production	1.145**	0.224	0.764**	3.191***	1.121*	0.215	0.740**	3.179***
	(0.578)	(0.150)	(0.350)	(0.355)	(0.578)	(0.150)	(0.351)	(0.354)
Log Distance	-2.267***	-0.628***	-0.349***	-0.501***	-2.267***	-0.628***	-0.333**	-0.499***
	(0.141)	(0.043)	(0.134)	(0.072)	(0.141)	(0.043)	(0.134)	(0.072)
Free Trade Agreement	2.328***	0.623***	0.084	-0.114	2.327***	0.621***	0.082	-0.103
	(0.313)	(0.086)	(0.198)	(0.132)	(0.314)	(0.086)	(0.198)	(0.132)
Common Language	0.211	0.251**		0.106	0.208	0.250**		0.093
	(0.339)	(0.104)		(0.165)	(0.339)	(0.104)		(0.165)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	-0.445	-0.144	-0.151	-0.097				
	(0.371)	(0.099)	(0.214)	(0.154)				
Log SPS_FMD					-0.264	-0.140	-0.515	-0.172
					(0.770)	(0.209)	(0.423)	(0.319)
Inverse Mills Ratio			-1.649***				-1.690***	
			(0.337)				(0.339)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	3,961	3,961	2,016	3,961	3,961	3,961	2,016	3,961
Percentage of Zeros	49.10%	49.10%	0.00%	49.10%	49.10%	49.10%	0.00%	49.10%

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels; “Yes” denotes that the fixed effects have been included in estimation.

Table 3.14: Parameter Estimates of Gravity Equations—HS 0202 Meat of Bovine Animals, Frozen (*Balanced Exporters*)

0202 Meat of Bovine Animals, Frozen (Balanced)	Without SPS				Aggregated SPS				SPS Goals			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.013	-0.094	0.916***	0.819***	0.010	-0.096	0.899***	0.806***	0.033	-0.064	0.993***	0.907***
	(0.155)	(0.078)	(0.191)	(0.187)	(0.156)	(0.079)	(0.192)	(0.189)	(0.160)	(0.081)	(0.199)	(0.201)
Log Importer Production	-0.737***	-0.599***	0.653*	-0.717*	-0.739***	-0.600***	0.658*	-0.734**	-0.749***	-0.624***	0.609*	-0.861**
	(0.278)	(0.148)	(0.369)	(0.367)	(0.279)	(0.148)	(0.369)	(0.365)	(0.279)	(0.149)	(0.370)	(0.380)
Log Exporter Production	-0.011	0.154	0.800**	3.353***	-0.011	0.153	0.780**	3.353***	-0.010	0.165	0.822**	3.401***
	(0.176)	(0.120)	(0.342)	(0.403)	(0.176)	(0.121)	(0.342)	(0.403)	(0.177)	(0.121)	(0.343)	(0.409)
Log Distance	-0.978***	-0.798***	-0.177	-0.582***	-0.978***	-0.798***	-0.176	-0.584***	-0.978***	-0.799***	-0.181	-0.557***
	(0.061)	(0.036)	(0.131)	(0.073)	(0.061)	(0.036)	(0.131)	(0.073)	(0.061)	(0.036)	(0.131)	(0.075)
Free Trade Agreement	2.792***	0.825***	-0.066	0.191	2.792***	0.825***	-0.075	0.169	2.790***	0.825***	-0.076	0.132
	(0.164)	(0.073)	(0.197)	(0.157)	(0.164)	(0.073)	(0.197)	(0.161)	(0.165)	(0.073)	(0.197)	(0.168)
Common Language	0.168	0.387***		0.766***	0.168	0.387***		0.780***	0.168	0.388***		0.752***
	(0.142)	(0.079)		(0.196)	(0.142)	(0.079)		(0.199)	(0.142)	(0.079)		(0.197)
Log Aggregated SPS					-0.014	-0.010	-0.084	-0.069				
					(0.080)	(0.041)	(0.099)	(0.083)				
Log SPS_Animal Health									-0.032	-0.048	-0.280	-0.325*
									(0.157)	(0.090)	(0.215)	(0.192)
Log SPS_Human Health									-0.082	-0.072	-0.114	-0.009
									(0.153)	(0.094)	(0.227)	(0.160)
Log SPS_Maximum Residue									0.123	0.109	0.126	0.047
									(0.180)	(0.101)	(0.241)	(0.194)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-1.685***				-1.693***				-1.702***	
			(0.248)				(0.248)				(0.248)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	12,257	12,257	2,016	12,257	12,257	12,257	2,016	12,257	12,257	12,257	2,016	12,257
Percentage of Zeros	83.55%	83.55%	0.00%	83.55%	83.55%	83.55%	0.00%	83.55%	83.55%	83.55%	0.00%	83.55%

(Table 3.14 continues)

0202 Meat of Bovine Animals, Frozen (Balanced)	**SPS BSE**				**SPS FMD**			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.011	-0.090	0.925***	0.828***	0.011	-0.094	0.921***	0.821***
	(0.155)	(0.078)	(0.191)	(0.188)	(0.155)	(0.078)	(0.191)	(0.187)
Log Importer Production	-0.759***	-0.620***	0.632*	-0.753**	-0.740***	-0.599***	0.658*	-0.710*
	(0.280)	(0.149)	(0.371)	(0.381)	(0.278)	(0.148)	(0.369)	(0.369)
Log Exporter Production	-0.010	0.159	0.806**	3.360***	-0.011	0.154	0.782**	3.354***
	(0.176)	(0.121)	(0.342)	(0.405)	(0.176)	(0.120)	(0.342)	(0.404)
Log Distance	-0.978***	-0.798***	-0.179	-0.583***	-0.978***	-0.798***	-0.169	-0.582***
	(0.061)	(0.036)	(0.131)	(0.073)	(0.061)	(0.036)	(0.132)	(0.073)
Free Trade Agreement	2.792***	0.825***	-0.072	0.183	2.793***	0.825***	-0.072	0.191
	(0.164)	(0.073)	(0.197)	(0.158)	(0.164)	(0.073)	(0.197)	(0.157)
Common Language	0.168	0.388***		0.773***	0.167	0.387***		0.762***
	(0.142)	(0.079)		(0.196)	(0.142)	(0.079)		(0.195)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	-0.103	-0.101	-0.164	-0.087				
	(0.141)	(0.085)	(0.212)	(0.171)				
Log SPS_FMD					0.256	0.00672	-0.636	-0.113
					(0.284)	(0.176)	(0.418)	(0.409)
Inverse Mills Ratio			-1.688***				-1.707***	
			(0.248)				(0.248)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	12,257	12,257	2,016	12,257	12,257	12,257	2,016	12,257
Percentage of Zeros	83.55%	83.55%	0.00%	83.55%	83.55%	83.55%	0.00%	83.55%

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels; "Yes" denotes that the fixed effects have been included in estimation.

5.3 HS 0203 Meat of Swine Animals, Fresh, Chilled or Frozen (Pork)

5.3.1 HS 0203-Unbalanced Exporters

Table 3.15 presents the estimation outcomes resulting from the three estimators for the product-level gravity equations of pork with unbalanced exporters. A total of 3,587 observations and 48.87% of the sample associated with zeros was specified. For all HMR estimators, the sample selection terms (inverse Mills ratios) are not statistically significant for all five SPS scenarios, which indicate that the issue of self-selection bias is not severe in this data set. At the same time, the results of RESET test reject the hypothesis that the coefficients on the test variables are zero for both OLS and HMR estimators under each SPS scenario. The tests suggest that the models estimated using the OLS and HMR are not appropriate in this pork case, whereas the PPML estimators for all models are correctly specified. So we focus on the PPML estimators below.

The parameter estimates of the gravity equations using PPML estimators have the same features across the five SPS scenarios. The results reveal that the estimated coefficients for GDP per capita in the destination market, importers' and exporters' production, geographic distance, dummy for regional FTAs, and common languages have the expected signs and are statistically significant. Higher incomes on a per capita basis in importing countries expand pork import values. More pork production made by importers generate less pork imports while increasing pork production in exporting countries improves export values. Notice that the regional FTAs facilitate pork trade flow significantly. For example, the coefficient of 1.12 in column (8) implies that the pork trade flows for country pairs with FTAs are two times ((exp(1.12)-1 × 100) larger than countries without FTAs. Besides that, the covariates of each gravity equation except SPS measures are similar among the five scenarios.

For the trade effects of SPS measures, most of the gravity equations do not support the notion that SPS regulations influence pork trade flow significantly, except the scenarios of aggregated SPS and BSE. To be specific, column (8) of Table 3.15 suggests that the sum of all SPS counts for a particular year has negative and significant effects on pork trade expenditures. The size of corresponding parameter estimate confirms that aggregated SPS measures decrease import values by 0.13% at 10% confidence level for each 1% increase in SPS. Interestingly, the sixteenth column of Table 3.15 indicates that the SPS measures related to BSE significantly foster the trade flow of pork. This finding suggests that BSE may have positive spillover effects on pork trade.

5.3.2 HS 0203-Balanced Exporters

Now we turn to the pork model using data with balanced exporters. As in previous tables, we specify sample data with a total of 12,259 observations and 85.04% of zeros. Table 3.16 presents the estimated coefficients of gravity equations for pork with balanced exporters. The logarithmic transformation of OLS estimator leads to biased and inconsistent estimates of the elasticities due to the significant deviation between data sets. Even if the significant inverse Mills ratios imply that a binary choice process is indeed necessary to account for importers' self-selections comparing with the results in Table 3.15, the Heckman selection model is still dominated by the PPML. The acceptance of RESET test as well as the robustness to extensive zeros and heteroscedasticity still show that PPML is the preferred estimators for all gravity equations in this case. All pork gravity equations are correctly specified by estimating PPML.

The PPML estimators present reasonable model specifications of gravity equations for each SPS scenario. Also, with the imposition of balanced exporters, the estimates of GDP per capita in the importing market, importers' and exporters' production, geographic distance, common language, and the regional FTAs dummy have the expected signs and are statistically significant. The overall sizes of these parameters are similar to these results in Table 3.15 even with a large portion of zeros, which indicates fairly good measurements provided by the PPML. Similarly, importing countries with higher GDP per capita also generate more pork trade. More pork produced by importing countries leads to less pork imports whereas increased exporters' pork production expands export values. On average, the coefficients on both the common language dummy and FTA dummy are positive and statistically significant across all specifications, which confirm the common notion that common language and FTAs are trade facilitators.

In the case of SPS measures, the negative and statistically significant coefficient for the aggregated SPS treatments in column (8) indicates that with a 1% increase in the sum of SPS counts in a given year, the trade flows (values) of pork diminish by 0.13%. This result is consistent with most of previous studies whereby SPS measure were treated as non-tariff barriers for trade. In addition, the spillover effect still exists in the gravity equation with BSE due to the positive and significant coefficient of BSE-related variable in column (16). The estimated coefficient (0.384) reveals that with 1% increase in BSE-related SPS measures, the trade values of pork increase by 0.38%.

In summary, the results from Table 3.11 to Table 3.16 reveal that trade expenditures of frozen beef and pork are more likely to be negatively affected by SPS measures than fresh/chill beef in world market. Meanwhile, the SPS measures in an aggregated level have negative and significant impacts on pork trade flows. Table 3.17 summarizes the results from Table 3.11 to Table 3.16, which provides a general idea about the signs and significances of the PPML estimators under three meat groups. Because of the insignificant effects of SPS measures for most scenarios, a strong tendency of SPS measures for each commodity cannot be determined from these results. However, the above results are generally informative and allow us to have a better understanding about of determinants of red meat trade.

Table 3.15: Parameter Estimates of Gravity Equations—0203 Meat of Swine, Fresh, Chilled, or Frozen (*Unbalanced Exporters*)

0203 Meat of Swine, Fresh, Chilled, or Frozen (Unbalanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.230	0.017	1.233***	1.224***	0.311	0.045	1.200***	1.076***	0.252	0.014	1.242***	1.014***
	(0.432)	(0.113)	(0.241)	(0.159)	(0.437)	(0.114)	(0.244)	(0.167)	(0.445)	(0.116)	(0.249)	(0.172)
Log Importer Production	-3.236***	-1.039***	-0.097	-0.787**	-3.303***	-1.060***	-0.068	-0.726*	-3.297***	-1.057***	-0.065	-0.782**
	(0.972)	(0.257)	(0.560)	(0.376)	(0.973)	(0.257)	(0.563)	(0.379)	(0.975)	(0.257)	(0.562)	(0.379)
Log Exporter Production	1.648***	0.366***	0.695**	1.164***	1.675***	0.376***	0.680*	1.099***	1.662***	0.368***	0.698**	1.078***
	(0.508)	(0.134)	(0.353)	(0.386)	(0.509)	(0.134)	(0.354)	(0.385)	(0.509)	(0.134)	(0.354)	(0.384)
Log Distance	-2.342***	-0.527***	-0.941***	-0.713***	-2.344***	-0.528***	-0.938***	-0.708***	-2.344***	-0.529***	-0.939***	-0.709***
	(0.139)	(0.039)	(0.115)	(0.070)	(0.139)	(0.039)	(0.115)	(0.070)	(0.139)	(0.039)	(0.115)	(0.069)
Free Trade Agreement	1.797***	0.385***	0.870***	1.107***	1.790***	0.385***	0.874***	1.120***	1.795***	0.387***	0.879***	1.121***
	(0.335)	(0.089)	(0.202)	(0.132)	(0.335)	(0.089)	(0.202)	(0.131)	(0.335)	(0.089)	(0.202)	(0.131)
Common Language	0.488	-0.026		0.404**	0.489	-0.027		0.403**	0.488	-0.029		0.401**
	(0.403)	(0.115)		(0.160)	(0.403)	(0.115)		(0.160)	(0.403)	(0.115)		(0.160)
Log Aggregated SPS					0.265	0.097*	-0.092	-0.132***				
					(0.210)	(0.056)	(0.111)	(0.050)				
Log SPS_Animal Health									0.248	0.088	-0.404	0.003
									(0.588)	(0.156)	(0.316)	(0.157)
Log SPS_Human Health									0.477	0.250	0.017	0.113
									(0.603)	(0.162)	(0.314)	(0.175)
Log SPS_Maximum Residue									-0.304	-0.197	-0.058	-0.298
									(0.649)	(0.174)	(0.338)	(0.197)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-0.449				-0.453				-0.440	
			(0.393)				(0.392)				(0.393)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	3,587	3,587	1,834	3,587	3,587	3,587	1,834	3,587	3,587	3,587	1,834	3,587
Percentage of Zeros	48.87%	48.87%	0.00%	48.87%	48.87%	48.87%	0.00%	48.87%	48.87%	48.87%	0.00%	48.87%

(Table 3.15 continues)

0203 Meat of Swine, Fresh, Chilled, or Frozen (Unbalanced)	SPS BSE				SPS FMD			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.226	0.0132	1.236***	1.228***	0.228	0.0171	1.234***	1.224***
	(0.432)	(0.113)	(0.242)	(0.158)	(0.432)	(0.113)	(0.241)	(0.159)
Log Importer Production	-3.254***	-1.044***	-0.102	-0.805**	-3.232***	-1.039***	-0.097	-0.787**
	(0.972)	(0.257)	(0.561)	(0.376)	(0.972)	(0.257)	(0.560)	(0.377)
Log Exporter Production	1.643***	0.362***	0.683*	1.188***	1.647***	0.366***	0.693**	1.157***
	(0.508)	(0.134)	(0.353)	(0.387)	(0.509)	(0.134)	(0.353)	(0.385)
Log Distance	-2.346***	-0.530***	-0.942***	-0.715***	-2.342***	-0.527***	-0.941***	-0.715***
	(0.139)	(0.039)	(0.115)	(0.069)	(0.139)	(0.039)	(0.115)	(0.070)
Free Trade Agreement	1.795***	0.388***	0.866***	1.104***	1.800***	0.385***	0.869***	1.110***
	(0.335)	(0.089)	(0.202)	(0.132)	(0.335)	(0.089)	(0.202)	(0.132)
Common Language	0.481	-0.027		0.402**	0.488	-0.026		0.402**
	(0.403)	(0.115)		(0.160)	(0.403)	(0.115)		(0.159)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	1.787	0.691**	0.373	0.388*				
	(1.130)	(0.309)	(0.583)	(0.198)				
Log SPS_FMD					0.380	0.019	-0.230	0.230
					(0.915)	(0.243)	(0.500)	(0.236)
Inverse Mills Ratio			-0.473				-0.453	
			(0.394)				(0.393)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	3,587	3,587	1,834	3,587	3,587	3,587	1,834	3,587
Percentage of Zeros	48.87%	48.87%	0.00%	48.87%	48.87%	48.87%	0.00%	48.87%

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels; “Yes” denotes that the fixed effects have been included in estimation

Table 3.16: Parameter Estimates of Gravity Equations—HS 0203 Meat of Swine, Fresh, Chilled, or Frozen (*Balanced Exporters*)

0203 Meat of Swine, Fresh, Chilled, or Frozen (Balanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$\ln(T_{ij}+1)$	P_{ij}	$\ln(T_{ij})$	T_{ij}	$\ln(T_{ij}+1)$	P_{ij}	$\ln(T_{ij})$	T_{ij}	$\ln(T_{ij}+1)$	P_{ij}	$\ln(T_{ij})$	T_{ij}
Log GDP Per Capita	-0.017	0.0128	1.231***	1.228***	0.009	0.036	1.200***	1.071***	0.008	0.002	1.242***	1.008***
	(0.152)	(0.102)	(0.241)	(0.161)	(0.153)	(0.103)	(0.244)	(0.169)	(0.155)	(0.105)	(0.249)	(0.174)
Log Importer Production	-0.868***	-0.855***	-0.134	-0.781**	-0.858***	-0.870***	-0.109	-0.714*	-0.861***	-0.871***	-0.103	-0.770**
	(0.284)	(0.227)	(0.545)	(0.388)	(0.284)	(0.227)	(0.547)	(0.391)	(0.284)	(0.227)	(0.547)	(0.392)
Log Exporter Production	0.176	0.225*	0.718**	1.093***	0.176	0.229*	0.706**	1.040***	0.176	0.224*	0.721**	1.025***
	(0.142)	(0.119)	(0.346)	(0.394)	(0.142)	(0.119)	(0.347)	(0.392)	(0.142)	(0.119)	(0.347)	(0.391)
Log Distance	-1.201***	-0.671***	-0.931***	-0.676***	-1.201***	-0.671***	-0.930***	-0.671***	-1.201***	-0.672***	-0.928***	-0.673***
	(0.054)	(0.035)	(0.102)	(0.079)	(0.054)	(0.035)	(0.102)	(0.078)	(0.054)	(0.035)	(0.102)	(0.078)
Free Trade Agreement	2.016***	0.650***	0.813***	1.346***	2.013***	0.650***	0.819***	1.360***	2.014***	0.653***	0.823***	1.361***
	(0.147)	(0.077)	(0.206)	(0.145)	(0.147)	(0.077)	(0.206)	(0.143)	(0.147)	(0.077)	(0.206)	(0.143)
Common Language	0.083	0.143		0.775***	0.083	0.141		0.770***	0.083	0.139		0.768***
	(0.127)	(0.095)		(0.173)	(0.127)	(0.096)		(0.171)	(0.127)	(0.10)		(0.171)
Log Aggregated SPS					0.116	0.0718	-0.088	-0.140***				
					(0.084)	(0.050)	(0.110)	(0.052)				
Log SPS_Animal Health									0.081	0.086	-0.404	-0.010
									(0.212)	(0.140)	(0.316)	(0.160)
Log SPS_Human Health									0.119	0.250*	0.021	0.120
									(0.204)	(0.141)	(0.313)	(0.182)
Log SPS_Maximum Residue									-0.007	-0.225	-0.059	-0.314
									(0.229)	(0.152)	(0.338)	(0.205)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-0.435*				-0.430*				-0.425*	
			(0.257)				(0.257)				(0.257)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	12,257	12,257	1,834	12,257	12,257	12,257	1,834	12,257	12,257	12,257	1,834	12,257
Percentage of Zeros	85.04%	85.04%	0.00%	85.04%	85.04%	85.04%	0.00%	85.04%	85.04%	85.04%	0.00%	85.04%

(Table 3.16 continues)

0203 Meat of Swine, Fresh, Chilled, or Frozen (Balanced)	**SPS BSE**				**SPS FMD**			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	-0.002	0.016	1.234***	1.233***	-0.018	0.013	1.233***	1.228***
	(0.152)	(0.102)	(0.241)	(0.160)	(0.152)	(0.102)	(0.241)	(0.161)
Log Importer Production	-0.897***	-0.872***	-0.145	-0.799**	-0.867***	-0.855***	-0.134	-0.782**
	(0.285)	(0.227)	(0.546)	(0.388)	(0.284)	(0.227)	(0.545)	(0.388)
Log Exporter Production	0.175	0.222*	0.709**	1.116***	0.176	0.225*	0.716**	1.087***
	(0.142)	(0.119)	(0.346)	(0.396)	(0.142)	(0.119)	(0.346)	(0.394)
Log Distance	-1.201***	-0.674***	-0.934***	-0.678***	-1.201***	-0.671***	-0.930***	-0.678***
	(0.054)	(0.035)	(0.102)	(0.079)	(0.054)	(0.035)	(0.102)	(0.079)
Free Trade Agreement	2.016***	0.652***	0.811***	1.343***	2.016***	0.650***	0.812***	1.349***
	(0.147)	(0.077)	(0.206)	(0.145)	(0.147)	(0.077)	(0.206)	(0.145)
Common Language	0.083	0.142		0.774***	0.083	0.143		0.775***
	(0.127)	(0.096)		(0.173)	(0.127)	(0.095)		(0.173)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	0.580	0.622**	0.395	0.384*				
	(0.357)	(0.244)	(0.578)	(0.202)				
Log SPS_FMD					0.075	-0.0240	-0.229	0.200
					(0.273)	(0.219)	(0.499)	(0.252)
Inverse Mills Ratio			-0.441*				-0.439*	
			(0.258)				(0.258)	
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	12,257	12,257	1,834	12,257	12,257	12,257	1,834	12,257
Percentage of Zeros	85.04%	85.04%	0.00%	85.04%	85.04%	85.04%	0.00%	85.04%

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels; "Yes" denotes that the fixed effects have been included in estimation

Table 3.17: Summary of Estimated Coefficients (PPML) from HS 0201, 0202, and 0203

Groups	HS 0201		HS 0202		HS 0203	
Data Types	Unbalanced	Balanced	Unbalanced	Balanced	Unbalanced	Balanced
Log GDP Per Capita	+***	+***	+***	+***	+***	+***
Log Importer Production	–***	–***	–*	–*	–**	–**
Log Exporter Production	+***	+***	+***	+***	+***	+***
Log Distance	–***	–***	–***	–***	–***	–***
Free Trade Agreement	+***	+***	–	+	+***	+***
Common Language	–***	–***	+	+***	+**	+***
Log Aggregate SPS	–	–	–	–	–***	–***
Log SPS_Animal Health	–	+	–*	–*	+	–
Log SPS_Human Health	–	–	–	–	+	+
Log SPS_Maximum Residue	–	+	–	+	–	–
Log SPS_BSE	–	–	–	–	+*	+*
Log SPS_FMD	–	+	–	–	+	+

Note: Single asterisks (*), double asterisks (**), and triple asterisks (***) denote significance at 1%, 5%, and 10% levels. “+” and “–” denote the sign of estimated coefficients.

5.4 Red Meat (Pooled over HS 0201, 0202, and 0203)

While the above results provide information about which meat products are mostly affected by SPS measures, it says little about how SPS measures perform in a more general red meat specification. In Table 3.18 and 3.19, the results of thirty gravity equations using pooled data are presented. This specification is important because it allows us to evaluate the red meat trade in a more general way by stacking all red meat products of HS 0201, 0202, and 0203 into a larger data set. This method is consistent with previous agricultural trade studies (Schlueter, 2009; Peterson *et al*., 2013; Grant *et al*., 2015). For the empirical estimations, commodity fixed effects, capturing unobserved red meat heterogeneity, are included in the gravity equation specifications. The superscript *k* which denotes meat products by HS codes, is omitted from the empirical equations because all three meat products are treated as an entire red meat group. Thus, for the data set with unbalanced exporters, the pooled data has a total of 10,625 observations and 48.52% of the sample are associated with zeros (Table 3.18). At the same time, the total number of observations for the data set with balanced exporters is 36,771 in which 85.15% of the sample are zeros (Table 3.19).

5.4.1 Red Meat (Pooled data)-Unbalanced Exporters

Table 3.18 presents the estimation outcomes resulting from the three techniques for the red meat gravity equations with unbalanced exporters. The misspecification tests still show that OLS and HMR are inferior to the PPML. Briefly, the parameter estimates of the gravity explanatory variables are rather similar in the five SPS model specifications. The estimated coefficients for importers' and exporters' production, GDP per capita, geographic distance, and the participation in FTAs have the expected sign and are statistically significant for each SPS scenario. Unexpectedly, the role of the common language has a significantly negative effect on the red meat sector, indicating that the common language may not as important as expected in global red meat market. The estimated coefficients of commodity fixed effects are also reported in this table (HS 0201 is the reference category). The significant and positive coefficients on pork fixed effect indicates that pork enjoys higher trade values than frozen beef as shown in Table 3.10.

As shown in Table 3.18, the SPS measures with multiple scenarios have no significant impacts on trade flow for red meat, except the SPS measures with policy goals in column (12). The twelfth column shows that the SPS measures with the policy objectives to protect animal health and reduce maximum residue limits have negative and significant effects on red meat trade flow. Meanwhile, the positive and significant coefficients for SPS regulations of protecting human health confirms the application of SPS measures providing a good human health for an active trade in red meat. However, since these effects can offset each other within a class, the overall effects of SPS measures still remain negative. This is a clear example of the benefit of examining SPS impacts in more detail than simply aggregating and estimating net impacts.

5.4.2 Red Meat (Pooled data)-Balanced Exporters

Table 3.19 reports the estimated coefficients of gravity equations for entire red meat with balanced exporters. Comparing with the results in Table 3.18, it is obvious that the estimates from the HMR and PPML do not present significant difference from those with unbalanced exporters. As discussed, the earlier data with balanced exporters, which may contains detailed information of why particular countries do not trade with each other, make the OLS estimator inconsistent. In contrast, the HMR and PPML have fairly robust performances even if the frequency of zero observation is extensive. However, the HMR estimators for all SPS scenarios are dominated by the PPML because the RESET test of each HMR rejects the null hypothesis that the coefficients on the test variables are zero. Similar to previous cases, the PPML is the only estimator with correct model specification.

From the results of PPML in Table 3.19, the estimates of GDP per capita in the importing market, exporters' production, geographic distance, and FTAs maintain the correct signs and are statistically significant as expected. Unlike Table 3.18, the importers' production and common language dummies no longer have negative influences on the entire trade flows of red meat. The pork fixed effects also have positive and significant effects on red meat trade. Same as the model with unbalanced data, the SPS measures with multiple scenarios show no significant impacts on trade flow for red meat, except the SPS measures with policy goals in column (12). The twelfth column shows that the SPS measures with the policy objectives to reduce maximum residue limits have negative and significant effects on red meat trade flow. Meanwhile, the positive and significant coefficient for SPS regulations of protecting human health confirms the use of measures providing a good human health for an active trade in red meat. SPS measures related to animal health are insignificant in this specification. All combined, these effects can offset each other within this scenario and the overall effects of SPS measures are still stay negative.

Table 3.18: Parameter Estimates of Gravity Equations—Pooled over HS 0201, 0202, and 0203 (*Unbalanced Exporters*)

Red Meat Trade (Unbalanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}
Log GDP Per Capita	0.355	-0.031	0.937***	0.982***	0.402*	-0.022	0.944***	0.980***	0.528**	0.013	0.960***	0.893***
	(0.224)	(0.052)	(0.134)	(0.121)	(0.225)	(0.053)	(0.135)	(0.129)	(0.232)	(0.054)	(0.139)	(0.133)
Log Importer Production	-0.600***	-0.147***	-0.387***	-0.009	-0.603***	-0.147***	-0.388***	-0.009	-0.602***	-0.147***	-0.387***	-0.029
	(0.083)	(0.019)	(0.051)	(0.046)	(0.083)	(0.020)	(0.050)	(0.046)	(0.083)	(0.019)	(0.051)	(0.046)
Log Exporter Production	2.554***	0.522***	1.225***	1.394***	2.555***	0.522***	1.226***	1.393***	2.557***	0.524***	1.226***	1.405***
	(0.081)	(0.021)	(0.088)	(0.107)	(0.081)	(0.021)	(0.088)	(0.107)	(0.081)	(0.020)	(0.088)	(0.108)
Log Distance	-2.630***	-0.616***	-0.974***	-0.549***	-2.630***	-0.616***	-0.975***	-0.549***	-2.630***	-0.616***	-0.974***	-0.559***
	(0.087)	(0.023)	(0.089)	(0.042)	(0.087)	(0.023)	(0.089)	(0.041)	(0.087)	(0.023)	(0.089)	(0.041)
Free Trade Agreement	1.843***	0.389***	0.475***	0.805***	1.844***	0.389***	0.476***	0.805***	1.844***	0.390***	0.477***	0.791***
	(0.198)	(0.047)	(0.125)	(0.108)	(0.198)	(0.047)	(0.126)	(0.107)	(0.198)	(0.047)	(0.126)	(0.108)
Common Language	0.319	0.125**		-0.200*	0.319	0.126**		-0.200*	0.324	0.128**		-0.202*
	(0.220)	(0.057)		(0.112)	(0.220)	(0.057)		(0.112)	(0.220)	(0.057)		(0.111)
Log Aggregated SPS					0.203*	0.0427	0.033	-0.003				
					(0.121)	(0.028)	(0.068)	(0.052)				
Log SPS_Animal Health									-0.427	-0.116*	-0.091	-0.277**
									(0.272)	(0.065)	(0.153)	(0.140)
Log SPS_Human Health									0.159	0.035	0.0743	0.430***
									(0.279)	(0.067)	(0.157)	(0.133)
Log SPS_Maximum Residue									0.203	0.052	-0.027	-0.502***
									(0.300)	(0.072)	(0.168)	(0.145)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-0.421*				-0.415				-0.422*	
			(0.253)				(0.253)				(0.252)	
Frozen Beef Fixed Effects	0.762***	0.210**	0.153***	-0.103	0.763***	0.211**	0.153***	-0.103	0.763***	0.210**	0.153***	-0.103
	(0.149)	(0.087)	(0.036)	(0.072)	(0.149)	(0.087)	(0.036)	(0.072)	(0.149)	(0.087)	(0.036)	(0.072)
Pork Fixed Effects	1.332***	0.875***	0.310***	0.687***	1.357***	0.880***	0.316***	0.686***	1.318***	0.877***	0.306***	0.742***
	(0.167)	(0.109)	(0.039)	(0.095)	(0.168)	(0.109)	(0.040)	(0.096)	(0.169)	(0.109)	(0.040)	(0.097)
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	10,625	10,625	5,469	10,625	10,625	10,625	5,469	10,625	10,625	10,625	5,469	10,625
Percentage of Zeros	48.52%	48.52%	0.00%	48.52%	48.52%	48.52%	0.00%	48.52%	48.52%	48.52%	0.00%	48.52%

(Table 3.18 continues)

Red Meat Trade	SPS BSE				SPS FMD			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}	$\mathrm{Ln}(T_{ij}+1)$	P_{ij}	$\mathrm{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.361	-0.028	0.935***	0.981***	0.356	-0.031	0.937***	0.984***
	(0.224)	(0.052)	(0.134)	(0.121)	(0.224)	(0.052)	(0.134)	(0.121)
Log Importer Production	-0.599***	-0.146***	-0.387***	-0.009	-0.600***	-0.146***	-0.388***	-0.009
	(0.083)	(0.020)	(0.051)	(0.047)	(0.083)	(0.019)	(0.051)	(0.046)
Log Exporter Production	2.554***	0.522***	1.223***	1.395***	2.554***	0.522***	1.225***	1.393***
	(0.081)	(0.021)	(0.088)	(0.107)	(0.081)	(0.021)	(0.088)	(0.107)
Log Distance	-2.630***	-0.616***	-0.972***	-0.548***	-2.630***	-0.616***	-0.974***	-0.549***
	(0.087)	(0.023)	(0.089)	(0.042)	(0.087)	(0.023)	(0.089)	(0.041)
Free Trade Agreement	1.843***	0.390***	0.475***	0.807***	1.843***	0.389***	0.476***	0.803***
	(0.198)	(0.047)	(0.126)	(0.107)	(0.198)	(0.047)	(0.125)	(0.108)
Common Language	0.322	0.126**		-0.201*	0.319	0.126**		-0.202*
	(0.220)	(0.057)		(0.112)	(0.220)	(0.057)		(0.112)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	-0.322	-0.097	0.052	0.066				
	(0.275)	(0.066)	(0.162)	(0.142)				
Log SPS_FMD					-0.096	-0.094	0.048	-0.117
					(0.517)	(0.122)	(0.299)	(0.251)
Inverse Mills Ratio			--0.425*				-0.419***	
			(0.253)				(0.261)	
Frozen Beef Fixed Effects	0.762***	0.210**	0.153***	-0.103	0.762***	0.210**	0.153***	-0.103
	(0.149)	(0.087)	(0.036)	(0.072)	(0.149)	(0.087)	(0.036)	(0.072)
Pork Fixed Effects	1.304***	0.879***	0.302***	0.694***	1.332***	0.876***	0.310***	0.686***
	(0.169)	(0.109)	(0.040)	(0.097)	(0.167)	(0.109)	(0.039)	(0.096)
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	10,625	10,625	5,469	10,625	10,625	10,625	5,469	10,625
Percentage of Zeros	48.52%	48.52%	0.00%	48.52%	48.52%	48.52%	0.00%	48.52%

Table 3.19: Parameter Estimates of Gravity Equations—Pooled over HS 0201, 0202, and 0203 (*Balanced Exporters*)

Red Meat Trade (Balanced)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML	OLS	Probit (1st)	Outcome (2nd)	PPML
Dependent Variable:	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}	$\text{Ln}(T_{ij}+1)$	P_{ij}	$\text{Ln}(T_{ij})$	T_{ij}
Log GDP Per Capita	0.055	-0.009	0.939***	0.995***	0.084	0.002	0.943***	0.992***	0.099	0.017	0.961***	0.910***
	(0.089)	(0.046)	(0.134)	(0.125)	(0.089)	(0.047)	(0.135)	(0.134)	(0.091)	(0.048)	(0.139)	(0.138)
Log Importer Production	-0.040*	-0.095***	-0.385***	-0.004	-0.041*	-0.096***	-0.385***	-0.004	-0.040*	-0.096***	-0.384***	-0.021
	(0.023)	(0.016)	(0.049)	(0.046)	(0.022)	(0.016)	(0.048)	(0.045)	(0.023)	(0.016)	(0.049)	(0.045)
Log Exporter Production	0.773***	0.613***	1.107***	1.390***	0.773***	0.613***	1.108***	1.390***	0.773***	0.614***	1.109***	1.397***
	(0.023)	(0.018)	(0.079)	(0.096)	(0.023)	(0.018)	(0.080)	(0.096)	(0.023)	(0.018)	(0.080)	(0.097)
Log Distance	-1.235***	-0.769***	-0.830***	-0.583***	-1.235***	-0.769***	-0.830***	-0.583***	-1.235***	-0.770***	-0.830***	-0.591***
	(0.035)	(0.020)	(0.083)	(0.045)	(0.035)	(0.020)	(0.083)	(0.046)	(0.035)	(0.020)	(0.083)	(0.045)
Free Trade Agreement	2.503***	0.669***	0.345***	1.008***	2.502***	0.670***	0.346***	1.007***	2.501***	0.670***	0.347***	0.999***
	(0.095)	(0.041)	(0.128)	(0.108)	(0.095)	(0.041)	(0.129)	(0.107)	(0.095)	(0.041)	(0.129)	(0.108)
Common Language	0.172**	0.344***		-0.154	0.172**	0.344***		-0.154	0.172**	0.345***		-0.150
	(0.082)	(0.045)		(0.121)	(0.082)	(0.045)		(0.121)	(0.082)	(0.045)		(0.121)
Log Aggregated SPS					0.117**	0.043*	0.023	-0.004				
					(0.048)	(0.025)	(0.069)	(0.054)				
Log SPS_Animal Health									0.002	-0.063	-0.098	-0.234
									(0.098)	(0.055)	(0.153)	(0.145)
Log SPS_Human Health									0.073	0.052	0.068	0.379***
									(0.094)	(0.056)	(0.158)	(0.138)
Log SPS_Maximum Residue									0.072	0.010	-0.029	-0.449***
									(0.110)	(0.061)	(0.168)	(0.151)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-0.709***				-0.708***				-0.708***	
			(0.171)				(0.171)				(0.170)	
Frozen Beef Fixed Effects	0.469***	0.325***	0.134	-0.028	0.469***	0.325***	0.134	-0.028	0.469***	0.325***	0.134	-0.028
	(0.051)	(0.030)	(0.089)	(0.076)	(0.051)	(0.030)	(0.089)	(0.076)	(0.051)	(0.030)	(0.089)	(0.076)
Pork Fixed Effects	0.346***	0.343***	0.816***	0.777***	0.361***	0.349***	0.819***	0.776***	0.355***	0.345***	0.816***	0.827***
	(0.052)	(0.033)	(0.106)	(0.099)	(0.052)	(0.033)	(0.107)	(0.0994)	(0.053)	(0.034)	(0.107)	(0.101)
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	36,771	36,771	5,469	36,771	36,771	36,771	5,469	36,771	36,771	36,771	5,469	36,771
Percentage of Zeros	85.12%	85.12%	0.00%	85.12%	85.12%	85.12%	0.00%	85.12%	85.12%	85.12%	0.00%	85.12%

(Table 3.19 continues)

Red Meat Trade	**SPS BSE**				**SPS FMD**			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}
Log GDP Per Capita	0.055	-0.007	0.937***	0.994***	0.053	-0.008	0.939***	0.996***
	(0.087)	(0.046)	(0.135)	(0.125)	(0.087)	(0.046)	(0.134)	(0.125)
Log Importer Production	-0.039*	-0.095***	-0.385***	-0.004	-0.039*	-0.095***	-0.385***	-0.004
	(0.023)	(0.016)	(0.048)	(0.046)	(0.023)	(0.016)	(0.049)	(0.046)
Log Exporter Production	0.773***	0.613***	1.107***	1.391***	0.773***	0.613***	1.107***	1.390***
	(0.023)	(0.018)	(0.079)	(0.096)	(0.023)	(0.018)	(0.079)	(0.096)
Log Distance	-1.235***	-0.769***	-0.829***	-0.582***	-1.235***	-0.769***	-0.830***	-0.583***
	(0.035)	(0.019)	(0.083)	(0.046)	(0.035)	(0.019)	(0.083)	(0.045)
Free Trade Agreement	2.503***	0.669***	0.346***	1.010***	2.503***	0.669***	0.346***	1.007***
	(0.095)	(0.041)	(0.129)	(0.107)	(0.095)	(0.041)	(0.128)	(0.108)
Common Language	0.172**	0.344***		-0.155	0.172**	0.344***		-0.155
	(0.082)	(0.045)		(0.120)	(0.082)	(0.045)		(0.120)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	-0.001	-0.040	0.049	0.056				
	(0.093)	(0.057)	(0.162)	(0.146)				
Log SPS_FMD					0.237	2.41e-05	0.0121	-0.029
					(0.167)	(0.105)	(0.300)	(0.268)
Inverse Mills Ratio			-0.709***				-0.709***	
			(0.171)				(0.171)	
Frozen Beef Fixed Effect	0.469***	0.325***	0.134	-0.028	0.469***	0.325***	0.134	-0.028
	(0.051)	(0.030)	(0.089)	(0.076)	(0.051)	(0.030)	(0.089)	(0.076)
Pork Fixed Effect	0.345***	0.340***	0.820***	0.784***	0.346***	0.343***	0.816***	0.777***
	(0.053)	(0.036)	(0.107)	(0.100)	(0.052)	(0.033)	(0.106)	(0.099)
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	36,771	36,771	5,469	36,771	36,771	36,771	5,469	36,771
Percentage of Zeros	85.12%	85.12%	0.00%	85.12%	85.12%	85.12%	0.00%	85.12%

Section 6 Spillover Effects and SPS Impacts on U.S. Red Meat Exports

Spillover effects across meat categories from FSIS recalls have been found in the domestic meat demand models in Chapter 2. Also the estimated results from pork trade model (Table 3.15 and 3.16) suggest that BSE may have positive spillover effects on pork trade. We expand those findings and aim to further investigate the potential spillover effects that may exist in red meat trade using gravity equations. Considering the diverse SPS regulations across multiple meat products (especially beef and pork), such spillover effects in red meat market can be classified into two categories: the effects of the different SPS regulations across different meat products and the product-specific spillovers on industry level. For instance, it is hypothesized that the imposition of SPS measures on pork (or beef) may have positive or negative effects on aggregated beef (or pork) trade flow. In order to have a general and direct understanding about spillover effects, the data set has been simplified, in which HS 0201 (meat of bovine animals, fresh or chilled) and HS 0202 are combined as one beef product. PPML estimator has proved an efficient and consistent estimator in the earlier results, the gravity equations for spillover effects are simply estimated by PPML.

Additionally, this section discusses the effects of SPS measures on the U.S. red meat exports. By sorting the existing data set, which contains fourteen red meat importers excluding the U.S. itself, the U.S. only red meat exports model is also estimated. As a result, the degrees of freedom have declined and it is therefore more difficult to identify the impacts of SPS measures with precision. Likewise, due to the limitations of degree of freedom, HS 0201 and HS 0202 are first combined as the U.S. beef export values and then stacked with U.S. pork exports to form a data set with larger number of observations. This data format helps to explain the impacts of SPS measures on U.S. red meat (group by beef and pork) exports.

6.1 Spillover Effects

The empirical models for detecting product-level spillover effects are developed from the previous gravity equations with PPML estimator. To be specific, two gravity equations standing for beef and pork are estimated individually with additional regressors. The ideas underlying the "spillover" are straightforward. First, by including the variables of production of another meat (say beef) along with the SPS measures on beef products in the pork gravity equation, one may identify and test how such beef-related factors impact the trade flows/values of pork. Second, a joint test of beef-related factors has been made to see whether the issues of production and food safety come from beef industry affect pork trade in a significant manner. However, one limitation of this "spillover" specification is that it cannot detect those effects across country pairs. The importer and exporter fixed effects controls for the aggregated impacts across country pairs which say nothing about specific spillover effects among countries. For instance, this model cannot specifically explain how Australian red meat trade values change when Asian countries imposed SPS measures on U.S. red meat exports. But it will say how global pork trade was impacted by beef SPS measures in an aggregated level.

Two model specifications have been identified. One of two gravity equations (e.g. pork) with PPML estimator is specified as follows:

(3.4)

$$T_{ijt}^{pork} = \exp\{\beta_0^{pork} + \beta_1^{pork}\ln(GDP_{it}) + \beta_2^{pork}\ln\left(IProd_{it}^{pork}\right) + \beta_3^{pork}\ln\left(EProd_{jt}^{pork}\right) + \beta_4^{pork}\ln\left(Dist_{ij}\right) + \beta_5^{pork}DFta_{ij} + \beta_6^{pork}DLan_{ij} + \lambda_1^{pork}Ln\left(SPS_{ijt}^{pork}\right) + \beta_7^{pork}\ln\left(IProd_{it}^{beef}\right) + \beta_8^{pork}\ln\left(EProd_{jt}^{beef}\right) + \lambda_2^{pork}Ln\left(SPS_{ijt}^{beef}\right) + \pi_i + \pi_j + \pi_t\}\varepsilon_{ijt}$$

Where the coefficients of β_7^{pork}, β_8^{pork}, and λ_2^{pork} capture the information about spillover effects individually and jointly from the beef industry to pork trade.

This study is the first known effort to detect the spillover effects over specific meat products. Table 3.20 and Table 3.21 presents the estimated coefficients of gravity equation with spillover effect for beef and pork, respectively. By looking at the estimated coefficients from the beef gravity equation (Table 3.20), the results say nothing about the pork-related SPS measures in an aggregated level have significant effects on beef trade flows. So the spillover effects from pork SPS regulations over beef trade do not exist. However, the coefficient of importers' pork production is negative and significant revealing that increasing pork production of importers also decrease beef trade flows. An interesting point here is that the importers' pork production even have larger negative effects than their beef production on beef trade flows. The p-value associated with the joint test of pork-related factors (pork production of importers and exporters and pork-related SPS measures) suggests that pork products demonstrate a significant spillover effect over beef trade at the industry level.

Table 3.21 shows the relevant information about pork trade. The individual factor such as exporters' beef production and beef-related SPS measures are insignificant among the beef-related coefficients in the pork gravity equation. Besides that, importers' beef production is detected to have a positive spillover effect over pork trade. However, the p-value associated with the joint test of beef-related factors (beef production of importers and exporters and beef-related SPS measures) suggests that beef products do not demonstrate a significant spillover effect over pork trade at the industry level. So pork trade may not be affected by beef production and the SPS measures related to other meat sectors.

Table 3.20: Estimated Coefficients of Beef Gravity Equation with Spillover Effects (PPML)

Variables	Coeff.	Std. Err.
Log GDP Per Capita	1.329***	(0.232)
Log Importer Production_Beef	-0.605**	(0.302)
Log Exporter Production_Beef	2.598***	(0.311)
Log Importer Production_Pork	-1.150***	(0.449)
Log Exporter Production_Pork	-0.166	(0.284)
Log Aggregate SPS_Beef	-0.065	(0.125)
Log Aggregate SPS_Pork	0.035	(0.139)
Log Distance	-1.051***	(0.055)
Free Trade Agreement	1.045***	(0.119)
Common Language	-0.263***	(0.130)
Joint test of pork-related factors (P-value)	0.038	
Fixed Effects	Yes	
No. of Observations/% of zeros	12,257/82.21%	

Table 3.21: Estimated Coefficients of Pork Gravity Equation with Spillover Effects (PPML)

Variables	Coeff.	Std. Err.
Log GDP Per Capita	1.109***	(0.168)
Log Importer Production_Pork	-0.825**	(0.406)
Log Exporter Production_Pork	0.719	(0.483)
Log Importer Production_Beef	0.418*	(0.231)
Log Exporter Production_Beef	0.425	(0.410)
Log Aggregate SPS_Pork	-0.123	(0.097)
Log Aggregate SPS_Beef	-0.020	(0.082)
Log Distance	-0.671***	(0.078)
Free Trade Agreement	1.362***	(0.144)
Common Language	0.774***	(0.172)
Joint test of beef-related factors (P-value)	0.172	
Fixed Effects	Yes	
No. of Observations/% of zeros	12,257/85.14%	

6.2 SPS Impacts on Red Meat Exports-the U.S. Only Case

In this subsection, the research about the determinants of red meat trade and the role of SPS moves from considering multiple exporters to a more narrow assessment of the U.S. only case. We demonstrate this research from the U.S. prospective because the U.S. is one of the most important red meat producers in the world[28]. The impacts of food safety and animal health concerns on meat trade are of particular significant to the U.S. due to the high value and large proportion of meat exports in the global market. On one hand, U.S. meat exports are vulnerable to food safety issues and SPS barriers. One particular example is the U.S. beef industry has experienced huge negative shocks following the outbreak of BSE in the state of Washington in 2003, which caused about $2.5 billion loss to the U.S. beef industry (Coffey *et al*., 2005). On the other hand, food safety and SPS barriers have been considered as important issues in negotiations on meat trades between the U.S. and other countries. SPS barriers related to animal hormone use, microbiological contamination, meat irradiation, and other requirements may impact the flow of red meat to some countries as well as impose additional costs on U.S. meat producers and exporters.

The data set estimated in this case is pooled over beef and pork. This is because we would like to have a general understanding about how SPS measures impact overall exports of U.S. red meat. Also, the issue of degrees of freedom for a single meat product is another concern. The data set is constructed by sorting the existing data which has fourteen importers in total. Consequently, there are only 238 (17 years × 14 importers × 1 commodity × 1 exporter) observations for estimation. So the single meat data sets have been stacked which creates a total of 476 (17 years × 14 importers × 2 commodities × 1 exporter) observations for red meat

[28] See Table 3.1 to Table 3.4 for reference.

products with 18.48% of zeros. On average, the imports from these fourteen importers account for above 80% of U.S. red meat (beef and pork) exports over the sample period.

The estimating procedures follow the same methodology as shown in previous table: three estimators are applied for regressions and the RESET test is used for misspecification. Since the U.S. is only exporter, no exporter fixed effect are included in the empirical gravity equations. The complete results of empirical gravity equations are reported in Table 3.22. The significant coefficients among inverse Mills ratio confirm the necessity of applying sample selection methods, but the RESET's reject the MHR due to the potential misspecification. The PPML is still considered as the only reliable estimator to get relatively robust and consistent estimates. For each coefficient, the variables including GDP per capita, the production volumes of importers and the U.S., geographic distance, and FTAs are significant and have the expected sign under all five SPS scenarios. Controversially, the coefficients for common language are negative and significant. This may be because the imports made by non-English speaking or Asian countries/regions (Japan, South Korea, Hong Kong, and Taiwan) account for bigger portion of U.S. red meat exports compared with other English-speaking countries, which alters the sign and significance of common language. A notable feature among these coefficients is that the sizes of exporters' red meat production, FTA dummy, and common language dummy are relatively larger than the results among previous tables. Two rationalizations can help interpret the sizes. First, due to the data availability, the importers are narrowed into fourteen countries for estimating use. The U.S. red meat exports maybe more sensitive than non-U.S. exporters. Second, a data set with relatively smaller number of observations (compared to data set in above case) may still contain the potential degree of freedom problem.

In general, our results supports the notion that SPS regulations reduce U.S. red meat exports. The coefficients on the aggregated SPS variable is negative and statistically significant across beef and pork exports in column (8) of Table 3.22. Also, the SPS measures with policy goals protecting human health negatively and significantly impact U.S. exports due to the healthy risk (column (12)). Furthermore, column (16) presents that the BES-related SPS measures significantly reduce red meat trade. Compared to the aggregated SPS and SPS with policy goals, the coefficient of BSE-related SPS measures have larger size (-0.738), which reveals that the BSE outbreak made U.S. meat industry suffer a great loss in world market.

Table 3.22: Parameter Estimates of Gravity Equations— *U.S. Meat Export (pooled over beef and pork)*

U.S. Meat Export (pooled over beef and pork)	**Without SPS**				**Aggregated SPS**				**SPS Goals**			
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}
Log GDP Per Capita	-0.993	-3.698**	1.339**	1.400***	-1.014	-3.771**	1.125*	0.873***	-1.129	-3.889**	1.247**	0.946***
	(0.840)	(1.860)	(0.600)	(0.210)	(0.860)	(1.891)	(0.585)	(0.219)	(0.879)	(1.950)	(0.527)	(0.223)
Log Importer Production	-0.861***	0.403	-0.351**	-0.132**	-0.861***	0.410	-0.355**	-0.140**	-0.858***	0.439	-0.383***	-0.150**
	(0.232)	(0.361)	(0.171)	(0.0644)	(0.232)	(0.369)	(0.164)	(0.0635)	(0.233)	(0.393)	(0.145)	(0.0643)
Log Exporter Production	21.66***	30.00***	4.249	4.370***	21.67***	28.35***	4.305	4.336***	21.61***	31.91***	4.451*	4.395***
	(4.212)	(10.68)	(3.042)	(0.754)	(4.219)	(10.54)	(2.907)	(0.694)	(4.229)	(11.36)	(2.563)	(0.704)
Log Distance	-2.751***	22.79	-10.90**	-0.697***	-2.752***	23.17	-10.21**	-0.686***	-2.767***	24.26	-11.72***	-0.686***
	(0.313)	(59.01)	(4.723)	(0.0667)	(0.314)	(59.37)	(4.545)	(0.0646)	(0.315)	(57.61)	(3.989)	(0.0642)
Free Trade Agreement	6.105***	0.330	2.354**	4.727***	6.086***	0.328	2.228**	4.695***	6.025***	0.627	2.536***	4.703***
	(1.043)	(0.933)	(0.953)	(0.520)	(1.058)	(0.942)	(0.916)	(0.519)	(1.060)	(0.979)	(0.803)	(0.518)
Common Language	-9.215***	-12.79		-5.886***	-9.201***	-12.92		-5.419***	-15.08***	-14.00		-5.450***
	(1.285)	(44.68)		(0.552)	(1.289)	(44.96)		(0.565)	(1.191)	(43.63)		(0.564)
Log Aggregated SPS					-0.0528	0.524	-0.547*	-0.292***				
					(0.462)	(0.506)	(0.303)	(0.0834)				
Log SPS_Animal Health									-0.380	-1.291	-0.0329	-0.288
									(1.103)	(0.894)	(0.661)	(0.248)
Log SPS_Human Health									0.570	2.292**	-1.606**	-0.491*
									(1.234)	(1.137)	(0.730)	(0.288)
Log SPS_Maximum Residue									-0.842	-1.473	1.186	0.251
									(1.323)	(2.598)	(0.776)	(0.302)
Log SPS_BSE												
Log SPS_FMD												
Inverse Mills Ratio			-2.567***				-2.454***				-2.165***	
			(0.753)				(0.714)				(0.591)	
Pork Fixed Effects	7.940***	1.393*	9.589***	1.016***	7.936***	1.372*	9.233***	0.995***	7.939***	1.395**	10.25***	0.997***
	(1.080)	(0.823)	(3.294)	(0.189)	(1.082)	(0.787)	(3.228)	(0.179)	(1.086)	(0.692)	(3.466)	(0.181)
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	476	476	388	476	476	476	388	476	476	476	388	476
Percentage of Zeros	18.48%	18.48%	0.00%	18.48%	18.48%	18.48%	0.00%	18.48%	18.48%	18.48%	0.00%	18.48%

(Table 3.22 continues)

U.S. Meat Export (pooled over beef and pork)	SPS BSE				SPS FMD			
Column:	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Estimator:	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML	OLS	Probit (1^{st})	Outcome (2^{nd})	PPML
Dependent Variable:	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}	$Ln(T_{ij}+1)$	P_{ij}	$Ln(T_{ij})$	T_{ij}
Log GDP Per Capita	-0.998	-3.819**	1.370**	1.402***	-0.968	-3.679**	1.361**	1.399***
	(0.841)	(1.889)	(0.579)	(0.216)	(0.841)	(1.873)	(0.607)	(0.209)
Log Importer Production	-0.859***	0.447	-0.362**	-0.153**	-0.862***	0.403	-0.348**	-0.132**
	(0.232)	(0.376)	(0.166)	(0.0643)	(0.232)	(0.362)	(0.173)	(0.0645)
Log Exporter Production	21.59***	28.67***	4.338	4.272***	21.60***	30.06***	4.257	4.370***
	(4.220)	(10.71)	(2.935)	(0.760)	(4.216)	(10.70)	(3.078)	(0.754)
Log Distance	-2.758***	23.65	-11.03**	-0.698***	-2.746***	22.76	-10.24**	-0.697***
	(0.314)	(58.67)	(4.527)	(0.0653)	(0.313)	(58.97)	(4.809)	(0.0667)
Free Trade Agreement	6.114***	0.216	2.419***	4.693***	6.140***	0.347	2.352**	4.726***
	(1.045)	(0.955)	(0.914)	(0.519)	(1.045)	(0.952)	(0.964)	(0.520)
Common Language	-9.253***	-13.23		-5.791***	-9.236***	-12.81		-5.889***
	(1.285)	(44.43)		(0.558)	(1.282)	(44.65)		(0.555)
Log Aggregated SPS								
Log SPS_Animal Health								
Log SPS_Human Health								
Log SPS_Maximum Residue								
Log SPS_BSE	0.532	0.934	-1.401*	-0.738**				
	(1.148)	(0.772)	(0.782)	(0.304)				
Log SPS_FMD					1.691	-0.131	2.025	-0.107
					(2.275)	(1.486)	(1.665)	(0.674)
Inverse Mills Ratio			-2.477***				-2.597***	
			(0.708)				(0.762)	
Pork Fixed Effects	7.964***	9.397***	1.320*	0.966***	7.933***	9.603***	1.393*	1.016***
	(1.083)	(3.290)	(0.796)	(0.193)	(1.081)	(3.294)	(0.833)	(0.189)
Importer Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Commodity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ramsey RESET	Reject	N/A	Reject	Accept	Reject	N/A	Reject	Accept
Observations	476	476	388	476	476	476	388	476
Percentage of Zeros	18.48%	18.48%	0.00%	18.48%	18.48%	18.48%	0.00%	18.48%

Section 7 Conclusion and Future Research

SPS measures imposed by importers are an important example of non-tariff measures faced by red meat exporters. Using a series of product-level gravity models with multiple estimators, this study analyzes the trade effects of diverse SPS measures that are imposed in the meat industry and discover the determinants of red meat trade. The red meat products have been classified by HS four-digit code and the data sets of balanced and unbalanced exporters with different portion of zero trade flows have been applied to identify the performance among three major estimators: the OLS, Heckman Selection, and PPML. Combined with Ramsey's RESET tests, the estimated results from ninety product-specific gravity equations have confirmed that the PPML is the only appreciate estimator which tolerates heteroscedasticity and maintains correct model specifications. Econometrically, the empirical results largely support the theory of Silva and Tenreyro (2006, 2011) and indicate that PPML estimator is generally well behaved, even when the conditional variance is far from being proportional to the conditional mean.

The current study sheds light on the determinants of red meat trade. By running the preferred gravity model specifications, the factors including personal income (measured by GDP per capita), exporters' meat production, and free trade agreements have been confirmed as the trade facilitators. For estimating SPS measures, diverse scenarios have been made by applying classification of measures into SPS areas and policy goals. Among multiple product-level gravity equations, the sum of all counts of SPS measures for a particular country do not present a significant effects on either beef or pork trade. The further disaggregated SPS measures with policy goals shows that there are specific SPS measures that have a substantial positive impact and others with a significant negative impact on either frozen beef or pork. These effect can offset each other within a class. Further research investigated the SPS impacts on U.S. red meat exports specifically. Empirical results imply that the BSE-related SPS measures tend to have more severely negative effects than other measures on U.S. red meat industry. Also, the size of estimated coefficients of the U.S. meat production and geographic distances are larger compared to the models with multiple exporters. All combined, the empirical results are mostly consistent with existing literature, in which SPS appear to be more of a trade barrier than a catalyst to trade.

Detecting spillover effects across and industries on trade is another contribution of this study. By checking the individual coefficient from an updated beef gravity equation, the results cannot provide a significant evidence that pork-related SPS measures have significant effects (or spillover) over beef trade flows. The spillover effects from pork regulations on beef trade do not exist. However, importers' pork production decreases beef trade flow. Furthermore, the joint test of pork-related factors suggests that pork products demonstrate a significant spillover effect over beef trade at the industry level.

Moreover, in-depth consideration of the trade effects of SPS measures should be noted by meat industry. Enhancing SPS measures and related food safety standards is associated with reducing the value and probability of bilateral red meat trade. However, if the fixed cost provided by SPS measures can be recovered by subsequent export sales, then the premium still might be obtained from being able to sell treated red meat products in destination country. Therefore, it is essential for exporters and meat industry to adopt and implement higher-level sanitary standards on every link of meat production which could help continuously maintain consumers' confidence in world market.

While the results from empirical models are fairly informative, additional consideration should be pointed out. First, due to the difficult nature of collecting detailed SPS data, the current study only uses the frequency of SPS measures issued in a given year without considering the closing date of that particular measures. The data for SPS measures is not accumulated over the sample period. Future research can extend the SPS data from WTO SPS-IMS and search for more detailed information or a better data collecting method. Second, due to the data availability, the red meat category is the research subject which only refers to beef and pork. Meanwhile, the four-digit HS code also could be further disaggregated into six-digit HS code and bring more specific products (e.g. HS 020110: meat of bovine animals, fresh and chilled—classification of carcasses and half-carcasses) into research. Any future research examining additional or more specified meat can enhance the understanding of meat trade effects and improve policy and industry SPS concerns.

In addition, from an estimation perspective, the time invariant country-pair fixed effects may help to explain and control the information that are unique to the bilateral country pair, such as geographic distance, common language, and other time invariant trade costs. This estimation of gravity models in future research would be beneficial by further controlling all country-specific dummy variables (e.g. language and distance) and refining focus on the effects of SPS measures. This may address the counter-intuitive results of language dummies in the fresh/chilled beef (HS 0201) models.

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Appendix to "Determinants of Red Meat Trade: the Role of SPS Measures"

This appendix is provided to accompany the main context of Chapter 3 by conducting a series of endogeneity tests for the variable of SPS measures. The data of SPS measures estimated in Chapter 3 is collected by a frequency method. The frequency of SPS measures account for the presence or absence of SPS regulations/standards in a particular time period. Previous studies such as Disdier *et al*. (2008) claimed that this approach could suffer an endogenous problem because it fails to provide information on possible effects of trade barriers on prices, production, and international trade. In order to confirm that the variables of SPS measures is acceptable in the empirical gravity equations, a bivariate probit model has been used to detect if the frequency approach can cause endogeneity.

The bivariate probit regression has two stages. The first stage examines the probability that a specific importer issues a SPS measure with the existing trade determinants including GDP per capita, meat production volumes, distance, common language, and free trade agreement. The second stage accounts for the information whether or not to trade between two countries given the estimation of first stage. The two equations are evaluated simultaneously using seemingly bivariate probit estimators. In this setting, the exogeneity condition is stated in terms of the correlation coefficient ρ, which can be interpreted as the correlation between the unobservable explanatory variables in the two equations. If $\rho = 0$, the two stages are uncorrelated and it is reasonable to consider SPS is exogenous in the second stage. Conversely if $\rho \neq 0$, this implies that SPS is correlated with the dependent variables (whether to trade or not) in the second stage. The tests results are presented in Table A3.1.

Table A3.1: Summary of Endogeneity Tests

Unbalanced Exporters	No Fixed Effects (FE)	FE on SPS Equation	FE on Trade Equation	FE on Both Equations
HS 0201	Endogeneity	Exogeneity	Endogeneity	Exogeneity
HS 0202	Endogeneity	Endogeneity	Exogeneity	Exogeneity
HS 0203	Endogeneity	Endogeneity	Exogeneity	Exogeneity
Pooled data	Endogeneity	Endogeneity	Exogeneity	Exogeneity
Balanced Exporters	No Fixed Effects (FE)	FE on SPS Equation	FE on Trade Equation	FE on Both Equations
HS 0201	Not converge	Endogeneity	Not converge	Exogeneity
HS 0202	Endogeneity	Endogeneity	Exogeneity	Exogeneity
HS 0203	Exogeneity	Endogeneity	Exogeneity	Not converge
Pooled data	Endogeneity	Endogeneity	Exogeneity	Exogeneity

Table A3.1 reports a summary of the endogeneity tests for each model specification with different meat products and data sets. In general, whether or not we include fixed effects[29] in each equation plays an important role for deciding if the SPS variable is endogenous or not. To be specific, the SPS variables in all models with fixed effects except HS 0203 (balanced exporters), display exogenous features in empirical estimations. Therefore, the frequency method to collect the data of SPS measures can be safely applied into our empirical research, which imposes fixed effects, without any concerns about endogeneity.

[29] Fixed effects here refer to importer fixed effects, exporter fixed effects, and year fixed effects together.

Chapter 4 - Summary

Food safety issues can potentially cause significant economic losses for meat producers in both domestic and international market. The assessment of the overall impacts on meat demand that may results from food safety issues requires a thorough understanding of meat safety regulations and policy. This dissertation consist of two research efforts focused on on both domestic and international meat markets. The two components of this dissertation are to assess the effect of food safety recall on U.S. meat demand across regions and products using scanner data, and to examine the determinants of red meat trade and the effects of Sanitary and Phytosanitary (SPS) measures.

The first research contributes to the applied economics literature related to food safety recalls and meat demand in several key ways. A series of Rotterdam models of consumer response are used to estimate own- and cross-effects of beef *E. coli* recall and beef non-*E. coli* recall on meat demand. Two model specifications varying in beef aggregation are constructed. The impacts of recall information are evaluated through a multi-regional modeling approach including total U.S. and eight separate regions facilitating regional comparisons. Combined, the multi-regional modeling approach, based upon monthly grocery-store scanner data, considering separate FSIS recall types, provides a much deeper understanding of current consumer responses to meat food safety events.

The Rotterdam model specifications are applied to monthly grocery-store scanner data from January 2009 to February 2014 to further assess the effects of food safety recall information on U.S. meat demand. To achieve this, we applied several approaches varying in imposed separability and autocorrelation corrections. We estimated meat demand models for different U.S. geographic regions for the first known time. Through multiple assessments, results suggest beef *E. coli* recalls significantly reduce the demand for ground beef contemporaneously among most, but not all, regions in the United States. Although the majority of other food safety recalls do not reveal statistically significant effects on meat demand in most of regions, joint tests of food safety recall effects still indicate that U.S. meat demand is affected by food safety incidents. The tests for regional heterogeneity fail to reject the hypothesis of no differences among regions in most cases, which indicates that the majority of food safety recalls have the same effects on consumer meat demand across regions.

The second study use a series of product-level gravity models to analyze the trade effects of diverse SPS measures on global red meat trade. Red meat products have been classified by HS four-digit code and the data sets of balanced and unbalanced exporters with different portion of zero trade flows have been applied to identify the performances among three major estimators: the OLS, Heckman Selection, and PPML. Ninety product-specific gravity equations have been examined and then confirmed that the PPML is the only appropriate estimator to deal with heteroscedasticity and maintains correct model specifications. This study also indicates the PPML estimator is generally well behaved, even when the conditional variance is far from being proportional to the conditional mean.

The second study also sheds light on the determinants of red meat trade. By running the preferred gravity model specifications, the factors including personal income (measured by GDP per capita), exporters' meat production, and free trade agreements have been confirmed as the trade facilitators. For estimating SPS measures, diverse scenarios have been made by applying classification of measures into SPS areas and policy goals. Among multiple product-level gravity equations, the aggregated SPS measures for a particular country do not present a significant effects on either beef or pork trade. The further disaggregated SPS measures with policy goals shows that there are specific SPS measures that have a substantial positive impact and others with a significant negative impact on either frozen beef or pork. Further research also been made to investigate the SPS impacts on U.S. red meat exports. Empirical results implies that the BSE-related SPS measures tend to have more severely negative effects than other measures on U.S. red meat industry. Overall, the empirical results support the existing literature, in which SPS appear to be more of a trade barrier than a catalyst to trade. We also test the potential spillover effects on red meat trade, the joint test of pork-related factors suggests that pork products demonstrate a significant spillover effect on beef trade at the industry level whereas beef does not.

Recognizing the limitations of this dissertation provides suggested directions for future studies. Results from the first study do not distinguish FSIS recall events by regions nor do we estimate the effects of meat recalls on restaurant food service demand. The two features are valuable for future work as corresponding data becomes available. The second study uses the frequency data of SPS measures issued in a particular year without knowing the closing date of that particular measures. Future research can extend the SPS data from WTO SPS-IMS and search for a better data collecting method to further refine the format of the SPS variables.