DISSERTATION

THREE ESSAYS ON ECONOMICS OF HIGHLY PATHOGENIC AVIAN INFLUENZA

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Fall 2016

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ABSTRACT

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Highly pathogenic disease can affect trade between countries. How health officials in an affected country manage a disease event can affect the potential impacts of a disease event. Highly pathogenic avian influenza (HPAI) and exotic Newcastle disease (ND) are two diseases that affect poultry industries and it is important to understand the ramifications of having an event of either of these diseases. The implications of an outbreak are first felt internally, where domestic markets are affected through changes in stocks and price changes. Secondly, the impacts are external. These external impacts can come in the form of potential trade bans from importing countries as a result of health concerns. This work analyzes both of these impacts to provide a holistic understanding of a HPAI or ND event on U.S. poultry markets.

The first essay models the U.S. egg layer industry to estimate the producer and consumer impacts of a regionalized disease outbreak to compare the benefits of using business continuity during a disease event. The estimated value of business continuity during a hypothetical disease event is $13.6 million in two quarters. The second essay then determines the factors that affect trade quantities for exporting countries including the effect of a disease outbreak on the quantity traded. Highly pathogenic avian influenza is found to change the composition of trade between different product categories, providing exporters a better understanding of how product mixture might change during a disease event. The third essay builds on the methodology of the second essay to compare modeling properties of an improved estimator in determining the factors that affect bilateral trade quantities. There are small efficiency gains captured by using a systems approach, but data are limited due to the methodology, causing a tradeoff between usable bilateral trade data and efficiency gains in estimation. The three essays combined provide an overview of how a highly pathogenic disease outbreak can affect U.S. markets for poultry products both domestically and internationally.

ACKNOWLEDGEMENTS

This material is based upon work supported by the U.S. Department of Homeland Security under Cooperative Agreement Number DHS 2010-ST-061-AG0002 and U.S. Department of Agricultural under Cooperative Agreement Number 14-9200-0374.

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official polices, either expressed or implied, of the U.S. Department of Homeland Security or U.S. Department of Agriculture.

DEDICATION

A posse ad esse, a Latin expression that embodies my PhD journey. From possibility to actuality, this has taken a lot of support, advice, and encouragement from many sources to become a reality. I dedicate this work to those who walked with me on this journey, those who taught me to rise above adversity, and those who encouraged me to stay the course. This is for you all.

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CHAPTER 1 - INTRODUCTION

Highly pathogenic disease events in animal agriculture can have severe and lasting effects on the entire food supply chain including production, consumption, and trade. In the United States, poultry production is a valuable domestic industry as well as export market. The 2015 value of U.S. poultry production was $48.0 billion (USDA-NASS, 2016) with 15% of total supply exported abroad (USDA-ERS, 2016). U.S. consumer preference for poultry products has steadily increased over the past 50 years. In 2015, per capita consumption of poultry products was 106.1 pounds, which translates to 50.3% of total U.S. meat consumption, making it the top protein consumed (The National Chicken Council, 2016). The poultry industry is important to U.S. agricultural production and a highly pathogenic disease event can have drastic and costly ramifications domestically and internationally along the supply chain.

In the poultry industry, exotic Newcastle disease (ND) and highly pathogenic avian influenza (HPAI) have caused billions of dollars worth of damage worldwide with over 71 distinct events from 2000 to 2015 (OIE, 2015). The United States has had a limited number of highly pathogenic poultry disease events. However, due to the nature of highly pathogenic diseases, the events in the United States have been severe. For example, HPAI was detected in a small backyard flock in Oregon on December 19, 2014. The virus soon migrated using bird migration routes called flyways. From Oregon, wild birds carried the virus through the Pacific Flyway to the Mississippi Flyway. The total number of birds affected grew to more than 48 million for 219 reported detections before it was eradicated, with the final detection on June 17, 2015 (USDA-APHIS, 2015a). Total costs to taxpayers were estimated to be greater than $950 million according to United States Department of Agriculture (USDA-APHIS, 2015b), which accounts for the government response cost including depopulation, disinfection, and indemnity.

Additionally, consumers faced drastically higher egg prices as a result of the disease event, further increasing the total impact (Huang, Hagerman, & Bessler, 2016).

Production losses can be compensated by federal agencies, which can provide indemnity and reimbursements for certain disease management requirements during a disease event. Consumer food prices can be impacted due to negative supply shocks, such as depopulation of infected animals that can drive supply shortages of domestic products. Trade from an infected country or region can be impacted due to trading decisions by importing countries to limit or stop all trade. Total welfare implications of a disease event depend on the severity and length of the event.

Each disease event is unique, and affected parties at all levels of the supply chain are impacted differently. If an exporting country could know the potential ramifications of a disease event, they could optimize their response and understand the value of a rapid eradication strategy. Producers that are able to move their products during a disease event benefit from potentially higher prices as a result of product shortages. Consumers are expected to have negative price implications from a disease event, but mitigation of supply losses can reduce these impacts. Processors might be able to better manage stocks of products, allocating goods along their production chain to best meet demand. Exporters would be interested in knowing the expected length of trade disruptions or the factors that contribute to increased trade disruptions.

The overarching theme of poultry disease impact analysis is developed for the following three essays to analyze highly pathogenic poultry disease events on the United States, focusing on total welfare and trade. These essays fill some of the gaps in the literature surrounding highly pathogenic poultry disease events by estimating a product category analysis of trade and estimating the impacts of business continuity on producers and consumers. The purpose of this research is to provide industry and government with an understanding of the economic impact of disease management strategies and trade implications during a disease event.

The objective of the first essay is to estimate the economic impacts of business continuity during a disease event. Business continuity allows for industries to prepare for unplanned situations so that they can function as smoothly as possible during an unexpected event. The second essay focuses on international trade implications of HPAI and ND disease events using a gravity model of trade for poultry products. The third essay is a methodological extension of the gravity model analysis to improve efficiency of the Hausman-Taylor (HT) estimator used in the second essay, focusing on methodological improvements of the estimator with empirical estimations. This research provides additional information to policy makers to help reduce the negative effects of highly pathogenic disease events.

The costs of any disease event can be significant. Thus, it is imperative to have best disease management practices to reduce the burden of an event while also maintaining the security and safety of the food supply. The first essay addresses these issues by analyzing the economic impacts of a simulated HPAI outbreak in Minnesota laying houses to compare scenarios that allow for business continuity versus do not allow business continuity. Business continuity implies a preplanning by industry actors such as firms or the government so that when major events occur, the disruptions to business processes are minimized. Business continuity is paramount for most industries, but especially so for those with high debt and asset fixity like the U.S. poultry industry. Farmers rely on contractual revenue streams to cover the high debt burden of production. If the revenue streams stop, a layer producer could cease to meet financial obligations within a few days without outside intervention or assistance.

During a disease event such as HPAI, the initial response for controlling and eradicating a highly contagious disease is to establish a control area around the infected premises. Movement restrictions, or stop movement orders, are given for these control areas, which limits movement onto and off of farms. These control areas could potentially encompass non-infected farms that would also be subject to the movement restrictions. Egg producers have limited storage capacity and are forced to dispose of products due to disease even if not infected. The costs of a disease event can be reduced and business continuity for the layer industry can be achieved by creating a process that allows the movement of product from premises that test negative for HPAI for a specified period of time provided in disease spread risk assessments. To estimate these impacts, a partial equilibrium model is developed for the U.S. layer industry. Disease shocks are applied with and without business continuity, and the disease effects are compared to assess permitting movement as a viable disease management practice. This analysis provides estimates of the market changes, in prices and quantities, and resulting welfare impacts of changing disease management practices to incorporate business continuity.

The focus of the first essay is the domestic implications of disease management. Although international trade is accounted for within the modeling framework, the focus on U.S. markets does not provide any understanding of the international trade implications of a disease event. The second essay addresses this matter by using an econometric approach to estimate the factors that influence the quantity of poultry products traded during a highly pathogenic poultry disease event, HPAI or ND. Estimating a model for international trade that accounts for the presence of disease events over time provide policy makers more information to plan for a potential future disease event and the ability to estimate the economic costs of disease-related polices while accounting for trade implications. Previous work has investigated factors that contribute to export revenue recovery after a disease event, but has not estimated changes in quantity traded (Johnson et al., 2015). By extending the discussion to quantity, this analysis provides insights into commodity-specific bilateral trading decisions during a disease event and can provide *ex ante* insights on potential subsequent trade implications.

To estimate the factors affecting trade, a gravity model of trade is applied to monthly bilateral trade data for 22 exporting countries that have had either HPAI and/or ND within the time frame of the data. The monthly data spans from 2004 to 2015 for 15 different poultry product categories (e.g., 020711 - Fresh Chicken not cut into pieces). Data are obtained from the Global Trade Information System's Global Trade Atlas. The disease event data are compiled from reported disease events through the World Organization for Animal Health (OIE) accounting for 71 distinct disease events (Johnson et al., 2015). The model is estimated with a Hausman-Taylor (HT) estimator for panel data to account for individual effects while also estimating the impacts of time variant and time invariant variables. For each product category, a separate HT estimation is modeled due to the dimensionality of the complete bilateral trading data. These results are expected to show differences in the effects of factors that influence trade of fresh and frozen poultry products differentiated by processing stage, a level of modeling not estimated previously. An exporting country's industry and government can use the estimates to understand the potential shift in import demand for products and modify production and processing for export during a disease event given the importer's trade response.

The final essay builds on the methodology of the second essay to address the need to estimate each product category individually. The methodology employed in the second essay does not take into account the underlying factors that influence the product categories simultaneously due to limitations in estimation. Typically, a seemingly unrelated regression

(SUR) would be applied to a system of related equations to gain efficiency across the estimations, which would account for the correlation in the error terms across models. A three-dimensional HT estimation has been developed and used in the political economy literature, but has not been employed in agricultural trade analyses. Trade analyses that use the HT approach are two-dimensional in nature as motivated by the data available. However, the data used in the second essay are three-dimensional: 1) time, 2) bilateral trade partners, and 3) individual product categories. To address this issue, a seemingly unrelated Hausman-Taylor estimator (HT-SUR) will be used to estimate the three dimensional model. These results will be compared with individual modeling as detailed in the second essay. The systems approach will be applied in an empirical estimation using data from the second essay including those observations that can be estimated with a SUR approach. This methodological extension expands the HT estimator for three-dimensional data not found in current economics literature and can provide researchers with efficiency gaining methodology.

Each of the three essays creates better understanding of the economic impacts of a poultry disease event in the United States as standalone studies. However, it is also the intention of this work to show complementarity of the findings from each essay to describe the implications of an avian disease event across the entire supply chain from consumers to international trading partners. The analyses provide research into the different levels of the supply chain to estimate the effects of domestic disease response throughout the economy and the factors that influence trade during a disease event. These analyses provide industry, government, and researchers with valuable insights that can be applied to future animal health events.

CHAPTER 2 - ECONOMIC IMPACTS OF BUSINESS CONTINUITY ON AN OUTBREAK OF HPAI IN MIDWEST EGG LAYING OPERATIONS

INTRODUCTION

Animal disease outbreaks, especially those involving pathogens that are transboundary and/or zoonotic, can have substantial potential for severe epidemiological and economic impacts throughout the animal supply chain.[1] The U.S. federal government's response to a positive identification of highly pathogenic avian influenza (HPAI) is 'stamping out', or depopulation of infected and contact premises. In addition, control areas are created around infected premises and restrictions of the movements of poultry and poultry products within and out of these control areas may be implemented, including stop movement orders (USDA-APHIS, 2012).[2] A stop movement order disease management strategy can have considerable economic implications for producers, and depending on the concentration of affected producers within the control area, could distress the entire industry. These potential consequences have led stakeholders to question whether or not there are cases where, after assessing the risk, it is deemed economically beneficial to allow monitored premises to move product within and from inside of to outside of a control area.[3]

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[1] Transboundary diseases are those that are highly transmissible or contagious and are not limited to a specific geography such as national borders. Zoonotic diseases are infectious diseases transmissible between animals and humans.
[2] A disease response plan reflecting changes to movement control regulations as suggested by business continuity work and the Secure Egg Supply Plan, has been drafted (USDA-APHIS, 2015).
[3] A monitored premises is an at-risk premises within a control that "objectively demonstrates that it is not an Infected Premises, Contact Premises, or Suspect Premises" (USDA-APHIS, 2015).

Business continuity planning is a means for industries to prepare for unplanned events so that businesses can function as smoothly as possible with the least disruption during these events (Miller & Parent, 2012; Zsidisin, Melnyk, & Ragatz, 2005). Outbreaks of HPAI in commercial poultry can have many economic impacts on producers (both contract and independent), processors (integrators), and consumers, as evidenced by the 2014-2015 outbreak of HPAI in domestic egg layer flocks in the United States. Pre-planning for animal disease outbreaks such as HPAI can potentially alleviate some of these business strains (Hennessey et al., 2010).

Studies have estimated the economic impacts of HPAI in a variety of geographic locations including Southeast Asia (Rushton et al., 2005) and the United States (Djunaidi & Djunaidi, 2007). The transboundary nature of HPAI lends itself to estimations of the economic cost of outbreaks and spread between closely connected countries (Beato & Capua, 2011). The use of spatial equilibrium modeling has been used heavily in these studies because of its tractable nature and ability to estimate economic implications prior to a disease event (Paarlberg, Seitzinger, & Lee, 2007; You & Diao, 2007). Johnson et al. (2014) estimated the potential economic impacts of a hypothetical HPAI outbreak on the Texas supply chain for broilers, turkeys, and egg production. Their research estimated the impacts of regionalization, (i.e., a separation of a specific section of geography from the rest of the United States.) In their work, Texas was regionalized during an HPAI outbreak. When trade restrictions were concentrated on Texas, the impacts of HPAI were lessened on the rest of the United States.

Objective

Similar to previous literature, the current analysis uses regionalization during a hypothetical outbreak of HPAI as a means of preserving international trade for the regions of the United States not affected by the outbreak. The goal of this paper is to evaluate the economic consequences of allowing business continuity during an outbreak. Specifically, this work evaluates the economic impacts of a hypothetical HPAI outbreak in the State of Minnesota by quantifying the regionalized domestic production and market effects while accounting for possible changes in international trade. Using disease spread data derived from an epidemiological model, a partial equilibrium model of the U.S. egg laying industry is constructed to assess the impacts of the movement of nest run eggs within and from within to outside of, control areas, as well as the ability of regionalization to meet domestic needs.

Figure 2-1 is a simplified schematic of the U.S. egg industry, outlining the diversion of egg products. Egg layers produce either hatching eggs or nest-run shell eggs, more commonly called shell eggs. Hatching eggs are excluded from this analysis as they are produced through special breeder houses and are not substitutable at the market level for consumption eggs. Shell eggs are diverted into table eggs or breaker eggs (to be further processed into specific final consumption products). Prior to packaging into cartons, table eggs must be processed (i.e., graded, washed, and sanitized). These cartons are then shipped to retailers or final consumers. Breaker eggs are broken and processed into liquid, dried, or frozen eggs. These egg products can be packaged and sold as processed eggs or used as inputs in other food products. For this study, liquid, dried, and frozen eggs are aggregated into one group called "processed eggs."

As the first study to estimate the economic impacts of business continuity, this analysis opens the dialog for benefits and costs to affected parties during a disease outbreak. Economic assessment of permitted movements will provide government and industry decision makers an *ex ante* evaluation of the potential plausibility and effectiveness of an outbreak response strategy that provides industry with business continuity.

BACKGROUND

Since 2006, risk analysts at the USDA's Center for Epidemiology and Animal Health have participated in a joint collaborative effort with industry, federal and state agencies, and academia, called the Egg Sector Working Group. This group estimated the potential risk of HPAI spread given movement of various poultry products from premises located in close proximity to a known infected premise during an outbreak. The collaborative effort is in support of the USDA's Animal and Plant Health Inspection Service's (APHIS) emergency preparedness and response planning. In response to topics identified by the Egg Sector Working Group, a set of proactive risk assessments have been crafted to analyze the disease spread risk of movement within and from inside to outside of a control area for various egg products.[4] These assessments adhere to the World Organization for Animal Health's (OIE) international standards and guidelines for risk analysis which are meant to ensure food safety as well as animal and plant health (2013a, 2013b), which arise from the Agreement on Sanitary and Phytosanitary Measures of the World Trade Organization.

Components of a proactive risk assessment include: entry assessment, exposure assessment, consequence assessment, and risk estimation. Entry assessments describe the pathways in which a pathogen, such as HPAI, can be introduced to an environment. Exposure assessments estimate the likelihood of disease transmission, or exposure occurring through different vectors. For HPAI, these assessments estimate the disease spread risks associated with product movement inside and outside of control areas. Entry and exposure assessments have

[4] This working group was instrumental in developing the Secure Egg Supply Plan to help support business continuity in the egg industry (Hennessey et al., 2010).

been estimated for eight egg commodities (USDA-APHIS, 2013).[5] This research builds on these risk assessments to create a consequence assessment, or a rigorous assessment of the direct and indirect impacts, for business continuity during a disease outbreak. The risk estimate is a combination of the first three assessments to generate a complete risk estimation for business continuity.

In deciding whether or not it is feasible to allow a permit system during a HPAI outbreak, risk assessors should consider many factors. First, they should consider the probability of the increased exposure of susceptible poultry due to product movement. Second, the likely social and economic consequences of this increased exposure due to product movement should be considered. Finally, if stop movement orders are in place, the social and economic impacts of these orders should be estimated.

Movement permits can be issued when premises are shown to be free from HPAI and following prescribed biosecurity measures. A movement permit allows for movement of sanctioned products within, into and out of control areas. These permits require a premises to test negative for HPAI prior to any movement, with continued testing to ensure a disease free premises (USDA-APHIS, 2013). Additionally, premises must follow strict biosecurity measures. When these requirements are met, premises may be granted movement permits that sanction selected movements (e.g., eggs and egg product) off farm or on farm (e.g., animal feed). Each of these additional movements poses a specific level of added risk for the potential spread of HPAI.

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[5] The eight egg products include: pasteurized liquid eggs, non-pasteurized liquid eggs, washed and sanitized shell eggs, nest run shell eggs, hatching eggs, day-old chicks, egg shells, and inedible eggs.

METHODOLOGY

This analysis involves two components. First, an epidemiological model is used to estimate the spread of HPAI in the State of Minnesota. Second, outputs from the epidemiological model are incorporated into a quarterly economic partial equilibrium model. Two outbreak management strategies are simulated in the epidemiological and economic models for comparison: 1) implementing business continuity; and 2) not implementing business continuity.

Epidemiological Modeling

Epidemiologic diseases are tools that can be used to study disease dynamics in a population and to evaluate the effectiveness of control measures and the impact of permitted movements. HPAI spread among commercial poultry operations in Minnesota is simulated using InterSpread Plus (Stevenson et al., 2013), an epidemiological modeling framework specifically parameterized for the scenario in Minnesota.[6] The model simulates disease spread among commercial poultry operations via movement of animals (direct contact), movement of people, vehicles, and other fomites (indirect contact), and local area spread or disease spread that is associated with distance between infectious and susceptible premises, but cannot be attributed to a specific mechanism or traced (e.g., via wildlife).[7]

Detection of infected premises occurs through either passive surveillance or active surveillance. The probability of detection of infected premises given the number of days since infection via passive surveillance is defined using a mortality threshold trigger applied to output from a separate within-flock disease spread model (Malladi et al., 2015). Passive surveillance applies to the entire population during the period prior to initial detection of disease and to

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[6] Disease parameters were established based on the 1983 Pennsylvania HPAI H5N2 virus strain.
[7] It is assumed in this study that movement of egg products from infected premises is prohibited.

premises located in the free area (i.e., outside of a control area) after initial disease detection. The probability of detection via active surveillance applies to premises located within control areas and is also derived from a within-flock disease spread model but every other day testing by real time reverse transcription-polymerase chain reaction (RRT-PCR) is assumed rather than a mortality threshold trigger. When business continuity measures are implemented in the model, table-egg layer premises located within control areas are assumed to be tested daily rather than every other day, consistent with those outlined in the Secure Egg Supply Plan; however, premises from other sectors of the poultry industry located within control areas continue to be tested every other day. Associated control measures that are implemented within the model are depopulation of infected premises, tracing of contact premises, creation of control areas, and movement controls for premises located within control areas. Infected and detected premises are quarantined while all other premises in the control area have reduced frequency of direct and indirect contacts.

Disease spread is simulated with 100 iterations under two scenarios: 1) allowing for business continuity; and 2) without business continuity. Allowing for business continuity, table-egg layer premises that are tested daily and are not infected, but are located within a control area, are permitted to move egg product outside the control area. With no business continuity measures, product movement from table egg layer premises out of the control areas is prohibited (i.e., any premises located within a control area must maintain a stop movement order whether or not infection has been detected on the premises). Model parameters for detection within control areas and on-farm biosecurity are different for the two management strategies. Daily testing of layers located in control areas is assumed for the business continuity scenario, whereas every other day testing is used for the no business continuity scenario. Enhanced biosecurity measures described in the Secure Egg Supply Plan are represented in the model by decreasing the probability of transmission given indirect contact.

Economic Modeling

The market impacts on control areas and the surrounding non-control areas will be estimated assuming stop movement orders are issued, as well as with permitted movement of products. Accordingly, a quarterly, partial equilibrium model is developed of the U.S. egg industry. The model accounts for the movement of eggs from farm to processor, diversion to type of final egg product, and movement from processor to consumer. Additionally, international trade is incorporated in the model. While trade quantities for egg commodities are relatively small compared to other poultry commodities, the inclusion of international trade allows for a complete model of the U.S. egg industry.

The partial equilibrium model used in this analysis models the diversion of farm eggs to the final end consumer.[8] This includes the processing decision to produce table or processed eggs. The model is written in its fully differentiated form such that all variables represented are percent changes (E is used to denote dln).

$$EP_i = \theta_{l,i}\, Ew + \theta_{s,i}\, EP_s + \theta_{k,i}\, Er_i \qquad (1)$$

Price (P_i) of output egg type i (*te*: table eggs; *pe*: processed eggs) is determined by the price of inputs used in production (w), the price of shell eggs (P_s), and returns to capital (r) in Equation 1. θ represents the unit revenue share for input (labor (l), shell eggs (s), and capital (k)) by egg type i.

$$ES = E\phi + \lambda_{s,te}\, Eq_{te} + \lambda_{s,pe}\, Eq_{pe} + \lambda_{s,te}\, Ea_{s,te} + \lambda_{s,pe}\, Ea_{s,pe} \qquad (2)$$

[8] For this analysis, shell eggs relate to eggs at the farm gate (i.e., those produced by layer birds), table eggs are cartons of eggs that consumers purchase, and processed eggs are an aggregation of final egg products of breaker eggs from Figure 2-1.

Shell egg supply (S) is a function of the quantity of eggs demanded (q_i) and the per-unit derived demand for eggs of different consumption types ($a_{s,i}$). λ represents the factor share of production. Exogenous shocks to the egg supply, such as depopulated poultry due to HPAI, can be applied using ϕ.

$$ES = \varepsilon_s EP_s \qquad (3)$$

Additionally, shell egg supply is a function of the producer price of shell eggs multiplied by the own-price elasticity of shell eggs (ε_S) (Eq. 3). This additional equation is applied to derive the change in shell egg price that drives changes in final demand prices.

$$Ek_i = Ea_{k,i} + Eq_i \qquad (4)$$

Industry capacity (k_i) is a function of the quantity and the per-unit derived demand of the i^{th} egg type (Eq. 4). While some asset fixity exists in egg processing capital, the assumption in this model is that there are marginal changes in efficiency in production given price incentives; thus, allowing for changes in industry capacity to occur.

$$Ea_{s,i} - Ea_{k,i} = -\sigma_{s,k|i}(EP_s - Er_i) \qquad (5)$$

$$Ea_{l,i} - Ea_{k,i} = -\sigma_{l,k|i}(Ew - Er_i) \qquad (6)$$

Equation 5 indicates substitutability of capital and shell egg inputs that depend on the returns to capital and returns to shell eggs. Equation 6 allows for the substitution between labor and capital. For both equations, σ represents the elasticity of substitution between the two inputs.

$$\theta_{e,i}\, Ea_{s,i} + \theta_{l,i}\, Ea_{l,i} + \theta_{k,i}\, Ea_{k,i} = 0 \qquad (7)$$

Equation 7 represents an adding up condition that dictates changes to the per-unit derived demand multiplied by its respective unit revenue share should sum to zero.

$$q_i Eq_{\,i} + I_{i,t-1} EI_{\,i,t-1} = (X_i - M_i)E(X_i - M_i) + D_i ED_{\,i} + I_{i,t} EI_{\,i,t} \qquad (8)$$

Market clearing conditions (Eq. 8) insure that the market clears such that net exports (exports (X_i) minus imports (M_i)), domestic consumption (D_i) and ending stocks (I_i) in the current period (t) should equal production plus beginning stocks ($I_{i,t-1}$) in the previous period (t-1). This condition holds for both table eggs and processed eggs.

$$EI_t = \varepsilon_{i,i} EP_s \quad (9)$$

Ending stocks (I_t) are a function of the price of shell eggs defined by equation (9) for current time period t.

$$ED_i = E\gamma_i + \varepsilon_{i,i}\, EP_i + \varepsilon_{i,j}\, EP_j \quad (10)$$

Domestic demand for egg type i is a function of own (P_i) and cross prices (P_j) and own- ($\varepsilon_{i,i}$) and cross-price elasticities ($\varepsilon_{i,j}$) (Eq. 10). Possible demand shocks to demand preferences during a disease outbreak are represented by γ. There are no published studies on the impacts of HPAI on U.S. egg consumption. A case study for Italian consumers (Beach et al., 2008) could be drawn upon to represent U.S. demand changes, but due to differences in consumer buying ability and additional factors such as specific attitudes regarding diseases that have not been researched for U.S. consumers, the exogenous change in demand is assumed zero for this analysis.

$$E(X_i - M_i) = E\delta_i + \varepsilon_{x-m,i} EP_i^w \quad (11)$$

Net exports are a function of the world reference price and shocks to net exports (Eq. 11). Net exports are regional exports (X_i) minus regional imports (M_i) for product i. This provides a means to model international trade embargos by region as a result of a disease outbreak. Exogenous trade shocks are represented by δ_i.

$$P_i^w EP_i^w = P_i\, EP_i + c_i Et_i \quad (12)$$

The world reference price, P_i^w, is assumed to be a function of U.S. domestic prices plus transportation costs (c_i) (Eq. 12). This reference price helps the markets clear within the model.

STUDY REGION

The Midwestern United States is the focal region for the study. Regions are defined based on geography and value of production using the 2013 percent of total United States production as published by USDA - National Agricultural Statistics Service (USDA-NASS, 2014). The Midwest region accounts for 43% of annual commercial egg production. Within the Midwest region, Minnesota produced 2,852 million eggs in 2013 making it the eleventh largest egg producing state (USDA-NASS, 2014). For this analysis, the index flock is located in Minnesota and the State of Minnesota is subsequently regionalized from the rest of the United States (ROUS). The ROUS is considered disease free and has reductions in state-level imports from Minnesota during regionalization. International trade is modeled to only affect Minnesota's exports as it is regionalized from the ROUS.

DISEASE MANAGEMENT STRATEGIES

Disease management strategies (or model scenarios) used in this analysis consist of an outbreak of HPAI originating in an egg layer house in Minnesota. The modeled outbreak is contained within the Minnesota layer industry (i.e., no transboundary or state-to-state transmission). Two disease management strategies are estimated for both the epidemiological and economic models: 1) allowing for business continuity; and 2) no business continuity.

The epidemiological model results provide a range for the number of affected birds that will then be incorporated in the economic model. Epidemiological model output is disaggregated into the number of depopulated birds and the number of surveyed birds affected (Table 2-1).

The number of affected birds enters the economic model as calculated shocks to the quantity of shell eggs given movement restrictions, or lack thereof. These shocks are calculated using the annual eggs per laying hen equivalency. Values are entered into the economic model stochastically using a triangular distribution that limits the lower end of birds affected to zero, in order to account for variability in epidemiological model outputs. Using Simetar software, the model is estimated for 500 iterations which provides the mean solutions reported as well as the variation around these estimates (Richardson, Feldman, & Schuemann, 2003). The average duration for the modeled HPAI outbreak is 42 days within the first quarter. The overwhelming majority of the estimated outbreaks are contained within the first quarter (91%), with eight percent of outbreaks lasting through the second quarter, and less than two percent of the epidemiological model outbreaks continuing to the third quarter. While market price implications can extend beyond this study period, layer repopulation is an ongoing process that reduces the duration of the disease impacts.

Repopulation is the process in which farms are restocked with new birds to start a new cycle of production. Repopulation processes typically include young pullets moved from pullet farms to layer farms prior to full maturity, or before the onset of egg production. Traditionally, the poultry industry has a supply chain for replacement birds. During an outbreak, replacement birds are used to replenish depopulated flocks, as well as increased hatching numbers. From the hatchery, bird maturity occurs in less than five months, or two quarters. Given that birds stocks could be significantly repopulated during this time, it is possible to rebuild similar bird populations that existed prior to the outbreak within two quarters. For this model, the economic impacts for both scenarios are estimated for two quarters coinciding with the epidemiological outbreak scenarios and industry repopulation potential.

DATA FOR THE ECONOMIC MODEL

Baseline data for supply and demand are collected from various USDA sources including Agricultural Marketing Service (AMS) (2015), Economic Research Service (ERS) (2013, 2015), National Agricultural Statistics Service (NASS) (2014, 2016), and the World Agricultural Supply and Demand Estimates (WASDE) (USDA-ERS, 2016). Data includes egg use, consumption, beginning and ending stocks, imports, exports, and egg prices for all levels of production. Exogenous shocks for the analysis are calculated as a percentage change from baseline egg production using the epidemiological model output. Parameters that are calculated are derived through substitution of the behavioral equations using parameters and initial baseline values where appropriate. Stocks, net exports, and price elasticities are estimated, as they are specific to the type of product, either table or processed eggs, as described in appendix 1.

RESULTS AND DISCUSSION

U.S. layer production is predominantly managed under contract farming in the United States (79%) and producers are responsible for facilities and management of layers birds under this system (MacDonald & Korb, 2011; USDA-NASS, 2014). Producers are paid on the number of eggs produced. During a disease outbreak, if movement restrictions are put in place, a non-infected farm that is unable to move eggs produced could become financially distressed and unable to meet financial obligations if the restrictions are persistent. Typical midsized commercial operations have three to four days of egg storage (USDA-NASS, 2014). After producers fill storage to capacity, they are left to bear the burden of these foregone earnings. Given a monitoring timeframe of at least 21 days (USDA, 2015), producers are left with no choice but to destroy eggs.[9] During this monitoring period, flocks are tested and monitored, or are under surveillance, for signs of HPAI infection.

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[9] It should be noted that producers can be compensated for disease management compliance in the interest of food safety and human health concerns, but the extent of these compensations are at the discretion of USDA (Johansson, Preston, & Seitzinger, 2016).

Table 2-2 is a summary of the economic impacts for Minnesota under both disease management strategies, with and without business continuity. The model results are estimated distributions around each of the endogenous variables. For the purpose of this exposition, the mean values are presented and discussed. In 97% of the epidemiological scenarios, the disease is contained within two quarters. While economic costs could continue beyond the simulated disease outbreak with industry repopulation efforts, the economic model results are only estimated for the first two quarters.

Minnesota Results

The loss of birds through depopulation and the reduction in shell egg supply as a result of movement restrictions, translates into the total reduction in the number of shell eggs supplied. As expected, shell egg prices increase in both scenarios due to the reduction in supply. In the business continuity scenario, the increase in shell egg price is muted as the reduction in supply is reduced. Eggs produced on premises within control areas are permitted to move, mitigating the losses associated with disease management. In quarter one, the change in shell egg price is 80.8% less when compared to the no business continuity scenario. Minnesota table egg prices were 41.0% higher in the same scenario, while processed egg prices were 16.9% higher with no business continuity. Table egg prices were affected more than processed eggs in relative terms due to changes in production, which is discussed below.

Pricing differences between the two scenarios are inherent in how the egg model handles surveyed birds (i.e., those birds being monitored for presence of disease); they are treated as birds removed from the system in the absence of business continuity. With fewer birds and no change in consumers' demand, prices increase for eggs and egg products. In this case, prices are driven higher with no business continuity as a result of supply shortages. Disease management practices that provide business continuity during an outbreak decreases the reduction in supply and lessens the consumer price impact as compared to not allowing business continuity.

In addition to price changes, there were also egg quantity changes due to the combined effects of the imposed reduction in shell eggs and the resulting model-predicted price effects. Production of table and processed eggs decreased over both quarters, consistent with a reduction in production inputs (shell eggs). In both quarters, the no business continuity scenario shows a greater reduction in production. Table egg and processed egg production were reduced by 18.8% and 44.8%, respectively, in quarter one as compared with the no business continuity scenario. The differences in these impacts are explained by how eggs are allocated in Minnesota. Part of the decision-making process along the supply chain is to choose how to allocate shell eggs between table eggs and processed eggs. In Minnesota, processed eggs were impacted to a greater degree than table eggs, as the higher price of table eggs incentivized more eggs to be diverted for table egg consumption. It is also important to remember that there are industry capacity constraints that limit the amount of eggs that can be diverted to either production process.

The quantity of eggs demanded in Minnesota decreased over both scenarios for table and processed eggs due to an increase in end product prices. Again, the differences between business continuity and no business continuity scenarios show a greater reduction in quantity demanded in the no business continuity case. The reductions in the quantity demanded led to increases in net state-level exports of both products in both scenarios and quarters. The net exports from Minnesota are modeled as movement to the ROUS as part of the economic model specification. There was a larger impact on net exports of table eggs than processed eggs.

Rest of the United States Results

The price impacts for the ROUS were similar in sign to Minnesota (Table 2-3). Prices for shell eggs, table eggs, and processed eggs all increased for both scenarios. However, the differences between the two disease management strategies were smaller than those for Minnesota; 0.4% and 0.2% for table and processed eggs, respectively, for quarter one. These differences are expected to be smaller than Minnesota's, as the ROUS shocks are only the reduction in trade with Minnesota, and the ROUS was still able to trade egg products internationally. The supplies from Minnesota that traditionally would have been exported were removed from the model as Minnesota was regionalized by importers.

Production changes differed for the ROUS as table egg production increased for both quarters. Processed egg production was estimated to decrease in the second quarter. These changes in processing are due to increases in net exports to fill the void caused by lost supply from Minnesota. As part of the market clearing conditions, it is expected that all excess eggs not consumed domestically are exported. While regional consumer population changes were exogenously increased in the model to reflect actual changes in consumer population, changes in the quantity demanded was estimated to decline due to higher prices of egg products. The market must clear the eggs, implying an increase in exports to trading partners.

Welfare Effects

Table 2-4 presents the changes in producer and consumer surplus. These measures were calculated using Wohlgenant's (2013) estimation of changes in consumer surplus (CS) and producer surplus (PS) when calculating a linearized partial equilibrium model. Equations 13 and 14 represents consumer and producer surplus, respectively.

$$\Delta CS_i = -(1+\varepsilon_i)^{-1} P_{0,i} Q_{0,i} (e^{(1+\varepsilon_i)EP - \varepsilon_i \delta} - 1) \quad (13)$$

$$\Delta PS_i = (1+\varepsilon_s)^{-1} P_{0,i} Q_{0,i} (e^{(1+\varepsilon_s)EP - \varepsilon_s \theta} - 1) \tag{14}$$

where $P_{0,i}$ and $Q_{0,i}$ are the original baseline price and quantity, ε_i is the price elasticity of demand for the *i*th good, ε_s is the price elasticity of shell egg supply, δ is a demand shock, and Φ is a supply shock.

For Minnesota, the total economic impact to the producer is the combination of calculated changes in producer surplus plus the exogenous cost of the shocks that are imposed. The model does not account for the excess burden on producers infected by HPAI including the explicit costs related to depopulation. The depopulation impacts are based on a conservative estimate of total depopulation costs ($0.89 per bird), which includes disposal, depopulation, cleaning and disinfection, and indemnity costs, multiplied by the number of affected birds.[10] Indemnity is estimated to be the average value of a layer for weeks 20-110, the typical lifespan of layer birds in commercial layer operations.

Non-infected producers that are able to sell their products during a disease outbreak benefit from increased prices. Changes in producer surplus are positive across all scenarios and quarters. The results for the no business continuity scenario show an additional $2.3 million in producer surplus over business continuity due to the steep price increase in quarter one. However, accounting for depopulation impacts that are not included in the producer surplus measure, total economic impact to the producer is negative for all quarters except quarter two of the business continuity scenario. These calculations are based on the expected number of affected birds, which was zero for quarter two of the business continuity scenario. For quarter

[10] The estimated depopulation cost of $0.89 per bird was elicited through expert opinion within the layer industry.

one, the total potential negative change in economic impact to the producer without business continuity is $9.4 million more than the case with business continuity.

As expected, changes in consumer surplus are negative for both scenarios due to price increases and reduced supply. For quarter one, business continuity provides a $3.7 million reduction in potential losses in consumer surplus in the face of no business continuity. By providing a disease management method that alleviates some of the supply stress, consumer surplus losses are minimal.

Total welfare effects for Minnesota are negative due to the combination of negative changes in total economic impact to producer and consumer welfare. Quarter one has a reduced total change in welfare of $5.9 million for business continuity and a reduction of $19.0 million for no business continuity, a difference of $13.1 million. The total difference for quarter two is $0.5 million, due to relatively smaller disease shocks and layer repopulation. The estimated welfare impact in Minnesota by allowing business continuity during a disease outbreak is $13.6 million; a conservative estimate given the low expected value of indemnity payments used for depopulated birds.

The ROUS has much smaller impacts in absolute dollar terms, as there were no infected birds in either scenario. This simplifies the welfare estimation for the ROUS, as the costs associated with depopulation do not apply. Producer surplus changes were relatively small, but positive, again due to increases in retail prices. Producers gained slightly more surplus during the no business continuity compared to business continuity. Similar to Minnesota, changes in consumer surplus losses were mitigated when allowing for business continuity. Total welfare changes for ROUS were nominal, including marginally positive effects for the business continuity scenario and marginally negative results for the no business continuity scenario.

The movement of shell eggs from non-infected, monitored premises poses relatively low risk for increased disease spread compared to movement restrictions (USDA-APHIS, 2010). Providing permits for movement from monitored premises reduces the loss in shell egg supply, which in turn reduces the price increases caused by supply shortfalls, resulting in muted welfare impacts relative to the no business continuity case. While there are other factors to consider when discussing disease management (such as disease spread risks, best management practices, and additional strain on management requirements), the economic implications for business continuity imply a social benefit for providing a mechanism for movement of products with low disease spread risk from non-infected premises.

CONCLUSIONS

During an outbreak, if stop movement orders are established within a control area, the total number of birds, or equivalent quantity of eggs supplied, is reduced not only by the number of depopulated birds, but also the quantity of product produced on premises within the control area. Business continuity allows premises that are not infected to move product out of the control area. To qualify for a movement permit, premises must submit to increased biosecurity measures in accordance with state animal health officials.

Business continuity maintains income streams for farms not infected with HPAI, and accordingly, decreases the negative supply shocks associated with traditional disease management strategies that do not allow for business continuity. This allows products that are not infected and considered low-risk for disease spread to move off monitored premises, thus alleviating some of the impacts of a HPAI outbreak. During the 2014-2015 HPAI outbreak in the United States, more than 7,800 permits were issued which reduced the financial strain on producers and consumers (Thompson & Pendell, 2016). The majority of these movements were for animal feed and eggs/egg products.

When comparing results between the two disease management strategies, business continuity vs. no business continuity, providing a system to issue permits for product movement reduces the negative economic impact of an outbreak. Business continuity during an outbreak decreases the negative welfare effects on consumers and producers by decreasing potential price increases for final egg products and minimizing potential revenue losses at the producer level. The total welfare impact on Minnesota, the infected region, of a HPAI outbreak may be reduced by $13.6 million if business continuity is allowed as a disease management strategy. The impacts on the ROUS are minimal under the business continuity scenario considering there is mitigated reduction in egg shocks in Minnesota. The total welfare impact includes the implicit costs such as disposal costs, depopulation, cleaning and disinfection, and indemnity. These are included in the analysis to account for the cost associated with the supply shock, which is typically excluded from traditional welfare measures. In addition, when discussing the economic impacts of the estimated hypothetical HPAI outbreak in Minnesota, the additional burden of financial stress beyond the cost of disposal was not calculated, but should be included in future research as additional costs of stop movement orders. The model provides a conservative, yet valuable benchmark estimate of the welfare effects of changing disease management practices to incorporate business continuity during a disease event.

This analysis estimates the impacts of an outbreak of HPAI in the United States, but the implications apply to other diseases and industries. The economic impacts of other foreign animal diseases could be mitigated through proactive risk assessments, sound disease control measures, and continually improving disease testing. Historically, an outbreak of a highly pathogenic disease has led to devastating reductions in animal stocks and costs across the affected industries. If the risk of spread can be estimated for different diseases and industries, it may prove valuable to move past traditional movement restrictions and allow for business continuity during an outbreak. The livestock industry, with a longer restocking phase than the poultry industry, would benefit from continued revenue streams during an outbreak. While the risk estimates for the livestock sector have not been conducted yet, the future of animal health management should to take into account the costs of traditional practices. With increases in biosecurity, surveillance, and detection, business continuity may be new norm as evidenced by this analysis and experience from the 2014-2015 outbreak of HPAI in the United States.

Table 2-1: Summary statistics of epidemiological model output for a hypothetical Midwestern U.S. highly pathogenic avian influenza outbreak (in numbers of birds)

Scenarios		Mean	Std. Dev.	Min	Max
Business Continuity					
Depopulation	Quarter 1	2,946,622	3,076,405	189,340	14,675,910
Depopulation	Quarter 2	38,547	320,158	0	6,828,979
Surveyed	Quarter 1	9,283,398	6,430,009	746,583	23,229,372
Surveyed	Quarter 2	150,405	817,428	0	11,219,885
No Business Continuity					
Depopulation	Quarter 1	3,598,477	3,721,945	189,340	20,004,252
Depopulation	Quarter 2	70,960	387,807	0	7,626,020
Surveyed	Quarter 1	9,283,398	6,430,009	746,583	23,229,372
Surveyed	Quarter 2	150,405	817,428	0	11,219,885
Outbreak Duration	Days	42	17	12	216

Source: Malladi et al., 2015

Table 2-2: Model estimated mean changes in HPAI economic impacts in Minnesota (%) with and without business continuity

		Business Continuity		No Business Continuity	
	Unit	Quarter 1	Quarter 2	Quarter 1	Quarter 2
Shell Egg Price	$/Dozen Eggs	38.4%	15.9%	119.2%	41.3%
		(0.19)	(0.10)	(0.39)	(0.20)
Table Egg Price	$/Dozen Eggs	22.1%	11.0%	63.1%	24.3%
		(0.10)	(0.05)	(0.20)	(0.10)
Processed Egg Price	$/ Equivalent Dozen Eggs	8.9%	4.1%	25.8%	9.2%
		(0.04)	(0.02)	(0.08)	(0.04)
Production Table Eggs	Dozen eggs	-6.5%	-1.1%	-25.3%	-6.5%
		(0.05)	(0.02)	(0.09)	(0.05)
Production Processed Eggs	Equivalent Dozen Eggs	-20.4%	-8.1%	-65.2%	-22.3%
		(0.11)	(0.05)	(0.22)	(0.11)
Net Exports Table Eggs	Millions of Dozens of Eggs	12.9%	6.4%	37.0%	14.2%
		(0.06)	(0.03)	(0.12)	(0.06)
Net Exports Processed Eggs	Millions of Equivalent Dozens of Eggs	2.2%	1.0%	6.4%	2.3%
		(0.01)	(0.01)	(0.02)	(0.01)
Demand Table Eggs	Millions of Dozens of Eggs	-10.6%	-5.3%	-30.1%	-11.7%
		(0.05)	(0.02)	(0.09)	(0.05)
Demand Processed Eggs	Millions of Equivalent Dozens of Eggs	-3.8%	-1.7%	-11.2%	-3.8%
		(0.02)	(0.01)	(0.04)	(0.02)

Source: Economic Model Estimations; Standard deviation in parentheses

Table 2-3: Model estimated changes in mean HPAI economic impacts for the rest of the United States (%) with and without business continuity

		Business Continuity		No Business Continuity	
	Unit	Quarter 1	Quarter 2	Quarter 1	Quarter 2
Shell Egg Price	$/Dozen Eggs	1.7%	1.7%	2.5%	2.5%
		(0.001)	(0.000)	(0.000)	(0.001)
Table Egg Price	$/Dozen Eggs	3.5%	3.5%	3.9%	4.0%
		(0.002)	(0.002)	(0.001)	(0.002)
Processed Egg Price	$/Equivalent Dozen Eggs	1.2%	1.2%	1.4%	1.4%
		(0.002)	(0.002)	(0.002)	(0.001)
Production Table Eggs	Dozen eggs	2.0%	2.0%	1.8%	1.8%
		(0.001)	(0.001)	(0.001)	(0.001)
Production Processed Eggs	Equivalent Dozen Eggs	0.0%	-0.1%	-0.5%	-0.5%
		(0.002)	(0.002)	(0.002)	(0.001)
Net Exports Table Eggs	Mill. of Dozens of Eggs	2.0%	2.1%	2.3%	2.3%
		(0.004)	(0.003)	(0.004)	(0.004)
Net Exports Processed Eggs	Mill. of Equivalent Dozens of Eggs	0.3%	0.3%	0.4%	0.3%
		(0.001)	(0.001)	(0.001)	(0.001)
Demand Table Eggs	Mill. of Dozens of Eggs	-1.7%	-1.7%	-1.9%	-1.9%
		(0.001)	(0.001)	(0.001)	(0.001)
Demand Processed Eggs	Mill. of Equivalent Dozens of Eggs	-0.5%	-0.5%	-0.5%	-0.5%
		(0.001)	(0.000)	(0.000)	(0.000)

Source: Economic Model Estimations; Standard deviation in parentheses

Table 2-4: Model estimated changes in producer and consumer surplus and depopulation costs resulting from a hypothetical HPAI outbreak in Minnesota with and without business continuity (Thousand $)

	Business Continuity		No Business Continuity	
	Quarter 1	Quarter 2	Quarter 1	Quarter 2
Producer Surplus Change	1,138	604	3,415	-439
Depopulation Costs	-5,284	0	-16,925	0
Total Economic Impact Producer	-4,147	604	-13,510	-439
Consumer Surplus Change	-1,796	-855	-5,543	-263
Total Change in Welfare	-5,942	-251	-19,053	-702

Source: Economic Model Estimations

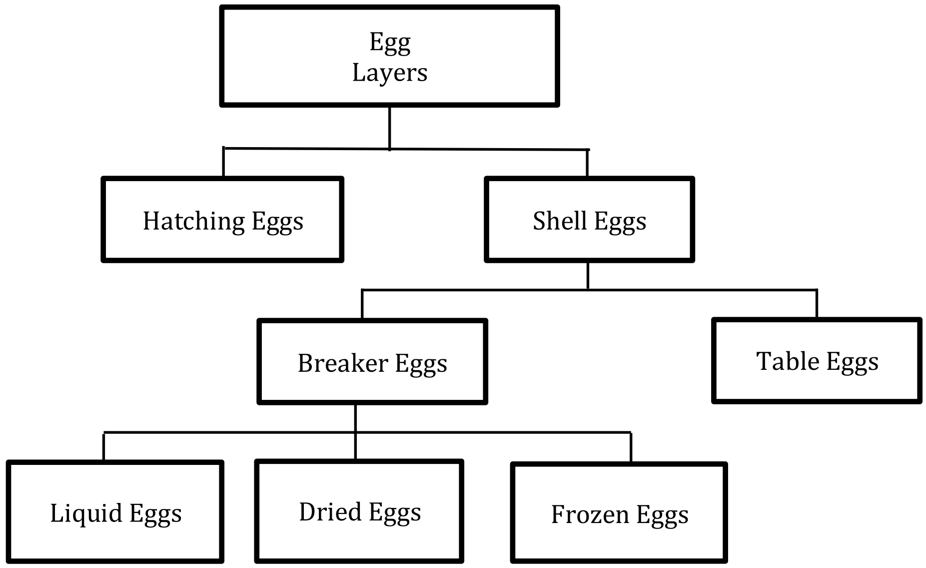

Figure 2-1: U.S. egg production by type of final consumption

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CHAPTER 3 - INTERNATIONAL TRADE IMPLICATIONS OF HIGHLY PATHOGENIC POULTRY DISEASE EVENTS ON QUANTITY TRADED

INTRODUCTION

Disruptions in international trade can cause negative and costly impacts to both exporting and importing countries. Disease events in animal agriculture can cause severe disruptions in trade and can be costly along the supply chain including the cost of mitigation or eradication of a disease (Huang, Hagerman, & Bessler, 2016; Paarlberg, Lee, & Seitzinger, 2003). The decisions regarding disease management further contribute to potential trade disruptions or can help reduce potential impacts (Seitzinger & Paarlberg, 2016). It is important to better understand the potential market disruptions and the associated costs as a result of an animal health event.

There are many factors that may lead to trade disruptions in animal agriculture including political policies, food safety concerns, and animal disease events in an exporting country. To complicate the trade disruptions further, importer responses to animal health events could vary by species (e.g., chicken or turkey), cut (e.g., whole or parts), and/or degree of processing (e.g., fresh or frozen) for meat and egg products. For the poultry industry, this could also include different species of birds. An importing country's response to a highly pathogenic disease event such as highly pathogenic avian influenza (HPAI) or highly pathogenic strains of Newcastle disease (ND) in the poultry industry can be thought of as involving a two-part decision process.[11]

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[11] Newcastle disease is defined by OIE as an infection of birds caused by a virus of avian paramyxovirus serotype 1 (APMV-1) that meets one of the following criteria for virulence: a) the virus has an intracerebral pathogenicity index (ICPI) in day-old chicks (Gallus gallus) of at least 0.7; or b) multiple basic amino acids have been demonstrated in the virus (either directly or by deduction) at the C-terminus of the F2 protein and phenylalanine at residue 117, which is the N-terminus of the F1 protein. Source: http://www.oie.int/fileadmin/Home/fr/ Health_standards/tahm/2.03.14_ NEWCASTLE_DIS.pdf.

First, does the situation warrant a limitation on trade from that exporting country? If so, what should the scope of that limitation be? The scope can be measured in terms of the relative risk posed by various product categories, geographic extent of the event, or the duration of limitations (Marsh, Wahl, & Suyambulingam, 2005). Each of these decisions intensifies or lessens the burden of trade embargos imposed on exporting countries.

Regionalization is another decision importers can consider concerning restrictions on trade with increased globalization. Regionalization is a means for continued exports from disease free regions or regions managing disease outbreaks with vaccinations (Blayney, Dyck, & Harvey, 2006). For example, foot-and-mouth (FMD) outbreaks in Argentina and Brazil were managed using regionalization, among other management tools, to which exporters could negotiate with importers testing free from infection in a given region (Countryman & Hagerman, 2016; Seitzinger & Paarlberg, 2016; Paarlberg, Seitzinger, & Lee, 2007; Steiger, 2006; U.N. Food and Agriculture Organization, 2006). While trade is still affected as a result of a disease event, the use of regionalization in negotiating bilateral trade can mitigate some of these impacts.

In animal agriculture, trade embargo decisions are complex, not just in scope, but also in terms of affected products as product categories within a commodity group can be impacted differently. For example, whole fresh chicken may have a different trade response than cooked chicken products. Commodity trade analyses typically aggregate commodities to their highest level that can over or underestimate the effects on individual product categories. Product categories separate commodities into species, processing level, and cut. The objective of this study is to analyze factors affecting poultry trade at a granular level not found in current literature. Instead of aggregated commodities, this analysis disaggregates poultry commodities into their six digit harmonized system categories. Using an augmented gravity model of trade

(AGM), these disaggregated individual product categories are estimated to determine what factors affect bilateral product trade flows during a disease outbreak and whether these differ by poultry product category.

BACKGROUND

The gravity model of trade has been widely used in trade literature to predict bilateral trade (Bergstrand, 1985; Salvatici, 2013; Serlenga & Shin, 2007; Tinbergen, 1962). Gravity models of trade have been used to evaluate factors that affect bilateral trade due to the predictive power of distance and purchasing power of the respective countries. Gravity models can also be adjusted (called augmented gravity models, AGM) to include additional information (e.g., financial, disease indicators, etc.) to estimate the impact of a disease event on bilateral trade (Martínez-Zarzoso & Nowak-Lehmann, 2003).

Many factors influence bilateral trade including geographical location, relative spending power of the importing or exporting country, and identifiable disruptions in trade such as a disease event. The size of the importing and exporting country's relative spending power measured by gross domestic product (GDP) weighted by the population of the trading partners has been shown to be a predictor of bilateral trade relationships (Tinbergen, 1962). The distance between trading partners also plays a role in bilateral trade. Distance influences transportation costs between partners and can also be an indicator of the strength of bilateral relationships. Geographical proximity can be an important factor in negotiating trade agreements (Sunge & Mapfumo, 2014), which can be a favorable means to secure export markets and increase trade flows between participating countries.

For the poultry industry, these additional variables could include the categories of products being exported, the nature of the disease event—which can be limited to wild birds or can be zoonotic—as well as other indicators of trade.[12] The types of products traded can change drastically during a disease event as substitutions can occur between fresh, frozen, and fully cooked products depending on the importer preference and risk acceptance. Products that can be viewed as having less risk for disease spread may be preferential to a risk averse importing country. A disease event that is viewed as riskier for consumers in an importing country may have a greater trade impact than those viewed as less risky. The augmented model allows for the extension of the gravity analysis to include these other contributing factors for a more robust analysis of trade and enables researchers to answer trade questions related to factors outside of the traditional gravity model.

Previous analyses of highly pathogenic avian diseases have estimated the time it takes for export market revenue to recover after a disease event (Johnson et al., 2015) and the impact on United States domestic markets (Brown et al., 2007; Djunaidi & Djunaidi, 2007; Johnson et al., 2014; Miller & Parent, 2012). The latter studies use a partial equilibrium modeling approach to estimate economic impacts of HPAI. Johnson et al. (2015) uses a zero inflated negative binomial model to determine recovery time for exporting countries. In their study, the authors determined that several factors, including type of domestic production and origin of exports, led to longer export revenue recovery times than the World Organization for Animal Health (OIE) guidelines on disease free status for a country given no new detections of infection (OIE 2013a, OIE 2013b).

This research extends previous literature by analyzing the bilateral trade implications of quantity of product traded of poultry products during a highly pathogenic disease event. Previous

[12] Zoonotic diseases are infections disease transmissible from animals to human, from either direct contact or carried by a vector.

work aggregates all poultry commodity exports into species or a total for all poultry trade, which can mute the effects on importer trade bans for specific product categories as defined by the harmonized commodity description system (e.g., Meat and Edible Offal of Chickens, Not cut into Pieces, Fresh or Chilled; see Table 3-1). By analyzing monthly bilateral trade and disaggregating the commodity groups, this study will be the first known research to evaluate the consequences of highly pathogenic disease events on specific products, both in cut and degree of processing. This will provide timely and policy relevant estimates of bilateral trade disruptions during a disease event.

METHODOLOGY

The gravity model of trade builds from Sir Isaac Newton's gravity equation, where gravitational force is directly proportional to the mass of two objects and indirectly proportional to the distance between the two objects. Tinbergen (1962) was one of the first to adopt the use of gravitational force as a model to describe trade flows. It has since continued to be used to estimate bilateral trade flows between countries and augmented to expand the explanatory variables beyond distance and size of the trading partners. To estimate the AGM, the model is linearized to facilitate estimation across panel data using the Hausman-Taylor estimator as seen in equation 1.

$$\ln q_{i,j}^{k} = \beta_0 + \beta_1 \ln(GDP_i\, GDP_j) + \beta_2 \ln[(GDP_i\, / Pop_i)(GDP_j / Pop_j)] \\ - \beta_3 \ln(Dist_{i,j}) + \gamma\, Z \tag{1}$$

where: i = exporter; j = importer; k = product category; *GDP* = Gross domestic product for both exporters and importers; *Pop* = Population of exporters and importers; *Dist* = Distance from trading center to from exporter from i to j; β = variable coefficients; γ = vector of coefficients; and Z = matrix of additional explanatory variables.

Augmented gravity models are traditionally estimated using ordinary least squares (OLS) with cross sectional data. This implies that these models are based on a single time period or that time or another dimension is collapsed when using panel data. Although a cross sectional analysis can provide valuable insights, it does not incorporate all of the available information that estimates effects across time if the underlying data available are panel.

A random effect approach is appropriate for AGMs if there are no individual effects (Baltagi, Bresson, & Pirotte, 2003). If this assumption is found to be erroneous, a fixed effect model can be used. However, fixed effect models also have limitations in simultaneously providing parameters for time invariant variables and estimations that can be extrapolated to the underlying population. Taking into account both the within and between variation in the panel, a consistent and efficient estimator for the AGM is a Hausman-Taylor (HT) estimator (Hausman & Taylor, 1981). A HT estimator assumes the regressors are correlated with the individual effects so it separates the variables into four categories (Eq. 2): 1) time variant exogenous (X_1); 2) time variant endogenous (X_2); 3) time invariant exogenous (W_1); and 4) time invariant endogenous (W_2). Equation 1's linearized model variables are separated into respective HT categories (Table 3-2) and estimated using equation 2:

$$y_{it} = \beta_1 X_{1it} + \beta_2 X_{2it} + \delta_1 W_{1it} + \delta_2 W_{2it} + \alpha_i + \epsilon_{it} \tag{2}$$

where: i = bilateral trade flows, t = monthly time period, β and δ are coefficients for factors that affect trade, and y is quantity traded. The endogenous variables are correlated with the individual effects (α_i). The assumption still holds that all variables are uncorrelated with the error term, $E[\epsilon_i \mid W_{jit}, X_{jit}] = 0$, but now the HT expands the model assumptions such that not all variables are uncorrelated with the individual effects, $E[\alpha_i \mid W_{2it}, X_{2it}] \neq 0$.

The HT estimator approximates the time invariant variables through an instrumental variable approach. The time variant exogenous variables are the instruments for the time invariant endogenous variables. By using this approach, it is possible to have estimates that can be predictive of the underlying population and include unbiased estimates of relevant time invariant variables, which are limitations of fixed effects models.

To correctly specify the model, a random effects model is estimated. To determine whether true random effects exist or if an OLS regression should be employed, the results of the random effects model are tested using a Breush–Pagan Lagrangian Multiplier test. The presence of random effects is statistically different from zero, thereby motivating the panel approach. Next, a Hausman specification test is performed to test whether a random or fixed effects model is more appropriate by testing if there are individual effects that are correlated with the error term. The Hausman specification test suggests a fixed effects model is appropriate for the data. A fixed effects model limits the analysis to between or within variation estimators. In order to capture both variations, a HT model is used. To address data heteroskedasticity, robust variances are used.

Summary statistics for the variables used in the analysis are listed in Table 3-2. The HT variable designation is provided and indicates whether a variable is time variant or time invariant, as well as endogenous or exogenous. Summary statistics are provided for the original data prior to linearization for equation 1, a step that occurs before estimation. *Population* and *Gross Domestic Product* (*GDP*) are the weights used in the AGM and enter as both exporter and importer partner values. The population and GDP weights are calculated prior to estimation. *Distance* is the measure in kilometers between the bilateral trading partners and is a proxy for the relative shipping costs between partners and is measured as the distance between the main shipping port in the exporting and importing country. Trading partners in closer proximity may have preferential trade as result of reduced shipping costs or reduced distance and this preferential proximity variability between trading partners is accounted in the *Distance* variable.

Additional factors are included in the analysis through the Z matrix in equation 1. The additional variables allow for the analysis to extend beyond prediction of trade to provide meaningful insights into the factors that influence trade. *Share* is the exporting county's annual share of the world market for poultry exports and is used to approximate the relative global importance of the exporter in the market. An exporting country's global share, *Share*, can affect how trading partners make trade restriction decisions. One key variables of interest, *ND*, is a binary variable that provides an estimate for the marginal effect a ND disease event has on quantity traded. Similarly, *HPAI*, another key variable, estimates the marginal trade impacts that occur with a HPAI disease event. Both ND and *HPAI* marginal effects provide more information for the change in quantity traded and composition of trade between bilateral partners due to a highly pathogenic disease event by product category. The composition of trade is the complete mix of product categories being imported by a trading partner and can change as a result of preferences, risk concerns, or trade response to a disease event. *Out Year*, a count of simultaneous disease events for the reporting year, is a global poultry health measure. The number of exporting countries known to be managing a disease event can influence importing partners' trading decisions. *Per capita* is a measure of the relative importance of poultry meat in importing markets as measured by the global per capita consumption of poultry products. While the value is the same for all similar time periods, this variable acts as a global preference trend variable.

There are additional variables included in the analysis to provide explanatory power for the strength of a trade relationship. These variables include *contiguous partners* and *common currency.* The binary variable *contiguous partners* indicates whether the bilateral trading partners are geographically contiguous. Countries that are contiguous can have preferential trade relationships due to reduced transportation costs or a historical trade relationship. For example, this would help to account for trading within the European Union during a disease event even when other trading partners reduced the quantity traded or changed the composition of trade. *Common currency* is a binary variable that designates whether the trading partners use a common currency. Like *contiguous partners,* countries with a common currency can have preferential treatment. This variable also accounts for slightly reduced transaction costs, as there are no currency conversion fees.

Finally, there are regional binary variables that account for region specific characteristics of importers. While proximity of trading partners is included in the gravity specification through *Distance*, there are regional differences in trade agreements, willingness to accept product from infected exporters, and risk aversion tied to the decision of when to resume trade, all of which are accounted for by the regional variables. The seven regional variables include: *Asia, Europe, South America, North America, Africa, Oceania,* and the *Middle East* (Appendix 3 Table A 3-1).

DATA

The data used for this research include poultry specific diseases events (i.e., HPAI or ND events). These data include 71 distinct disease events affecting 382 bilateral trade relationships for 15 poultry product categories from January 2004 to December 2014. Information concerning the disease events are available on the OIE website, which includes number of infected flocks, the number of outbreaks during a disease event, and the nature of the disease event (OIE, 2015).

Using these categorizations, individual disease events are recorded in geopolitically defined countries that are non-endemic for HPAI or ND, where an endemic disease is one that is persistent in a population without external influences.

Bilateral trade data for this analysis are from the Global Trade Information Services' Global Trade Atlas. Monthly bilateral trade data are used for 24 exporting countries for 24 months prior to a disease event and 24 months after the OIE declared the country disease free.[13,14] Bilateral trade is limited to trade relationships that accounted for more than five percent of total exports from each reporting country in 2013. This excludes countries that have variable trade relationships for reasons extending beyond animal and food health concerns as well as economically less significant trading partners. This also excludes non-recognized trading partners such as "High Seas" and "International Waters." The trade data spans from 2004 to 2015 for 15 poultry product categories based on the harmonized system code (HS code) at the six-digit level (Table 3-1). The dataset used is composed of three dimensions: 1) bilateral trade flows; 2) time; and 3) product categories. To estimate the factors that affect trade, individual models are estimated for each of the 15 product categories. For additional information regarding the dataset used in this analysis, see Johnson et al. (2015).

Additional information included in the analysis are publically available data. Population and real GDP data are annual values reported by USDA-ERS (2015). Distance and geographical indicators are retrieved from the GeoDist database published through the Centre D'Etudes

[13] Austria, Belgium, Brazil, Canada, Chile, China, Denmark, France, Germany, Greece, Hungry, Italy, Japan, Mexico, Netherlands, Poland, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, the United Kingdom, and the United States.

[14] It was possible that a repeat disease event occurred within the 24-month post disease period that made it impossible to have the 24-month period disease free buffer around the first event. Due to data limitations there is not a 24-month period to any outbreaks occurring before January 2006.

Prospectives et D'Informations Internationales, commonly called CEPII (Mayer & Zignago, 2011). Country currencies, as reported by United Nations' Food and Agriculture Organization Corporate Statistical Database (FAOStat), are used to determine if a trading pair used a common currency (2015a). Annual global per capita consumption of poultry is recorded from the UN's Organization for Economic Co-operation and Development (OECD)-FAO Agricultural Outlook (2015b).

RESULTS AND DISCUSSION

Poultry product category regression estimates are presented in Table 3-3. The uneven panel was estimated after compiling and transforming the data for the linearized model. Individual models were estimated for each product category listed in Table 3-1; thus, providing insights into disaggregated commodity groups and the factors influencing the quantity traded between bilateral partners.

Each individual model represents a different poultry product cut (i.e., whole or parts), species (i.e., chicken, turkey, or other), and processing level (i.e., live, fresh, frozen, or cooked). This allows for comparison of how changes occur across different products groups. For instance, share of global export market (*Share*) had a significant positive impact on trade for live chickens, but was not a significant factor for live turkey trade. Each individual product category model provides an analysis of the factors that influence its trade.

For both whole chicken models (fresh and frozen), population in the exporting country had a significant impact on quantity traded; however, each product category was affected differently. For whole fresh chicken, exporter population negatively affected quantity traded while the opposite was found for whole frozen chicken. Specifically, as exporter population increases by 1%, quantity traded is expected to decrease by 11.8% for whole fresh chicken and is expected to increase by 11.9% for whole frozen chicken. As population grows, across time and between exporters, fresh chicken exports tend to decrease in favor of frozen chicken. Changes in composition of exports may be driven by the between variation of exporters. Larger exporters, such as the United States or Brazil, tend to have trading partners at a greater distance requiring more stable transportation methods than countries who ship within region (e.g., Turkey or Belgium).

GDP of importing and exporting partners also contributes to the quantity of poultry traded. Across the chicken and turkey models, the parameter estimates for importer GDP was a significant factor affecting trade, implying that across these models, as importing countries become wealthier, their demand for poultry products increases. For frozen chicken parts, a 1% increase in the importing country's GDP increases the quantity of trade by 1.2%. As importing partners become wealthier, preferences are for increased imports of poultry products. In contrast, there were a few product categories that were negatively impacted due to increases in importer GDP. For example, frozen turkey parts decrease by 0.9% with an increase in importing country GDP. This could indicate a change in preferences and trade composition as an importing country increases in relative wealth.

Comparing the impact of importing country's GDP on product categories across constitution, there are greater impacts for fresh products than frozen. For example, given a 1% change in importing country GDP, whole fresh chicken export quantity is expected to increase by 5.0% compared to 0.9% for whole frozen chicken. One explanation for these changes is the nature of markets in the importing countries. Some importers have an agrarian focused open market that values fresh products. Typically, more developed market structures, such as in the European Union (EU) or the United States, have different market preferences that may not include open markets. Increases in exporting country's GDP leads to increases in exports of whole fresh chicken, which can be explained by the composition of trade demanded by importers. The composition may change due to increases in further processing in response to importer risk concerns. Neighboring partners, where further processing occurs after shipment, could also increase import demand for fresh products. For example, the United States ships the majority of whole fresh chicken exports to Mexico, providing for reduced transportation costs and flexibility in composition of products exported.[15]

The composition, or mix of products, being traded is also an important factor that affects trade. Countries that import poultry meat, typically import frozen products (61% of meat products exported in 2013 were frozen products), possibly due to their hardiness to withstand transportation. Countries with contiguous national borders appear to import more cooked products than those that do not. Having a contiguous national border is expected to increase quantity traded of cooked chicken and cooked turkey by 22% and 19%, respectively.

Trading partners that have a common currency tend to have increased trade quantities. For example, live birds have a 45% increase in trade quantity when the bilateral trading partners share a common currency. While exchange rate variability could explain some of the preference for a common currency, the more likely explanation could be tied to proximity. For example, within the EU, countries have preferential trade between EU member states, close proximity, and a common currency that facilitates easier transactions within the Euro zone.

The world export market share positively affects the quantity traded for all products except live turkeys. As a country's share of the global export market increases, the quantities of

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[15] As evidenced by the bilateral trade data used in this analysis where 77% of the whole fresh chicken was exported to Mexico in the base year of 2013.

poultry products exported increases. As an exporter has a greater share of the market, this creates precedence for trade relationships based on exporter reputation.

Finally, the disease variables *HPAI* and *ND* were only significant for select product category models. The *ND* variable was only significant for half of the estimated models including: whole fresh chicken, frozen turkey parts, egg products, and all three cooked products. These results tend to show an increase in quantity traded during a disease event. For example, whole fresh chicken is expected to increase trade by 21% during a disease event. These results indicate a change in composition of trade. While total quantity across all poultry products may decrease during a disease event, this indicates that whole fresh chicken trade increases. This could be due to the preferences of certain trading partners for products to be further processed or this could indicate an increase in cheaper products that some importing partners are willing to accept, as whole fresh chicken is relatively less expensive. It is important to note that less than 2% of the panel was affected by ND, which could imply its relative rarity as a trade disruption. Additionally, in terms of the duration of a disease event from first reported outbreak until last reported outbreak, ND had less than 3% of the reported events lasting more than a year, whereas this was closer to 18% for HPAI events. Importing counties can respond to any event, but an explanation for why ND does not significantly contribute to changes in trade might be tied to the relative shorter disease duration.

Highly pathogenic avian influenza has varying impacts on the quantity traded across poultry product category models. HPAI has a significant negative impact except for positive signs for select categories: live chickens, live turkeys, whole fresh chicken, whole frozen chicken, fresh chicken parts, frozen chicken parts, whole frozen turkey, whole fresh turkey, and cooked turkey. As expected, several models estimate that trade quantity decreases as a result of a

HPAI event. Whole fresh chicken exports were estimated to decrease by 15% in the event of a HPAI event, all else equal. Contrarily, live chicken trade increased by 43% during a disease event and whole frozen turkey exports were estimated to increase by 53%. This counter intuitive increase in live birds could be explained by demand for replacement birds, or new hatchlings, in importing countries. Importers who are geographically close to the infected exporter, especially for European partners where the importing country might also be infected, could lead to an increase in demand as the importers could need to repopulate farms as a result of a domestic highly pathogenic disease event. This increase could also be driven by a decrease in the price for live birds in the infected exporting country. In the exporting country, it could be possible that these birds, which cannot be more than 6.5 ounces (see Table 3-1), could not be placed on farms still under surveillance. This would lead to an oversupply of birds that could be placed on farms, in which an importer could procure at a reduced price. The increase in whole frozen turkey represents a change in composition of trade. The lengthier production times for turkeys lead to a higher premium price when there are shortages. During a disease event in which birds are potentially depopulated, the shortage and expected future shortage could decrease the exporter's desire to sell whole frozen turkey. For all other products, a HPAI disease event significantly decreases the total quantity traded through increased importer trade barriers as well as a change in exporter supply.

CONCLUSION

Many factors affect global poultry trade and impact bilateral trade relationships differently. Trade relationships may be driven by proximity, product and country reputation, and importer preferences to name a few. Highly pathogenic poultry disease events can cause disruptions in trade flows, leading to changes in the quantity of product traded, composition of products traded, and sources of imports. This analysis provides information on the factors that influence trade and quantify the impact a highly pathogenic poultry disease event has on quantities traded. Highly pathogenic disease events can have negative effects on exporter trade quantity. Exporters with more information can potentially better forecast trade implications of a domestic disease event, enabling them to adapt more quickly to changes in importers' trade composition preferences and the price of exports.

In addition to the analysis of factors that affect trade, the individual product category model results suggest that HPAI disease events tend to have a greater impact across all poultry product categories when compared to ND. While ND does have an impact on trade, particularly for cooked poultry products, HPAI has a significant impact on bilateral trade in more poultry product categories. This could be due to the small number of ND disease events, the highly prolific nature of HPAI, or that HPAI has many strains with zoonotic potential. However, this information does reveal the differing impact of risks associated with specific poultry diseases for trade restriction decisions. This reinforces the importance of disease mitigation strategies domestically and the importance of biosecurity for reducing the risk of having a disease event.

Analyzing trade flows by product category allows for product category specific changes to be estimated to provide valuable insights for production decisions in the face of a disease event. For aggregated analyses, the actual change in composition is not parsed out and estimations can over or underestimate the impact of the factors affecting trade. By understanding the trade implications of disease event, it might be possible to alleviate some of the economic strain that these events pose and aid in market recovery. A limitation of this work lies with the individual product category estimations, which do not account for potential endogeneity across the product categories. An extension of this research would be extending the methodology by creating a system of trade equations to potentially improve model efficiency within the HT context. Other future extensions of this work could include other animal commodities to determine their trade influencing factors or cross product analyses to investigate the total composition of meat demand by importers in the face of a disease event.

Table 3-1: Poultry product categories used in bilateral trade analysis

Product Short Name	Product Name	HS Code
Live Chickens	Commodity: 010511, Chickens, Live, Weighing Not More Than 185 G (6.53 Oz.) Each	10511
Live Turkeys	Commodity: 010512, Turkeys, Live, Weighing Not More Than 185 G (6.53 Oz.) Each	10512
Whole Chicken: Fresh	Commodity: 020711, Meat And Edible Offal Of Chickens, Not Cut In Pieces, Fresh Or Chilled	20711
Whole Chicken: Frozen	Commodity: 020712, Meat And Edible Offal Of Chickens, Not Cut In Pieces, Frozen	20712
Chicken Parts: Fresh	Commodity: 020713, Chicken Cuts And Edible Offal (Including Livers) Fresh Or Chilled	20713
Chicken Parts: Frozen	Commodity: 020714, Chicken Cuts And Edible Offal (Including Livers) Frozen	20714
Whole Turkey: Frozen	Commodity: 020725, Turkeys, Not Cut In Pieces, Frozen	20725
Whole Turkey: Fresh	Commodity: 020726, Turkey Cuts And Edible Offal (Including Livers), Fresh Or Chilled	20726
Turkey Parts: Frozen	Commodity: 020727, Turkey Cuts And Edible Offal (Including Liver) Frozen	20727
Shell Eggs	Commodity: 0407, Birds' Eggs, In Shell, Fresh, Preserved Or Cooked	407
Eggs Products	Commodity: 0408, Birds' Eggs, Not In Shell And Egg Yolks, Fresh, Dried, Cooked By Steam Etc., Molded, Frozen Or Otherwise Preserved, Sweetened Or Not	408
Cooked Turkey	Commodity: 160231, Meat Or Meat Offal Of Turkeys, Prepared Or Preserved, N.E.S.O.I.	160231
Cooked Chicken	Commodity: 160232, Prepared Or Preserved Chicken Meat, Meat Offal Or Blood, N.E.S.O.I.	16032
Cooked Other	Commodity: 160239, Meat Or Meat Offal Of Chickens, Ducks, Geese And Guineas, Prepared Or Preserved, N.E.S.O.I.	160239

Source: Global Trade Information System – Global Trade Atlas; HS: Harmonized System

Table 3-2: Descriptive statistics and Hausman-Taylor model descriptions for variables used in bilateral quantity trade analysis

Name	Variable Description	Unit	HT[3] Description	Mean	Min	Max
Quantity[1]	Exporting quantity	Pounds	TV[4], Exogenous	281,484	1	120,000,000
$Population_i$	Population for trading partner i[2]	Per Capita	TV, Exogenous	83,800,000	102,918	1,360,000,000
GDP_i	Real GDP for trading partner i[2]	Billions of USD	TV, Exogenous	1,841.75	0.71	16,271
Distance	Distance between trading partners	Kilometers	TIV[5], Endogenous	2,497	60	19,080
Share	Annual share of world export market	%	TV, Endogenous	0.05	0.00	0.33
Highly Pathogenic Newcastle Disease (ND)	Binary variable indicating if ND was reported	0,1	TV, Endogenous	0.02	0	1
Highly Pathogenic Avian Influenza (HPAI)	Binary variable indicating whether HPAI was reported	0,1	TV, Endogenous	0.07	0	1
OutYear	The number of simultaneous disease events in a given year	Number	TV, Exogenous	5.28	0	15
Percent Capita	Annual global per capita consumption of poultry meat	%	TV, Exogenous	12.15	10.7	13.74
Contiguous Partners	Binary variable to indicating partners who are geographically contiguous	0,1	TIV, Exogenous	0.45	0	1
Common Currency	Binary variable indicating trading partners who share a common currency	0,1	TIV, Exogenous	0.27	0	1
Asia	Binary variable for exporting country	0,1	TIV, Exogenous	0.10	0	1
Europe	Binary variable for exporting country	0,1	TIV, Exogenous	0.70	0	1
South America	Binary variable for exporting country	0,1	TIV, Exogenous	0.03	0	1

Table 3-2: Descriptive statistics and Hausman-Taylor model descriptions for variables used in bilateral quantity trade analysis, cont.

Name	Variable Description	Unit	HT[3] Description	Mean	Min	Max
North America	Binary variable for exporting country	0,1	TIV, Exogenous	0.06	0	1
Africa	Binary variable for exporting country	0,1	TIV, Exogenous	0.06	0	1
Oceania	Binary variable for exporting country	0,1	TIV, Exogenous	0.01	0	1
Middle East	Binary variable for exporting country	0,1	TIV, Exogenous	0.04	0	1

[1] Dependent Variable
[2] i = exporter, importer
[3]HT Description=Hausman Taylor variable description
[4]TV: Time Variant
[5]TIV Time Invariant

Table 3-3: Individual model estimations for factors contributing to quantity exported by product category for monthly bilateral trade data, 2004-2015

	Live Chicken	Live Turkey	Whole Fresh Chicken	Whole Frozen Chicken	Fresh Chicken Parts
Importer Population	-0.36	-6.22***	-1.18	0.45	-2.09***
	(0.80)	(1.24)	(0.81)	(0.43)	(0.42)
Importer GDP	1.28***	0.20	4.99***	0.91***	0.92***
	(0.25)	(0.37)	(0.35)	(0.17)	(0.19)
Exporter GDP	-8.43***	0.47	-2.12***	-0.87***	-0.32
	(0.28)	(0.49)	(0.25)	(0.16)	(0.21)
Exporter Population	4.14***	1.98	-11.80***	11.87***	-0.61
	(1.11)	(1.92)	(1.21)	(1.02)	(0.54)
Per Capita	4.39***	2.15***	3.76***	-0.60**	5.47***
	(0.41)	(0.52)	(0.32)	(0.29)	(0.21)
Out Year Count	0.03***	-0.01	-0.02***	0.00	0.02***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
Contiguous Partners	0.45***	0.14	-0.17***	0.02	0.07**
	(0.07)	(0.08)	(0.05)	(0.04)	(0.03)
Common Currency	0.07	-0.41***	0.14***	0.03	0.31***
	(0.06)	(0.10)	(0.05)	(0.06)	(0.04)
Highly Pathogenic Newcastle Disease	-0.04	-0.08	0.21***	0.08	0.07
	(0.12)	(0.14)	(0.08)	(0.06)	(0.06)
Highly Pathogenic Avian Influenza	0.43***	-0.14*	-0.15**	-0.09	-0.16***
	(0.09)	(0.08)	(0.07)	(0.06)	(0.05)
Share	0.57***	0.15	1.02***	1.32***	1.29***
	(0.08)	(0.13)	(0.07)	(0.06)	(0.05)
Asia	-11.27	-	-	-26.79	-5.67
	(11.54)	-	-	(45.33)	(5.00)
Europe	-13.97	-1.70	-33.68	-19.75	0.91
	(13.91)	(15.63)	(35.92)	(51.77)	(5.35)
South America	-13.92	-	-	-11.80	-0.20
	(13.40)	-	-	(46.80)	(6.10)
North America	-4.24	3.21	-27.70	-26.10	3.90
	(13.77)	(17.52)	(37.15)	(51.09)	(5.64)
Africa	-10.45	-	-72.20*	-1.97	-
	(14.88)	-	(41.19)	(41.85)	-
Middle East	-15.27	-1.63	-32.26	-16.42	0.12
	(14.05)	(21.27)	(39.32)	(42.37)	(5.61)
Distance	-0.28	3.28	16.77	-8.04	1.43
	(2.79)	(5.63)	(11.53)	(10.72)	(1.55)
Constant	2.93	53.38	134.00	-125.20	29.33*
	(34.56)	(42.71)	(93.53)	(109.44)	(15.04)
Observations	4,675	2,448	4,605	7,219	6,352
No. Trade Partners	49	32	47	80	60
R^2	0.02	0.03	0.04	0.18	0.00

Table 3-3: Individual model estimations for factors contributing to quantity exported by product category for monthly bilateral trade data, 2004-2015, cont.

	Frozen Chicken Parts	Whole Frozen Turkey	Whole Fresh Turkey	Frozen Turkey Parts	Shell Eggs
Importer Population	-0.06	-3.16***	-2.08***	5.16***	0.27
	(0.24)	(1.20)	(0.52)	(0.33)	(0.89)
Importer GDP	1.21***	0.50	2.20***	-0.87***	-0.80***
	(0.11)	(0.42)	(0.27)	(0.15)	(0.26)
Exporter GDP	-0.27**	1.05	1.51***	2.46***	-5.97***
	(0.12)	(0.86)	(0.29)	(0.20)	(0.37)
Exporter Population	0.15	2.97	-2.26***	-4.75***	-3.89***
	(0.38)	(3.01)	(0.82)	(0.70)	(1.31)
Per Capita	3.13***	-0.29	2.78***	1.55***	9.82***
	(0.21)	(0.98)	(0.26)	(0.24)	(0.50)
Out Year Count	-0.00	0.00	-0.01	-0.01*	0.06***
	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)
Contiguous Partners	-0.05	0.10	0.06*	-0.09***	-0.11
	(0.03)	(0.10)	(0.03)	(0.03)	(0.10)
Common Currency	0.19***	0.27**	0.02	0.01	1.32***
	(0.04)	(0.13)	(0.04)	(0.04)	(0.14)
Highly Pathogenic Newcastle Disease	-0.07	-0.06	-0.02	0.11*	-0.04
	(0.06)	(0.17)	(0.08)	(0.06)	(0.15)
Highly Pathogenic Avian Influenza	-0.11***	0.53***	-0.15***	0.06	0.05
	(0.04)	(0.17)	(0.05)	(0.05)	(0.10)
Share	0.73***	0.32*	0.15**	0.24***	1.15***
	(0.03)	(0.17)	(0.07)	(0.05)	(0.07)
Asia	-2.50	-5.86	-	2.98	-5.87
	(4.92)	(29.41)	-	(12.44)	(13.54)
Europe	-11.21*	-23.95	-1.49	6.98	-21.31**
	(6.38)	(29.69)	(6.00)	(12.76)	(10.26)
South America	-4.24	-17.01	-	11.19	-19.39
	(6.78)	(26.55)	-	(12.97)	(13.92)
North America	-7.49	-8.64	-1.19	2.11	-
	(5.54)	(26.88)	(7.38)	(12.55)	-
Africa	-1.98	-10.93	-4.79	9.64	-23.83*
	(5.06)	(22.60)	(6.94)	(11.22)	(13.43)
Middle East	-3.13	-17.51	-	14.57	-20.63
	(5.41)	(24.41)	-	(12.99)	(13.17)
Distance	-2.87**	-6.31	2.51	-0.55	3.19
	(1.41)	(7.48)	(2.19)	(2.39)	(3.35)
Constant	23.88*	62.18	33.18*	-19.20	97.18***
	(14.20)	(68.30)	(17.63)	(25.01)	(30.99)
Observations	10,725	1,743	5,259	8,619	8,526
No. Trade Partners	99	54	53	86	82
R^2	0.08	0.05	0.10	0.00	0.00

Table 3-3: Individual model estimations for factors contributing to quantity exported by product category for monthly bilateral trade data, 2004-2015, cont.

	Egg Products	Skin & Feathers	Cooked Turkey	Cooked Chicken	Cooked Other
Importer Population	4.84***	1.69	-7.68***	3.00***	3.00***
	(0.61)	(1.06)	(0.68)	(0.60)	(0.60)
Importer GDP	-0.53**	-0.53**	-0.25	0.55**	0.55**
	(0.26)	(0.21)	(0.25)	(0.21)	(0.21)
Exporter GDP	0.30**	0.70***	-0.29	0.04	0.04
	(0.15)	(0.16)	(0.25)	(0.15)	(0.15)
Exporter Population	-0.57	-1.77*	-0.48	-1.40*	-1.40*
	(0.86)	(1.02)	(0.90)	(0.72)	(0.72)
Per Capita	3.05***	0.64	4.97***	6.73***	6.73***
	(0.29)	(0.43)	(0.30)	(0.25)	(0.25)
Out Year Count	-0.02***	-0.01*	0.02***	0.01*	0.01*
	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Contiguous Partners	0.00	0.12*	0.19***	0.22***	0.22***
	(0.03)	(0.06)	(0.04)	(0.03)	(0.03)
Common Currency	-0.31***	0.58***	-0.10**	0.33***	0.33***
	(0.05)	(0.08)	(0.05)	(0.05)	(0.05)
Highly Pathogenic Newcastle Disease	0.11*	-0.04	0.13*	0.23***	0.23***
	(0.06)	(0.13)	(0.08)	(0.07)	(0.07)
Highly Pathogenic Avian Influenza	0.02	-0.09	0.15**	-0.02	-0.02
	(0.06)	(0.07)	(0.06)	(0.05)	(0.05)
Share	0.20***	0.45***	0.47***	0.04*	0.04*
	(0.03)	(0.05)	(0.04)	(0.02)	(0.02)
Asia	9.35	3.40	-10.19	2.54	2.54
	(13.42)	(12.21)	(27.21)	(12.41)	(12.41)
Europe	-1.21	6.66	21.63	-0.21	-0.21
	(15.72)	(14.89)	(22.68)	(12.96)	(12.96)
South America	12.66	6.31	7.65	4.19	4.19
	(14.40)	(14.20)	(24.48)	(12.09)	(12.09)
North America	-2.30	3.29	28.65	-1.70	-1.70
	(15.26)	(13.53)	(24.04)	(13.44)	(13.44)
Africa	-3.51	4.22	-	-	-
	(18.85)	(17.44)	-	-	-
Middle East	19.69	8.85	-0.92	1.53	1.53
	(15.36)	(18.29)	(23.87)	(16.27)	(16.27)
Distance	-6.99	1.74	7.46**	-0.04	-0.04
	(5.14)	(3.34)	(3.71)	(2.43)	(2.43)
Constant	-27.78	-13.93	62.44	-43.02	-43.02
	(44.48)	(36.66)	(39.66)	(26.16)	(26.16)
Observations	6,546	4,572	6,770	8,213	8,213
No. Trade Partners	74	57	66	72	72
R^2	0.09	0.05	0.11	0.00	0.10

Source: Model Results; Standard errors in parentheses; ***, **, * indicate p< 0.01, p<0.05, and p<0.1, respectively.

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CHAPTER 4 - SYSTEMS APPROACH FOR THREE-DIMENSIONAL PANEL DATA TO ESTIMATE POUTLRY TRADE IMPACTS DUE TO ANIMAL DISEASE EVENTS

INTRODUCTION

As described in chapter three, highly pathogenic disease events can cause costly disruptions in international trade. These disruptions can come in the form of trade embargos, changes in exporter supply, or importer preference changes. Management of a highly pathogenic disease event can contribute to an importer country's decision in determining trade limits, if any (Marsh, Wahl, & Suyambulingam, 2005; Seitzinger & Paarlberg, 2016; USDA-FAS, 2016). It is important to know the factors that influence bilateral trade of a commodity to understand the ramifications a disease event can have on bilateral trade and domestic markets.

Global consumer demand for poultry products has steadily increased over the last half century and has been gaining in popularity as an affordable source of protein. The 2015 annual U.S. poultry consumption was estimated at 106 pounds per capita for poultry products as compared to 105 pounds per capita for beef and pork combined (The National Chicken Council, 2016b; USDA-ERS, 2016). Despite growing domestic demand, U.S. poultry remains highly competitive in international markets. U.S. broiler exports were 32% of the 2014 global poultry exports among major traders (USDA-FAS, 2016) and U.S. broiler exports accounted for 19% of total broiler production (The National Chicken Council, 2016a). During the 2014-2015 HPAI event in U.S. layer and turkey flocks, U.S. exports decreased for the first time since 2006 as a result of trade bans by importing countries and reduction in bird stocks (Seitzinger & Paarlberg, 2016; USDA-FAS, 2016). Increases in bird stocks and lifting of trade bans has aided in U.S.

poultry market recovery, but the reduction in U.S. poultry exports allowed for a shift in trade to other exporters, mainly Brazil (USDA-FAS, 2016).

Highly pathogenic avian influenza (HPAI) and exotic Newcastle disease (ND) are of particular concern to the poultry industry due to their pathogenic nature and potential losses as a result of a disease event. The most recent outbreak of HPAI in the United States resulted in depopulation of more than 48 million birds and an estimated one billion dollar cost to the U.S. government (USDA-APHIS, 2015; USDA-Office of Communications, 2015). Globally from 2000 to 2015 there were more than 400 distinct HPAI or ND disease events in non-endemic regions, or those regions that a disease is not regularly found (OIE, 2015). Each of these events had implications for domestic markets and potentially affected the global market.

Poultry trade in general can be affected as a result of a disease event, but trade disruptions on commodity categories can differ based on the level of processing (e.g., fresh, frozen, or cooked), cut (e.g., whole or parts), and type of product (e.g., chicken or turkey). Disaggregating commodity data into sub-commodity product categories allows for an understanding of the impact highly pathogenic diseases can have on trade of specific product categories. Disaggregation of commodities into specific product categories has traditionally been limited in estimation due to dimensionality of the data. Dimensionality refers to the number of different identifiers in a dataset such as time, bilateral trading partners, or product group, a case in which there would be three dimensions. Limiting an analysis to aggregated commodities can lead to less accurate analyses of how trade of a specific product category might change during a disease event.

During a disease event, importing countries may choose to limit trade with an exporting country known to have a disease event (Jarvis, Cancino, & Bervejillo, 2005; Marsh, Wahl, &

Suyambulingam, 2005; Paarlberg & Lee, 1998). Importing countries may ban products or change the composition, or mix of imported goods, as a result of a disease event (Djunaidi & Djunaidi, 2007; Seitzinger & Paarlberg, 2016). To better understand the factors that affect poultry trade, this study evaluates disaggregated poultry product categories at the six-digit HS level to estimate bilateral trade quantities during a HPAI or ND event. Specifically, the objective of this study is to determine the factors that influence the quantity of bilateral trade using a three-dimensional system of Hausman-Taylor estimators (HT-SUR). The results from the systems methodology will then be compared to the use of individual Hausman-Taylor estimated models, thus providing an agricultural trade analysis of the effects of pathogenic disease events on exports by product category.

BACKGROUND

A system of Hausman-Taylor estimations (HT-SUR) was first presented by Egger and Pfaffermayr (2004a) to address limitations in panel estimators across three-dimensional data. The methodology employed in this research incorporates panel unrelated regression to the Hausman-Taylor (HT) estimator creating the HT-SUR estimations, which should provide efficiency gains for estimations and consistent estimates of the factors that influence bilateral trade during a disease event. While HT-SUR is applicable across many fields of research, it has been mainly applied in the political economy literature to assess the political factors influencing trade (Angulo, López, & Mur, 2011; Serlenga & Shin, 2007). Few studies have employed this methodology in the agricultural trade literature (Slangen, Beugelsdijk, & Hennart, 2011). Often, the methodological innovation of Egger and Pfaffermayr is overlooked in favor of the contribution to foreign direct investment (FDI) analyses (Egger & Pfaffermayr, 2004b; Egger &

Winner, 2005; Fratianni, Marchionne, & Hoon Oh, 2011; Mitze, Alecke, & Untiedt, 2007; Türkcan, 2011).

It is important for exporting partners to understand the contributing factors that can cause trade disruptions or changes in trade composition as a result of a highly pathogenic outbreak. These changes can be costly when considering importer risk acceptance and long term revenue recovery (Jin, McCarl, & Elbakidze, 2009; Johnson et al., 2011; Johnson et al., 2015). Using the HT-SUR methodology, better disaggregation and efficient estimation of product categories can be estimated (Egger & Pfaffermayr, 2004a). This will allow exporters to understand potential impacts of a disease outbreak and adjust business practices accordingly to potentially mitigate some of the economic costs of an outbreak.

METHODOLOGY

Random effect estimators provide the most information when analyzing panel data as it provides estimates of the within and between variation of the data. However, the assumptions of a random effects model are often violated, especially that of no correlation between the individual effects and the error term. An alternative estimator when this key assumption is violated is the fixed effects model. The fixed effects model removes individual specific effects by decomposing the random effects estimate into two components: 1) between; and 2) within variation. Between estimators model the cross sectional effects across time for individuals, but cannot be applied to the underlying population, as they are sample specific. Within estimators compare effects across identifiers, but do not estimate time invariant variables.

A hybrid solution to account for both the between and within variation is a Hausman-Taylor (HT) estimator (Hausman & Taylor, 1981). This multistep approach estimates coefficients of both the within and between estimators for variables that vary across time or are constant (i.e., time variant and time invariant variables). The HT estimator provides estimates over two-dimensional panel data. These dimensions can be time, unique identifiers, geography, etc. Traditionally, if a dataset is three-dimensional, a researcher must choose which dimension to collapse to facilitate estimation, or must choose to estimate M equations (where M is the number of unique identifiers in the data's third dimension). Collapsing the dataset implies averaging over that dimension and can reduce the efficiency of the analysis. For example, if the third dimension is commodity type (e.g., whole chicken or frozen turkey), and only select commodities have a response to some external factor such as a disease outbreak, collapsing the data across these commodities might lead to statistically insignificant estimates of disease impacts for aggregated data. However, there may be statistically significant impacts estimated for a specific commodity had it been modeled individually. Furthermore, individual models do not account for correlations in the error terms across these models, if present.

This analysis uses the augmented gravity model of trade specification and is estimated with a HT estimator. The HT estimator assumes that some regressors are correlated with the unknown individual effects (α_i). The HT estimator separates the variables into four categories: time variant exogenous (X_1), time variant endogenous (X_2), time invariant exogenous (W_1), and time invariant endogenous (W_2). The variables used in the gravity model are separated into these HT designations and calculated using equation (1):

$$y_{it} = X_{1it}'\beta_1 + X_{2it}'\beta_2 + W_{1it}'\delta_1 + W_{2it}'\delta_2 + \alpha_i + \varepsilon_{it} \qquad (1)$$

where i is the unique identifier, t is time, y is the bilateral trading quantity, β and δ are vectors of coefficients, and ε are the residuals. Matrix dimension of i is N and t is T such that y_{it} is NTx1.

The endogenous variables are those variables that are correlated with the individual effects. The assumption that all variables are uncorrelated with the error term, $E[\varepsilon_i|W_{jit},X_{jit}] = 0$, still holds as with other panel estimators, but model assumptions are now extended so that not all variables are uncorrelated with the individual effects, $E[\alpha_i|W_{2it}, X_{2it}] \neq 0$. Important assumptions of the HT estimator include (Cameron & Trivedi, 2009; Hausman & Taylor, 1981):

1) $E[\alpha_i|X_{1it}, W_{1it}] = 0$; $E[\alpha_i|X_{2it}, W_{2it}] \neq 0$
2) $V[\alpha_i|X_{1it}, W_{1it}, X_2, W_2] = \sigma_\alpha^2$
3) $Cov[(\alpha_i, \varepsilon_i)|X_1, W_1, X_2, W_2] = 0$
4) $V[(\alpha_i + \varepsilon_i)|X_1, W_1, X_2, W_2] = \sigma_\alpha^2 + \sigma_\varepsilon^2$
5) $Corr\,[(\alpha_i + \varepsilon_{it}\,;\, \alpha_i + \varepsilon_{is})|\,X_1\,,\, W_1,\, X_2\,,\, W_2] = \frac{\sigma_\alpha^2}{(\sigma_\alpha^2 + \sigma_\varepsilon^2)}$.

The first assumption implies only certain variables are endogenous. Assumption 2 defines the variance of the random effects model that is used in later assumptions. Assumption 3 assumes that there is no covariance between the individual effects and the error term. Assumption 4 defines total HT variance as the sum of the variance for the individual effects and the error term variance. Assumption 5 is the correlation between panel observations. If these assumptions are true, then the HT estimation will be consistent and efficient.

The HT estimator is a multistep process that approximates the time invariant variables through an instrumental variable approach using the time variant exogenous variables as instruments for the time invariant endogenous variables. The HT estimator then estimates a weight for a feasible generalized least squares (FGLS) estimator using the estimated variances. This approach makes it is possible to have coefficients that can be predictive of the underlying population and include unbiased estimates of relevant time invariant variables, which are both limitations of using either of the classes of fixed effects models individually. Below is a brief description of the solution method, steps 1-5, adapted from Hausman and Taylor (1981) and Greene (2001).

1) Estimate the model with either a within or least squares dummy variable approach. The within estimation is presented in equation (2). This estimates the cross sectional variation consistently. Variance of this estimation will be σ_{ε}^{2}.

$$y_{it} - \overline{y_{\iota}} = (X_{1it} - \bar{X}_{1i})'\beta_1 + (X_{2it} - \bar{X}_{2i})'\beta_2 + (\varepsilon_{it} - \overline{\varepsilon_{\iota}}) \tag{2}$$

2) Calculate the residuals from step 1 by subtracting the estimated *y* from the observed *y*. Next, calculate the mean residual by time for individual *i*. Stack these to create a vector of mean residuals, e_i^*.

3) Use e_i^* as the dependent variable in an instrumental variable regression with W_{1it} and X_{1it} as instruments (Z_{1i} and Z_{2i}) for W_1 and W_2. This will consistently, but not efficiently, estimate δ_1 and δ_2 from equation (2). Additionally, this provides an estimate for σ^2 to be used in later steps.

4) Using assumption four from above regarding overall HT variance, σ_{α}^{2} can be calculated using the estimated variance from step 1 for the within estimation or σ_{ε}^{2}, (eq. 3) where T is the number of periods. Using the calculated variances, a weight for the FGLS in step 5 can be estimated using equation 4.

$$\sigma^2 = \sigma_{\alpha}^{2} + {\sigma_{\varepsilon}^{2}}/{T} \tag{3}$$

$$\hat{\theta} = 1 - \sqrt{\frac{\sigma_{\alpha}^{2}}{(T\sigma_{\alpha}^{2} + \sigma_{\varepsilon}^{2})}} \tag{4}$$

5) Use the estimated weights, θ, from equation (4) to create a new W* matrix.

$$W^* = [X_{1it}, X_{2it}, Z_{1i}, Z_{2i}] - \hat{\theta}[X_{1it}, X_{2it}, Z_{1i}, Z_{2i}] \tag{5}$$

$$y^* = y_{it} - \hat{\theta} y_{it} \tag{6}$$

$$V_{it} = [(X_{1it} - \bar{X}_{1i})', (X_{2it} - \bar{X}_{2i})', Z'_{1i}, \bar{X}_{1i}] \tag{7}$$

A final two stage least squares (2SLS) is estimated of y* on W* with instruments V_{it}.

Estimating individual HT models for data that are composed of three dimensions would result in consistent estimates across the two included dimensions, with the third dimension determining the individual models. However, if there are unknown factors that are endogenous across the M models, this information is not incorporated into the modeling framework. To account for the relationship across the error terms in related models, a system of equations should be used, such as a system of seemingly unrelated regressions (SUR). To account for three-dimensional panel data, a HT-SUR estimation that creates a system of HT estimations (eq. 8) should be used which expands the model to a system of k models. The key relevant aspect of this approach is that the variance of the estimator incorporates not only the combined variance of the within and between estimators, but also includes the variance across the individual HT estimators to capture those efficiency gains.

$$y_{it}^{k} = X_{1it}'\beta_1 + X_{2it}'\beta_2 + W_{1it}'\delta_1 + W_{2it}'\delta_2 + \alpha_i + \varepsilon_{it} \tag{8}$$

where i is the unique identifier, t is time, k is the third dimension (i.e., poultry product categories), and the other variables are defined above.

The HT-SUR uses the same steps as the HT estimator, except there is a stacking of equations. This implies that the dimensions of y change from NTx1 to NTKx1, where each NTx1 matrix is stacked by k, or the third dimension (e.g., poultry product categories). The variance is no longer σ^2I for each individual model, but now implies $\Sigma \otimes I$ where diagonal components are individual model variance covariance matrices and off diagonal components are the covariance between individual models.

To empirically test the HT-SUR model, a system of individual models estimated for poultry product categories will be compared to individually estimated models (as presented in Chapter 3). In order to correctly specify the appropriate model, a random effects model was estimated and results were tested using a Breush and Pagan Lagrangian Multiplier test to determine whether true random effects exist or if ordinary least squares regression would be better suited. The presence of random effects was statistically different from zero, thereby motivating the panel approach. Next, a Hausman specification test is performed to test between random and fixed effects models, which determined whether or not the individual effects are correlated with the error term. The Hausman specification test suggested a fixed effects model is appropriate. In order to have the most complete set of explanatory variables, a system of HT models are used to capture both the within and between variation of the data.

DATA

The HT-SUR estimator will be applied to the three-dimensional poultry trade dataset used in Chapter 3. The data are a combination of disease outbreaks of HPAI or ND and trade data from the Global Trade Information Services' Global Trade Atlas. The data consist of monthly bilateral trade for 24 exporting countries, from January 2004 to December 2015 for fourteen different poultry categories (Table 4-1).[16] Information concerning the diseases are recorded for HPAI and ND and reported on the World Organization for Animal Health (OIE) website (OIE, 2015). The OIE detailed reports on disease outbreaks included number of infected flocks, the number of outbreaks during a disease event, and the nature of a disease event in geopolitically defined countries. This study limits these outbreaks to those that are non-endemic for HPAI or ND. For more information on the diseases dataset see Johnson et al., 2015.

Bilateral trade is recorded for United Nation (UN) recognized trading partners so as to eliminate non-recognized trading partners such as "International Waters" or "High Seas." In

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[16] Austria, Belgium, Brazil, Canada, Chile, China, Denmark, France, Germany, Greece, Hungry, Italy, Japan, Mexico, Netherlands, Poland, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, the United Kingdom, and the United States.

addition, only trading partners that account for at least 5% of trade from the exporting country for the base year of 2013 are included in the analysis, as this is a period in which there were no outbreaks from non-endemic trading countries and should represent a non-infected, or “normal,” year’s trading value.

Poultry product categories are assigned based on the six-digit level of the harmonized system code (HS code) for fourteen poultry products (Table 4-1). Product categories are assigned a HT-SUR model group based on the nature of the product as indicated in the product name. For example, Live Chickens (HS 010511) is assigned to the live model and Whole Fresh Chicken (HS 020711) in the fresh model. These groupings were determined based on similar patterns of bilateral trade changes as well as feasibility in estimation. More aggregated groups, such as a turkey or a chicken model, were considered, but data limitations as a result of the SUR estimation exclude these more aggregated groupings.

Additional data are recorded from publically available sources. Annual population and real GDP data are reported by United States Department of Agriculture - Economic Research Service (USDA-ERS, 2015). Distance and geographical indicators are published in the GeoDist database through the Centre D’Etudes Prospectives et D’Informations Internationales, or CEPII (Mayer & Zignago, 2011). Country currencies, as reported by UN’s Food and Agriculture Organization Corporate Statistical Database (FAOStat) (2015a), are used to determine if a trading pair uses a common currency. Annual global per capita consumption of poultry is recorded from the UN’s Organization for Economic Co-operation and Development (OECD)-FAO Agricultural Outlook (2015b).

Variable summary statistics for this analysis are presented in Table 4-2. These include the variables necessary for a gravity model of trade: *GDP* and *population,* of both exporting and importing partners, as well as *distance* between trading partners. *Share* indicates the share of the world's export market and is included as an indicator for the relative importance of the exporter on the global market.

The two disease variables of interest are *ND* and *HPAI*, which indicate discreetly whether there was a disease event of either ND or HPAI in the exporting region. Additional disease information include *out year*, which is a count of simultaneous outbreaks in a given year. While some importers may not change their preferences during a global disease event, there is a possibility that with increased global disease pressure an importer may change the types of products imported or ban imports from infected exporters.

Per capita is the annual per capita consumption of poultry meat, which provides a variable to account for the global trend in consumption of poultry products across time. *Contiguous partners* specify whether trading partners share a common border and *common currency* specifies whether trading partners have a common currency. Both *contiguous partners* and *common currency* are variables meant to provide insights into potential trading favorability based on either proximity or reduced transaction costs in either shipping or exchange fees. To account for potential regional and cultural variability, region variables are included to indicate the region of the exporter.

RESULTS AND DISCUSSION

To compare the two methodologies presented in chapter 3 and chapter 4, 14 different HT models were estimated for each of the different poultry product categories creating a baseline to compare to the five HT-SUR models (Table A 4-1 and Table A 4-2). To compare the two model results, data were limited in the individual models to only those observations that could be used in the HT-SUR models. For the seemingly unrelated regression analysis, observations must be consistent across identifiers. Only those bilateral partners that traded all products in the HT-SUR group could be included. While this is not optimal for estimation, this allows the researchers to compare similar modeling results. The HT and HT-SUR models were estimated using Stata (StataCorp, 2016). Full results are presented in Appendix 4 Tables A 4-1 and 4-2, respectively. Selected results are presented in Table 4-3 for select poultry product categories assigned to the frozen model for both the HT and HT-SUR estimations. The frozen category includes chicken and turkey as well as different cuts of meat (i.e., whole and parts). The individual models are those that were estimated as an individual model and would represent the traditional method of estimating three-dimensional data (as described in Chapter 3). The three product categories included in the frozen model were estimated in the system of equations as part of the HT-SUR estimation.

Using a Z-test, assuming asymptotic normality, the coefficients of the HT and HT-SUR models were tested to see if they are significantly different. For all significant levels, the tests fail to reject the null hypothesis that the values are statistically similar. Testing provides assurances that the coefficients are statistically the same and supports consistency in estimation across the two modeling frameworks.

For both the HT and the HT-SUR estimations, similar variables are estimated to be significant. An instance where this varies can be observed in the *per capita* variable, which is estimated to have significantly influenced bilateral trade for whole frozen turkey in the HT-SUR estimation, but was not statistically different than zero in the individual HT model. The expectation of the HT-SUR estimator is an increase in modeling efficiency. In this analysis, there are small improvements in the standard errors, 2.57 for the HT estimator and 2.53 for the HT-SUR. The estimated coefficients differ, such that given the standard error estimated, it is determined significant at the 0.1 level, or 90% confidence. This significance implies that increases in global poultry consumption by 1% decreases the quantity of bilateral trade of whole frozen turkey by 4.24%. The individual model results indicate no significant relationship between global consumption trends and quantity traded.

Variables influencing trade based on the gravity model of trade specification tend to be significant in determining bilateral trade quantities. These include importer and exporter population and GDP as well as the distance between trading partners. *Importer population* significantly affects all sample models except whole frozen chicken. *Distance* significantly impacts all sample models. Directionally, distance negatively influences whole frozen chicken and frozen chicken parts, a decrease of 2.4% and 0.34% respectively for a 1% increase in distance between partners for the HT-SUR estimation. This implies that as the distance between bilateral partners increases, indicating a change in partners, the quantity traded of these products decreases. The opposite is true for frozen turkey product categories. The further the distance between trading partners the greater the quantity traded of whole frozen turkey, or an increase of 0.95% for a 1% increase in distance. These results reflect differences in preferences in importing countries as well as preferences for shipping methods.

The two disease variables *HPAI* and *ND* were predominantly insignificant influencing factors for the quantity traded of frozen poultry products with the exception of whole frozen chicken for both modeling frameworks. The quantity of whole frozen chicken is estimated to decrease during an outbreak of HPAI. These results are surprising in that a disease outbreak of HPAI is traditionally expected to influence bilateral trade. This is not to say that countries do not respond, but that in the reduced dataset, it was not statistically significant for the frozen product categories. Extending this to compare all poultry product categories (Tables A 4-1 and A 4-2) there are more product categories with the *HPAI* variable that are statically significant. One explanation for this is in terms of composition of trade. Some commodities might not be affected, as importers are not sensitive to those products due to preferences or risk perceptions of those products. Others could increase or decrease trade based on type of product. A ND event is not a significant factor affecting trade in any of the commodity groups. This is an important point to note, that during a disease event trade may be affected between some trading partners, but not so much as to significantly change the total quantity traded.

Limitations of this analysis lie with an unbalanced panel in the underlying data. Given that the HT-SUR must have a balanced panel to estimate, observations were excluded when estimating both models. This limits the bilateral trade pairs that are being used in the estimation. For a balanced panel, this would not be an issue as the HT-SUR estimator would not drop those observations missing by bilateral trading pair. Consistently, the results indicate slight efficiency gains by using the HT-SUR model, motiving its potential methodological appropriateness for three-dimensional data. Future research with balanced panels could benefit from using this methodology as a way to estimate three-dimensional datasets consistently and efficiently without having to collapse across one of the dimensions.

CONCLUSION

Many factors affect global poultry trade, and are of interest to exporting and importing partners during a disease event such as HPAI or ND. Understanding the influencing factors provides increased understanding of the consequences of a disease event in an exporting country. This work estimates the factors affecting bilateral trade, and compares the extended HT-SUR methodology to a traditional HT approach. The empirical results provide a deeper understanding of those factors, which can be used to estimate the changes in quantity traded of a poultry product category given a highly pathogenic disease event.

The augmented gravity model of trade provides a means for specifying predictive factors of the quantity of bilateral trade. The additional information included in this analysis allows for increased predictability, accounting for changes in global tastes and preferences across time, relative importance of the exporting partner, and a measure for preferences linked to geographic proximity and potential economic favorability (e.g., *common currency)*.

Using the HT-SUR estimator, this work bridges the gap from the political economy literature to agricultural trade in showing the gains in estimator efficiency by using a systems approach for three-dimensional panel. The data used in this analysis are a unique bilateral trade dataset across time and product categories. The use of the HT-SUR allows researchers to maintain data dimensionality, not typical of panel data analyses in the agricultural economics literature. Often these compromises come in the form of aggregation across one of the dimensions, which can smooth out potential effects of explanatory variables. By using the HT-SUR, this aggregation is not necessary, providing a framework for a three-dimensional analysis. The presented method is not limited to trade, in that any dataset with three-dimensions and time variant and time invariant variables that have individual effects could be estimated using this methodology, gaining in efficiency without compromising one of the dimensions or consistency in estimation. Using this methodology, future work could include other agricultural sectors to estimate the effects of major trade distorting events to improve the available information to exporting and importing countries.

Table 4-1: Poultry product categories used in bilateral trade analysis with the associated HT-SUR model

Product Short Name	Product Name	HS Code	HT-SUR Model
Live Chickens	Commodity: 010511, Chickens, Live, Weighing Not More Than 185 G (6.53 Oz.) Each	10511	Live
Live Turkeys	Commodity: 010512, Turkeys, Live, Weighing Not More Than 185 G (6.53 Oz.) Each	10512	Live
Whole Chicken: Fresh	Commodity: 020711, Meat And Edible Offal Of Chickens, Not Cut In Pieces, Fresh Or Chilled	20711	Fresh
Whole Chicken: Frozen	Commodity: 020712, Meat And Edible Offal Of Chickens, Not Cut In Pieces, Frozen	20712	Frozen
Chicken Parts: Fresh	Commodity: 020713, Chicken Cuts And Edible Offal (Including Livers) Fresh Or Chilled	20713	Fresh
Chicken Parts: Frozen	Commodity: 020714, Chicken Cuts And Edible Offal (Including Livers) Frozen	20714	Frozen
Whole Turkey: Frozen	Commodity: 020725, Turkeys, Not Cut In Pieces, Frozen	20725	Frozen
Whole Turkey: Fresh	Commodity: 020726, Turkey Cuts And Edible Offal (Including Livers), Fresh Or Chilled	20726	Fresh
Turkey Parts: Frozen	Commodity: 020727, Turkey Cuts And Edible Offal (Including Liver) Frozen	20727	Frozen
Shell Eggs	Commodity: 0407, Birds' Eggs, In Shell, Fresh, Preserved Or Cooked	407	Eggs
Eggs Products	Commodity: 0408, Birds' Eggs, Not In Shell And Egg Yolks, Fresh, Dried, Cooked By Steam Etc., Molded, Frozen Or Otherwise Preserved, Sweetened Or Not	408	Eggs
Cooked Turkey	Commodity: 160231, Meat Or Meat Offal Of Turkeys, Prepared Or Preserved, N.E.S.O.I.	160231	Prepared
Cooked Chicken	Commodity: 160232, Prepared Or Preserved Chicken Meat, Meat Offal Or Blood, N.E.S.O.I.	16032	Prepared
Cooked Other	Commodity: 160239, Meat Or Meat Offal Of Chickens, Ducks, Geese And Guineas, Prepared Or Preserved, N.E.S.O.I.	160239	Prepared

Source: Global Trade Information System – Global Trade Atlas; HS: Harmonized System; HT-SUR Model based on similar product processing levels.

Table 4-2: Descriptive statistics and Hausman-Taylor model descriptions for variables used in bilateral quantity trade analysis

Name	Variable Description	Unit	HT[3] Description	Mean	Min	Max
Quantity[1]	Exporting quantity	Pounds	TV[4], Exogenous	281,484	1	120,000,000
$Population_i$	Population for trading partner i[2]	Per Capita	TV, Exogenous	83,800,000	102,918	1,360,000,000
GDP_i	Real GDP for trading partner i[2]	Billions of USD	TV, Exogenous	1,841.75	0.71	16,271
Distance	Distance between trading partners	Kilometers	TIV[5], Endogenous	2,497	60	19,080
Share	Annual share of world export market	%	TV, Endogenous	0.05	0.00	0.33
Highly Pathogenic Newcastle Disease (ND)	Binary variable indicating if ND was reported	0,1	TV, Endogenous	0.02	0	1
Highly Pathogenic Avian Influenza (HPAI)	Binary variable indicating whether HPAI was reported	0,1	TV, Endogenous	0.07	0	1
OutYear	The number of simultaneous disease events in a given year	Count	TV, Exogenous	5.28	0	15
Percent Capita	Annual global per capita consumption of poultry meat	%	TV, Exogenous	12.15	10.7	13.74
Contiguous Partners	Binary variable to indicating partners who are geographically contiguous	0,1	TIV, Exogenous	0.45	0	1
Common Currency	Binary variable indicating trading partners who share a common currency	0,1	TIV, Exogenous	0.27	0	1
Asia	Binary variable for exporting country	0,1	TIV, Exogenous	0.10	0	1
Europe	Binary variable for exporting country	0,1	TIV, Exogenous	0.70	0	1
South America	Binary variable for exporting country	0,1	TIV, Exogenous	0.03	0	1

Table 4-2: Descriptive statistics and Hausman-Taylor model descriptions for variables used in bilateral quantity trade analysis, cont.

Name	Variable Description	Unit	HT[3] Description	Mean	Min	Max
North America	Binary variable for exporting country	0,1	TIV, Exogenous	0.06	0	1
Africa	Binary variable for exporting country	0,1	TIV, Exogenous	0.06	0	1
Oceania	Binary variable for exporting country	0,1	TIV, Exogenous	0.01	0	1
Middle East	Binary variable for exporting country	0,1	TIV, Exogenous	0.04	0	1

[1] Dependent Variable
[2] i = exporter, importer
[3] HT Description=Hausman Taylor variable description
[4] TV: Time Variant
[5] TIV Time Invariant

Table 4-3: Selected results for estimated factors influencing bilateral poultry trade comparing Hausman-Taylor to Hausman-Taylor seemingly unrelated regression models

	Frozen Model			Individual	Individual	Individual
	Whole Frozen Chicken	Frozen Chicken Parts	Whole Frozen Turkey	Whole Frozen Chicken	Frozen Chicken Parts	Whole Frozen Turkey
Importer Population	-5.86	9.26***	-13.65***	-5.77	8.91***	-14.76***
	(4.85)	(2.33)	(4.98)	(4.93)	(2.37)	(5.06)
Importer GDP	-1.27	0.98	8.92***	0.28	1.34	9.25***
	(2.19)	(1.10)	(2.17)	(2.22)	(1.12)	(2.20)
Exporter GDP	11.08***	-2.47**	-1.19	10.30***	-2.79**	-0.92
	(2.37)	(1.15)	(2.83)	(2.41)	(1.17)	(2.89)
Exporter Population	-3.47	-10.57**	21.15**	-12.20	-11.80**	18.01*
	(10.21)	(4.91)	(10.73)	(10.38)	(5.00)	(10.93)
Distance	-2.40***	-0.34***	0.95***	-2.25***	-0.25***	1.04***
	(0.23)	(0.09)	(0.14)	(0.23)	(0.09)	(0.14)
Per Capita	6.48**	0.58	-4.24*	6.83**	1.05	-3.42
	(2.61)	(1.30)	(2.53)	(2.64)	(1.33)	(2.57)
Share	0.94**	1.27***	0.61	1.08**	1.30***	0.61
	(0.47)	(0.23)	(0.51)	(0.48)	(0.23)	(0.52)
ND	0.30	0.10	-0.32	0.23	0.13	-0.31
	(0.42)	(0.20)	(0.42)	(0.43)	(0.20)	(0.43)
HPAI	-1.14***	-0.08	0.42	-1.15***	-0.09	0.39
	(0.40)	(0.17)	(0.36)	(0.41)	(0.17)	(0.37)
Out Year Count	0.06**	-0.00	-0.02	0.07**	0.00	-0.01
	(0.03)	(0.01)	(0.03)	(0.03)	(0.01)	(0.03)

Table 4-3: Selected results for estimated factors influencing bilateral poultry trade comparing Hausman-Taylor to Hausman-Taylor seemingly unrelated regression models, cont.

	Frozen Model			Individual	Individual	Individual
	Whole Frozen Chicken	Frozen Chicken Parts	Whole Frozen Turkey	Whole Frozen Chicken	Frozen Chicken Parts	Whole Frozen Turkey
Contiguous Partners	-0.32	-0.65***	-0.02	-1.00**	-0.69***	-0.19
	(0.45)	(0.23)	(0.34)	(0.46)	(0.24)	(0.34)
Common Currency	2.82***	1.40***	-0.39	3.74***	1.51***	-0.29
	(0.43)	(0.33)	(0.32)	(0.45)	(0.35)	(0.33)
Constant	222.25	100.16	-336.25	538.83*	149.74	-206.15
	(302.75)	(136.41)	(296.02)	(308.18)	(139.85)	(301.72)
Number of Observations	478	478	478	478	478	478
R^2	0.556	0.680	0.622	0.560	0.681	0.623

Source: Model Estimations; Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

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CHAPTER 5 - CONCLUSIONS

Highly pathogenic diseases can spread quickly and can be virulent, thus potentially infecting a great number of animals and creating a significant burden on the food supply chain. The overarching theme of this work is estimating the impacts of a highly pathogenic poultry disease event on the U.S. poultry supply chain. Highly pathogenic diseases have the potential to devastate stocks of animals in a matter of months, especially if uncontrollable vectors carry them. For the poultry industry, HPAI is particularly of concern due to its virulence and pathology. For example, in two quarters during the 2014-2015 outbreak of HPAI in the United States, more than 48 million birds were affected. The economic impact of a disease event includes direct disease costs such as the cost of depopulation, cleaning and disinfecting, restocking, etc., and also indirect costs that are the effects of having a confirmed disease event such as export losses due to trade embargos and negative effects on consumer and producer welfare (Thompson & Pendell, 2016). As global trade increases, disease management will continue to be an issue of great importance to ensure the healthfulness of domestic production and the competiveness of markets domestically and internationally.

The first essay shows that farm level disease management decisions from animal health officials have impacts along the supply chain. Decisions to continue stop movement orders potentially impact uninfected premises within the control zone with a loss of potential revenue (Thompson & Pendell, 2016). Producers that are able to move products can benefit from increased prices, but taking into account the losses to the affected producers leaves the net impact to producers as a loss in total welfare. Consumers are affected by disease management decisions through changes in final prices of goods. Stop movement orders effectively exacerbate the reduction in egg supply caused by the disease event itself. The resulting changes in prices can lead to losses in total welfare. By providing a proactive plan for business continuity, $13.6 million in forgone welfare may be recovered in the simulated outbreak. These economic losses of a disease event with only stop movement orders show the value of a permitting process based on proactive risk assessments. By assessing the value and the potential risks of business continuity practices, policy makers can make more informed decisions.

The second essay analyzes the impact of a disease event in exporting countries on bilateral trade. Importers can choose which trade restrictions to impose on various products and for how long. These decisions can drive changes in the composition of trade as importing countries may choose to import from other sources or import other products. Model estimates show that commodities are influenced differently by disease, emphasizing the impact of commodity specific estimations. While HPAI and ND both have impacts on total bilateral trade, when modeling individual product categories, HPAI was found to significantly impact trade in certain product categories. ND was not found to significantly influence trade quantity during a disease event. The analysis also estimated the effects of other factors that influence trade including common currency or contagious partners. The individual product category estimations help to provide more accurate *ex ante* results to be used in the face of a disease event and provide practitioners with improved understanding of bilateral trade flow influencing factors and composition during a disease event.

The final essay builds from the limitations of current trade literature to show methodological efficiency gains by using a system of HT equations instead of product category individual models. Extending the methodology to incorporate the HT-SUR model developed by Egger and Pfaffermayr (2004) provides an estimator that is capable of analyzing three-dimensional data without compromising any of the dimensions. Robust bilateral trading data for multiple commodities over time are often collapsed over one of the dimensions in practice. Using the HT-SUR estimator, factors that influence quantity traded were investigated. The limitation of this analysis is in the usable observations for the system of equations. However, even limiting the comparison across methodologies to the same observations, there was evidence of slight efficiency gains using the systems approach. These gains imply that future work on panel data do not have to compromise a dimension in estimation, especially considering the rich data available to researchers.

The negative impacts of disease events are never desired, but this work shows that there are mechanisms that can be used to mitigate some disease-related impacts and provides estimates to understand the potential trade implications. Business continuity can provide a reduction in negative welfare effects throughout the supply chain by allowing for a quicker permitting process to move products or goods on or off of premises within a control area. By knowing the trade impacts of a disease event, exporters can more readily predict implications, and may be better prepared to respond to potential trade restrictions in the case of a disease event. These analyses provide usable tools and methodologies that can be used in the event of a highly pathogenic event, such as HPAI, in the United States to understand the economic costs associated with disease-related management practices and trade impacts. This also provides a framework that can be used to study disease events in other industries such as beef or pork. These analyses can be extended to other industries to determine if similar disease management practices are economically viable or to more fully understand the factors that influence trade.

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APPENDIX 1: MODEL PARAMETER CALCULATION DESCRIPTIONS

This appendix provides further explanation for the calculated parameters. All parameters are reported in Table A 2-1 below.

Unit Revenue Shares

Unit revenue shares are derived from published information (Bell, 2001) and supplemented with industry expert opinions. The revenue shares are calculated as a percent of the price going to different factors of production. These are aggregated into three main categories: 1) shell eggs (breaker eggs); 2) costs of processing; and 3) margin. The most likely values are requested when eliciting expert opinion. In order to compare prices across multiple products, the processed egg products are calculated using a shell egg equivalent. Where necessary, the shell egg equivalent conversion factor used is 1.4 pounds per dozen shell eggs (USDA-AMS, 2015).

Egg prices used to calculate the unit revenue shares are the 2014 mean prices as reported by the USDA-AMS (2015). Table eggs are the average 2014 prices of Grade A, white, large eggs. For processed eggs, an aggregate processed egg price is calculated using the AMS reported prices in conjunction with expert opinion for the diversion of eggs into the three processed egg categories: liquid, frozen, or dried eggs. Each product and product price is converted to a shell egg equivalent. The average tended toward the average frozen processed egg prices.

Costs used in calculations are general values for either table or processed eggs (Ibarburu & Bell, 2014). All transportation costs are assumed to be 10 cents per dozen. Table egg costs consist of 22 cents per dozen processing costs for washing, sanitizing, and cartooning the eggs plus transportation costs. Processed egg costs are estimated as 24 cents per equivalent dozen, which include transportation, processing, and pasteurizing. The processing costs include the costs associated with breaking eggs. Eggs are typically pasteurized as egg products, such that a shell egg equivalent had to be used to estimate the cost on a per egg basis. These costs were elicited from industry experts.

Margin on eggs is assumed to be the difference between the end prices of products (USDA-AMS, 2015) minus the aforementioned costs. This reduces the sensitive nature of eliciting opinion on margin values from producers. This margin accrues to the processor and retailer as well as any additional middle steps including wholesaler, warehousing, or additional transportation outside transportation costs.

Product Specific Elasticities

The nature of the economic egg model diverts eggs into either table or processed eggs. In order to parameterize the model appropriately, elasticities specific to end product are needed for most accurate results. These are not found in current literature or government sources. Available elasticities are generalized egg elasticities that include all egg products (including hatching eggs). In order to facilitate modeling endeavors, stock, net export, and price elasticities are calculated by end product used in the model (i.e., individually for table and processed eggs). This provides a means to differentiate market responses by product type, instead of assuming similar responses by type of product. All elasticities are calculated by use of double log models, which assume constant elasticities.

Stock Elasticities

To estimate the stock elasticities ($\varepsilon_{I,i}$), individual models are calculated using ordinary least squares for ending stocks (I_t) for both i goods (i.e., table and processed eggs) as a function of the price of shell eggs (P_s) during the current time period t. The values were logged, assuming constant elasticities in equation 1.

(1) $EI_t = \beta_1 + \varepsilon_{I,i} EP_s$

Net Export Elasticities

Net export elasticities had to be calculated for both egg product types due to limitation of the available net exports elasticities. Elasticities in the relevant literature were aggregated for all egg product and were separated into import and export elasticities. To calculate the net export elasticities ($\varepsilon_{x-m,i}$), a simple ordinary least squares regression was estimated for net exports (X_i-M_i) for both table and processed eggs using world price (P_i^w) for the respective egg type as the regressor. All variables were logged such that the resulting coefficients are the elasticities. Below are the equations used in these calculations.

(2) $E(X_{TE} - M_{TE}) = \beta_1 + \varepsilon_{x-m,TE} EP_{TE}^w$

(3) $E(X_{PE} - M_{PE}) = \beta_1 + \varepsilon_{x-m,PE} EP_{PE}^w$

Price Elasticities

For similar reasons as above, the elasticities for the individual egg type were calculated to better parameterize the U.S. Egg Model. These again were estimated with ordinary least squares on a double log specified model. The quantity, or D_i, is regressed on the own and cross prices to better estimate the price elasticities.

(4) $ED_{TE} = \beta_1 + \varepsilon_{TE,TE}\ EP_{TE} + \varepsilon_{TE,PE}\ EP_{PE}$

(5) $ED_{PE} = \beta_1 + \varepsilon_{PE,PE}\ EP_{PE} + \varepsilon_{PE,TE}\ EP_{TE}$

Calculated Parameters

Calculated parameters are those parameters that are defined through the model substitution process. When substituting to reduce the 22 equations into the three final equations to be solved using inverse matrix algebra, these were the newly defined coefficients on variables. They are defined using the exogenous parameters specified in the Table A 2-1. Appendix equations 6, 7, 9, and 10 are all input elasticities for either table or processed eggs. These elasticities represent the relative change in quantity given a change in an input for the *i* product. Equations 8 and 11 represent the supply elasticity for the *i,i* product, which is the change in quantity supplied given a change in the end price of that product. All parameters have been defined in the text and summary is provided in Table A 2-1.

(6) $$_{TE,w} = \frac{_{l,TE}\left(_{l,k|TE}\left(_{k,TE} + _{l,TE}\right) + _{s,TE} \; _{s,k|TE}\right)}{_{k,TE}}$$

(7) $$_{TE,s} = \frac{_{s,TE}\left(_{s,k|TE}\left(_{k,TE} + _{s,TE}\right) + _{l,TE} \; _{l,k|TE}\right)}{_{k,TE}}$$

(8) $$_{TE,TE} = \frac{_{l,TE} \; _{l,k|TE} + _{s,TE} \; _{s,k|TE}}{_{k,TE}}$$

(9) $$_{PE,w} = \frac{_{l,PE}\left(_{l,k|PE}\left(_{k,PE} + _{l,PE}\right) + _{s,PE} \; _{s,k|PE}\right)}{_{k,PE}}$$

(10) $$_{PE,s} = \frac{_{s,PE}\left(_{s,k|PE}\left(_{k,PE} + _{s,PE}\right) + _{l,PE} \; _{l,k|PE}\right)}{_{k,PE}}$$

(11) $$_{PE,PE} = \frac{_{l,PE} \; _{l,k|PE} + _{s,PE} \; _{s,k|PE}}{_{k,PE}}$$

Table A 2-1: Summary of parameters used in the economic model analysis and their sources

Parameters	Description	Value	Source
$\theta_{l, te}$	Unit revenue shares	0.160	Bell, (2001); Industry Expertise
$\theta_{s,te}$	Unit revenue shares	0.515	Bell, (2001); Industry Expertise
$\theta_{k,te}$	Unit revenue shares	0.325	Bell, (2001); Industry Expertise
$\theta_{l, pe}$	Unit revenue shares	0.164	Bell, (2001); Industry Expertise
$\theta_{s,pe}$	Unit revenue shares	0.532	Bell, (2001); Industry Expertise
$\theta_{k,pe}$	Unit revenue shares	0.304	Bell, (2001); Industry Expertise
$\lambda_{s, te}$	Factor Share	0.700	USDA – AMS (2015)
$\lambda_{s, pe}$	Factor Share	0.300	USDA – AMS (2015)
$\varepsilon_{y,te}$	Income Elasticity	0.346	USDA – ERS (2013)
$\varepsilon_{y,pe}$	Income Elasticity	0.346	USDA – ERS (2013)
$\varepsilon_{i, te}$	Stock Elasticity	-1.315	Author's Calculation
$\varepsilon_{i, pe}$	Stock Elasticity	-0.108	Author's Calculation
$\varepsilon_{x, te}$	Net Export Elasticity	0.590	Author's Calculation
$\varepsilon_{x,pe}$	Net Export Elasticity	0.250	Author's Calculation
$\varepsilon_{te,pe}$	Cross Price Elasticity	0.149	Author's Calculation
ε_{te}	Own Price Elasticity	-0.538	Author's Calculation
ε_{pe}	Own Price Elasticity	-0.801	Author's Calculation
$\sigma_{s,k: te}$	Substitution Elasticity	0.436	Ollinger, MacDonald, & Madison (2005)
$\sigma_{l,k: te}$	Substitution Elasticity	0.436	Ollinger, MacDonald, & Madison (2005)
$\sigma_{s,k: pe}$	Substitution Elasticity	0.436	Ollinger, MacDonald, & Madison (2005)
$\sigma_{l,k: pe}$	Substitution Elasticity	0.436	Ollinger, MacDonald, & Madison (2005)
ε_{s}	Egg Price Elasticity	-0.088	USDA – ERS (2013)
η_{s}	Raw Egg Supply Elasticity	1.000	USDA – ERS (2013)
$\eta_{te, w}$	Input Elasticity	0.215	Author’s Calculation
$\eta_{te, s}$	Input Elasticity	0.692	Author’s Calculation
$\eta_{te, te}$	Supply Elasticity	0.907	Author’s Calculation
$\eta_{pe, w}$	Input Elasticity	0.321	Author’s Calculation
$\eta_{pe, s}$	Input Elasticity	0.762	Author’s Calculation
$\eta_{pe, pe}$	Supply Elasticity	0.996	Author’s Calculation

APPENDIX 2: EXPANDED MODEL EQUATIONS FOR U.S. EGG INDUSTRY

The model is written in its fully differentiated form such that all variables represented are percent changes (*E* is used to denote dln, e.g., $dlnP_i$ is noted as EP_i).

(1) $EP_{TE} = \theta_{l,TE}\, Ew + \theta_{s,TE}\, EP_s + \theta_{k,TE}\, Er_{TE}$

(2) $EP_{PE} = \theta_{l,PE}\, Ew + \theta_{s,PE}\, EP_s + \theta_{k,PE}\, Er_{PE}$

(3) $ES = E\phi + \lambda_{s,te}\, Eq_{te} + \lambda_{s,pe}\, Eq_{pe} + \lambda_{s,te}\, Ea_{s,te} + \lambda_{s,pe}\, Ea_{s,pe}$

(4) $ES = \varepsilon_s EP_s$

(5) $Ek_{TE} = Ea_{k,TE} + Eq_{TE}$

(6) $Ek_{PE} = Ea_{k,PE} + Eq_{PE}$

(7) $Ea_{s,TE} - Ea_{k,TE} = -\sigma_{s,k|TE}(EP_s - Er_{TE})$

(8) $Ea_{l,TE} - Ea_{k,TE} = -\sigma_{l,k|TE}(Ew - Er_{TE})$

(9) $\theta_{e,TE}\, Ea_{e,TE} + \theta_{l,TE}\, Ea_{l,TE} + \theta_{k,TE}\, Ea_{k,TE} = 0$

(10) $Ea_{s,PE} - Ea_{k,PE} = -\sigma_{s,k|PE}(EP_s - Er_{PE})$

(11) $Ea_{l,PE} - Ea_{k,PE} = -\sigma_{l,k|PE}(Ew - Er_{PE})$

(12) $\theta_{s,PE}\, Ea_{s,PE} + \theta_{l,PE}\, Ea_{l,PE} + \theta_{k,PE}\, Ea_{k,PE} = 0$

(13) $q_{TE}Eq_{\ TE} + I_{TE,t-1}EI_{\ TE,t-1} = (X_{TE} - M_{TE})E(X_{TE} - M_{TE}) + D_{TE}ED_{\ TE} + I_{TE,t}EI_{\ TE,t}$

(14) $q_{PE}Eq_{\ PE} + I_{PE,t-1}EI_{\ PE,t-1} = (X_{PE} - M_{PE})E(X_{PE} - M_{PE}) + D_{PE}ED_{\ PE} + I_{PE,t}EI_{\ PE,t}$

(15) $EI_t = \varepsilon_{I,TE}EP_s$

(16) $EI_t = \varepsilon_{I,PE}EP_s$

(17) $ED_{TE} = E\gamma_{TE} + \varepsilon_{TE,TE}\, EP_{TE} + \varepsilon_{TE,PE}\, EP_{PE}$

(18) $ED_{PE} = E\gamma_{PE} + \varepsilon_{PE,PE}\, EP_{PE} + \varepsilon_{PE,TE}\, EP_{TE}$

(19) $E(X_{TE} - M_{TE}) = \delta_{TE} + \varepsilon_{x-m,TE} EP_{TE}^{w}$

(20) $E(X_{PE} - M_{PE}) = \delta_{PE} + \varepsilon_{x-m,PE} EP_{PE}^{w}$

(21) $P_{TE}^{w} EP_{TE}^{w} = P_{TE}\, EP_{TE} + c_{TE} Et_{TE}$

(22) $P_{PE}^{w} EP_{PE}^{w} = P_{PE}\, EP_{PE} + c_{PE} Et_{PE}$

APPENDIX 3: REGION SPECIFICATION USED IN GRAVITY ANALYSIS

Table A 3-1: Region specification for gravity model region factors

Region	Model Region	Country	Region	Model Region	Country
Asia	1	China	South America	3	Brazil
Asia	1	Hong Kong	South America	3	Chile
Asia	1	Hong Kong	South America	3	Costa Rica
Asia	1	Japan	South America	3	Cuba
Asia	1	Kazakhstan	South America	3	Dominican Republic
Asia	1	Singapore	South America	3	Guatemala
Asia	1	Taiwan	South America	3	Haiti
Asia	1	Vietnam	South America	3	Jamaica
Europe	2	Belgium	South America	3	Paraguay
Europe	2	Croatia	South America	3	Trinidad & Tobago
Europe	2	Estonia	South America	3	Venezuela
Europe	2	France	North America	4	Canada
Europe	2	Georgia	North America	4	Mexico
Europe	2	Germany	North America	4	United States
Europe	2	Ireland	Africa	5	Angola
Europe	2	Latvia	Africa	5	Libya
Europe	2	Netherlands	Africa	5	Senegal
Europe	2	Poland	Africa	5	South Africa
Europe	2	Portugal	Oceania	6	Australia
Europe	2	Romania	Oceania	6	Indonesia
Europe	2	Russia	Oceania	6	Philippines
Europe	2	Spain	Middle East	7	Kuwait
Europe	2	Turkey	Middle East	7	Oman
Europe	2	United Kingdom	Middle East	7	Qatar
South America	3	Argentina	Middle East	7	Saudi Arabia
South America	3	Bahamas	Middle East	7	United Arab Emirates
South America	3	Bolivia	Middle East	7	Yemen

APPENDIX 4: COMPLETE RESULTS FOR CHAPTER 4 ANALYSES

Table A 4-1: Estimated factors influencing bilateral poultry trade using Hausman-Taylor individual models

	Live Chickens	Live Turkeys	Whole Fresh Chicken	Whole Frozen Chicken	Fresh Chicken Parts
Importer Population	10.99**	-4.86***	0.93	-5.77	0.54
	(4.31)	(1.24)	(1.47)	(4.93)	(1.56)
Importer GDP	0.92	-0.34	0.62	0.28	-0.65
	(0.96)	(0.28)	(0.46)	(2.22)	(0.58)
Exporter GDP	5.40***	0.26	-0.07	10.30***	2.00***
	(1.18)	(0.34)	(0.61)	(2.41)	(0.71)
Exporter Population	-38.64***	3.36	-7.63***	-12.20	1.78
	(6.98)	(2.07)	(1.93)	(10.38)	(2.31)
Distance	0.71***	-0.28***	0.12***	-2.25***	-0.22***
	(0.10)	(0.02)	(0.03)	(0.23)	(0.04)
Per Capita	7.84***	1.14**	2.86***	6.83**	1.66**
	(1.44)	(0.47)	(0.58)	(2.64)	(0.68)
Share	-0.94***	0.12	0.51***	1.08**	1.04***
	(0.35)	(0.11)	(0.13)	(0.48)	(0.15)
END	0.02	-0.09	0.05	0.23	-0.00
	(0.31)	(0.11)	(0.12)	(0.43)	(0.14)
HPAI	0.58**	-0.04	-0.29**	-1.15***	-0.20
	(0.23)	(0.08)	(0.12)	(0.41)	(0.14)
Europe	-	-2.30***	-0.11	-15.11***	4.96***
	-	(0.09)	(0.72)	(1.59)	(0.88)
North America	1.12***	-	0.98	-0.91	7.74***
	(0.39)	-	(0.71)	(0.97)	(0.87)
Africa	-2.39	-1.64***	-	-	-
	(2.22)	(0.54)	-	-	-
Out Year Count	-0.03	0.01	-0.00	0.07**	0.00
	(0.02)	(0.01)	(0.01)	(0.03)	(0.01)
Contiguous Partners	1.45***	0.45***	-0.11	-1.00**	0.05
	(0.38)	(0.09)	(0.09)	(0.46)	(0.11)
Common Currency	-0.78**	-0.90***	0.86***	3.74***	1.11***
	(0.39)	(0.13)	(0.08)	(0.45)	(0.11)
Constant	1,331.27***	66.52	217.77***	538.83*	-93.15
	(253.70)	(55.73)	(59.43)	(308.18)	(70.41)
Observations	1,161	1,161	2,235	480	2,235
R-squared	0.177	0.497	0.141	0.560	0.191

Table A 4-1: Estimated factors influencing bilateral poultry trade using Hausman-Taylor individual models, cont.

	Frozen Chicken Parts	Whole Frozen Turkey	Whole Fresh Turkey	Frozen Turkey Parts	Shell Eggs
Importer Population	8.91***	-14.76***	6.40***	31.16***	4.04
	(2.37)	(5.06)	(1.16)	(4.57)	(2.82)
Importer GDP	1.34	9.25***	0.56	-1.15	0.21
	(1.12)	(2.20)	(0.44)	(1.99)	(1.49)
Exporter GDP	-2.79**	-0.92	-0.39	8.54***	-6.12***
	(1.17)	(2.89)	(0.54)	(2.35)	(0.84)
Exporter Population	-11.80**	18.01*	-3.54**	-56.60***	-24.42***
	(5.00)	(10.93)	(1.68)	(10.02)	(4.50)
Distance	-0.25***	1.04***	0.78***	2.26***	0.70***
	(0.09)	(0.14)	(0.03)	(0.17)	(0.14)
Per Capita	1.05	-3.42	1.40***	-7.82***	8.66***
	(1.33)	(2.57)	(0.49)	(2.34)	(1.38)
Share	1.30***	0.61	1.18***	0.94*	0.30
	(0.23)	(0.52)	(0.12)	(0.49)	(0.25)
END	0.13	-0.31	-0.09	-0.22	0.12
	(0.20)	(0.43)	(0.10)	(0.40)	(0.33)
HPAI	-0.09	0.39	-0.31***	-0.43	-0.09
	(0.17)	(0.37)	(0.10)	(0.35)	(0.24)
Asia	-	-	-	-	-1.79***
	-	-	-	-	(0.59)
Europe	-1.44**	2.40***	7.29***	14.64***	-1.60***
	(0.56)	(0.86)	(0.51)	(1.24)	(0.51)
North America	3.71***	5.47***	7.91***	14.25***	-0.50
	(0.34)	(0.70)	(0.51)	(0.70)	(0.54)
Out Year Count	0.00	-0.01	0.01*	0.01	0.02
	(0.01)	(0.03)	(0.01)	(0.02)	(0.02)
Contiguous Partners	-0.69***	-0.19	-0.06	-2.96***	-0.54***
	(0.24)	(0.34)	(0.07)	(0.35)	(0.14)
Common Currency	1.51***	-0.29	0.51***	1.95***	1.23***
	(0.35)	(0.33)	(0.07)	(0.41)	(0.13)
Constant	149.74	-206.15	-95.03**	837.05***	497.56***
	(139.85)	(301.72)	(48.19)	(286.69)	(93.66)
Observations	480	478	2,235	480	3,511
R-squared	0.681	0.623	0.391	0.817	0.064

Table A 4-1: Estimated factors influencing bilateral poultry trade using Hausman-Taylor individual models, cont.

	Egg Products	Cooked Turkey	Cooked Chicken	Cooked Other
Importer Population	5.90***	-7.80***	-1.66	-9.90***
	(1.35)	(2.35)	(1.13)	(1.35)
Importer GDP	-4.19***	-0.18	0.22	-1.65*
	(0.73)	(1.42)	(0.68)	(0.84)
Exporter GDP	1.72***	2.92***	0.37	-1.39**
	(0.44)	(0.98)	(0.49)	(0.65)
Exporter Population	-9.92***	-8.19**	2.29	2.49
	(2.27)	(3.35)	(1.61)	(1.97)
Distance	-0.10*	0.22***	-0.84***	0.21***
	(0.06)	(0.07)	(0.04)	(0.05)
Per Capita	5.74***	3.97***	3.13***	6.73***
	(0.76)	(1.16)	(0.57)	(0.71)
Share	0.68***	0.40***	-0.11	-0.18*
	(0.14)	(0.15)	(0.08)	(0.10)
END	0.06	-0.14	0.06	-0.06
	(0.18)	(0.19)	(0.09)	(0.11)
HPAI	0.15	0.04	-0.14	0.13
	(0.12)	(0.19)	(0.09)	(0.12)
Asia	-0.85***	-	-	-
	(0.26)	-	-	-
Europe	0.59***	2.99***	-	1.34**
	(0.22)	(0.31)	-	(0.58)
North America	1.46***	-	1.95***	-0.75
	(0.23)	-	(0.15)	(0.58)
Middle East	-	-4.47***	4.45***	-
	-	(1.04)	(0.53)	-
Out Year Count	-0.00	0.00	0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)
Contiguous Partners	0.13**	0.91***	-0.03	-0.41***
	(0.06)	(0.17)	(0.09)	(0.10)
Common Currency	0.79***	1.32***	1.03***	0.53***
	(0.06)	(0.16)	(0.08)	(0.10)
Constant	88.00**	514.20***	-29.57	242.17***
	(41.33)	(122.43)	(54.09)	(66.61)
Observations	3,511	1,922	1,922	1,905
R-squared	0.149	0.159	0.289	0.211

Source: Model Estimations; Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A 4-2: Estimated factors influencing bilateral poultry trade using Hausman-Taylor seemingly unrelated regression

HT-SUR Model	Live		Prepared		
	Live Chickens	Live Turkeys	Cooked Turkey	Cooked Chicken	Cooked Other
Importer Population	10.99**	-4.90***	-8.86***	-1.52	-9.80***
	(4.29)	(1.23)	(2.32)	(1.12)	(1.34)
Importer GDP	0.92	-0.34	-1.78	-0.19	-1.76**
	(0.96)	(0.28)	(1.40)	(0.67)	(0.83)
Exporter GDP	5.40***	0.25	3.02***	0.55	-1.23*
	(1.17)	(0.34)	(1.03)	(0.52)	(0.65)
Exporter Population	-38.61***	3.47*	-12.29***	0.98	-1.64
	(6.93)	(2.06)	(3.29)	(1.59)	(1.95)
Distance	0.71***	-0.28***	0.30***	-0.78***	0.10*
	(0.10)	(0.02)	(0.07)	(0.04)	(0.05)
Per Capita	7.84***	1.12**	6.16***	3.69***	7.17***
	(1.43)	(0.46)	(1.15)	(0.57)	(0.70)
Share	-0.94***	0.12	0.32**	-0.09	-0.17*
	(0.34)	(0.11)	(0.15)	(0.08)	(0.10)
END	0.02	-0.09	-0.13	0.07	-0.06
	(0.31)	(0.10)	(0.19)	(0.09)	(0.11)
HPAI	0.58**	-0.04	0.09	-0.11	0.25**
	(0.23)	(0.08)	(0.19)	(0.09)	(0.12)
Europe	1,330.05***	61.45	706.55***	9.66	0.49
	(252.06)	(55.36)	(120.28)	(53.86)	(0.58)
North America	1,331.18***	63.76	703.53***	11.54	-1.51***
	(252.07)	(55.36)	(120.31)	(53.87)	(0.58)
Africa	1,327.68***	62.12	-	-	-
	(252.12)	(55.36)	-	-	-
Middle East	-	-	698.97***	13.95	-
	-	-	(120.38)	(53.99)	-
Out Year Count	-0.03*	0.01	0.01	0.00	-0.00
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Contiguous Partners	1.46***	0.46***	1.06***	0.17**	-0.60***
	(0.38)	(0.09)	(0.15)	(0.08)	(0.09)
Common Currency	-0.75*	-0.91***	1.98***	1.00***	1.13***
	(0.39)	(0.13)	(0.15)	(0.08)	(0.09)
Constant	-	-	-	-	375.02***
	-	-	-	-	(65.83)
Observations	1,161	1,161	1,905	1,905	1,905
R-squared	0.177	0.497	0.155	0.267	0.193

Table A 4-2: Estimated factors influencing bilateral poultry trade using Hausman-Taylor seemingly unrelated regression, cont.

HT-SUR Model	Fresh			Eggs	
	Whole Fresh Chicken	Fresh Chicken Parts	Whole Fresh Turkey	Shell Eggs	Egg Products
Importer Population	1.55	-0.25	6.19***	0.57	3.41**
	(1.46)	(1.55)	(1.15)	(2.81)	(1.34)
Importer GDP	0.72	0.09	0.63	0.65	-3.75***
	(0.46)	(0.58)	(0.44)	(1.47)	(0.72)
Exporter GDP	-0.52	0.95	-0.44	-6.22***	1.36***
	(0.61)	(0.71)	(0.54)	(0.83)	(0.43)
Exporter Population	-8.99***	-2.29	-4.46***	-28.75***	-9.30***
	(1.91)	(2.29)	(1.67)	(4.47)	(2.26)
Distance	0.08***	-0.24***	0.78***	0.24*	-0.23***
	(0.02)	(0.04)	(0.03)	(0.14)	(0.06)
Per Capita	3.14***	3.30***	1.63***	10.41***	6.08***
	(0.57)	(0.68)	(0.48)	(1.38)	(0.75)
Share	0.58***	0.97***	1.16***	0.37	0.64***
	(0.13)	(0.15)	(0.11)	(0.25)	(0.14)
END	0.05	0.02	-0.09	0.19	-0.08
	(0.12)	(0.14)	(0.10)	(0.33)	(0.17)
HPAI	-0.31**	-0.27*	-0.33***	-0.19	0.18
	(0.12)	(0.14)	(0.10)	(0.23)	(0.12)
Asia	-	-	-	665.35***	-0.70***
	-	-	-	(92.99)	(0.26)
Europe	248.34***	4.42***	-52.53	665.31***	0.55**
	(58.66)	(0.87)	(48.00)	(92.98)	(0.22)
North America	249.57***	7.30***	-51.90	666.43***	1.52***
	(58.67)	(0.87)	(48.00)	(92.99)	(0.23)
Middle East	248.55***	-	-59.90	667.27***	-
	(58.87)	-	(47.99)	(93.04)	-
Out Year Count	-0.00	0.01	0.01*	0.03*	-0.00
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Contiguous Partners	-0.21**	0.08	-0.18**	-0.22*	0.12**
	(0.09)	(0.11)	(0.07)	(0.13)	(0.06)
Common Currency	0.80***	1.25***	0.51***	0.73***	0.74***
	(0.08)	(0.10)	(0.07)	(0.13)	(0.06)
Constant	-	72.67	-	-	123.05***
	-	(69.87)	-	-	(41.00)
Observations	2,235	2,235	2,235	3,511	3,511
R-squared	0.139	0.185	0.390	0.056	0.146

Table A 4-2: Estimated factors influencing bilateral poultry trade using Hausman-Taylor seemingly unrelated regression, cont.

HT-SUR Model	Frozen			
	Whole Frozen Chicken	Frozen Chicken Parts	Whole Frozen Turkey	Frozen Turkey Parts
Importer Population	-5.86	9.26***	-13.65***	33.01***
	(4.85)	(2.33)	(4.98)	(4.50)
Importer GDP	-1.27	0.98	8.92***	-1.35
	(2.19)	(1.10)	(2.17)	(1.96)
Exporter GDP	11.08***	-2.47**	-1.19	6.82***
	(2.37)	(1.15)	(2.83)	(2.32)
Exporter Population	-3.47	-10.57**	21.15**	-46.24***
	(10.21)	(4.91)	(10.73)	(9.84)
Distance	-2.40***	-0.34***	0.95***	2.12***
	(0.23)	(0.09)	(0.14)	(0.17)
Per Capita	6.48**	0.58	-4.24*	-8.51***
	(2.61)	(1.30)	(2.53)	(2.31)
Share	0.94**	1.27***	0.61	1.16**
	(0.47)	(0.23)	(0.51)	(0.48)
END	0.30	0.10	-0.32	-0.24
	(0.42)	(0.20)	(0.42)	(0.39)
HPAI	-1.14***	-0.08	0.42	-0.42
	(0.40)	(0.17)	(0.36)	(0.34)
Europe	-15.39***	-1.84***	1.96**	13.87***
	(1.56)	(0.55)	(0.85)	(1.23)
North America	-0.90	3.62***	5.41***	14.21***
	(0.95)	(0.33)	(0.69)	(0.69)
Out Year Count	0.06**	-0.00	-0.02	0.00
	(0.03)	(0.01)	(0.03)	(0.02)
Contiguous Partners	-0.32	-0.65***	-0.02	-2.16***
	(0.45)	(0.23)	(0.34)	(0.34)
Common Currency	2.82***	1.40***	-0.39	1.11***
	(0.43)	(0.33)	(0.32)	(0.39)
Constant	222.25	100.16	-336.25	442.41
	(302.75)	(136.41)	(296.02)	(280.55)
Observations	478	478	478	478
R-squared	0.556	0.680	0.622	0.814

Source: Model Estimations; Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1