MARKET REACTIONS TO ANIMAL DISEASE: THE CASE OF BOVINE SPONGIFORM ENCEPHALOPATHY DISCOVERIES IN NORTH AMERICA

A Dissertation

by

RONG HU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2008

Major Subject: Agricultural Economics

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ABSTRACT

Market Reactions to Animal Disease: The Case of Bovine Spongiform Encephalopathy Discoveries in North America. (August 2008)

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The increasing awareness of, and concern over, possible terrorist attacks using biological threats has increased attention and efforts for safeguarding U.S. agriculture. Whether intentional or unintentional, a biological event likely would cause substantial consequences well beyond the U.S. agricultural sector with considerable economic, social, and political costs. One significant impact would involve trade disruptions. This dissertation investigates biosecurity risk impacts with a focus on animal disease outbreaks using data from recent U.S. and Canada bovine spongiform encephalopathy (BSE) cases.

An empirical study was carried out on the impact of the North American BSE cases. Using a time series approach, this study detected a significant structural break during the second half of 2003 when two BSE cases were confirmed in North America. Results showed that U.S. beef prices responded to the disruptions in cattle and beef trade

caused by the BSE cases. The ban on beef and cattle imports from Canada and the ban on U.S. beef exports were major contributors to the fluctuation in beef prices. This showed that trade disruptions following the BSE discoveries in North America resulted in a supply shift and affected the movement of beef prices afterwards. The study did not find strong evidence that the 2003 North American BSE cases and associated trade disruptions greatly affected per capita beef consumption.

In turn, a simulation study was conducted to examine the impact of major BSE outbreaks, associated trade disruptions, and demand shifts on U.S. welfare and the livestock industry. Six alternative scenarios were simulated and compared with the base scenario where there was no trade disruption and demand shift. The six scenarios consisted of various combinations of cattle and beef trade restrictions, livestock production adjustment, and beef demand shift. When beef and cattle trade, and market demand are greatly reduced in the wake of the BSE events in both Canada and the U.S., the impact on the U.S. welfare, meat trade, and regional livestock production would be the greatest. Beef price and production could reduce by 26% and 16% respectively. Regional impact on beef and livestock production would also be substantial in this case.

DEDICATION

To my family

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CHAPTER I

INTRODUCTION

The terrorism attack on September 11, 2001 sounded the alarm for all that U.S. national and global security is at risk from terrorist attacks. Among possible targets, U.S. agriculture and the food supply chain are highly vulnerable (Dyckman 2003). The U.S. is well known for its efficient and highly interrelated agricultural production, processing and distribution system. Agricultural operations are particularly vulnerable to biological threats because of sector and food supply chain characteristics. Many components of U.S. agriculture are highly concentrated along the supply chain as well as geographically. Agricultural products routinely move long distances. Furthermore, a lack of physical security and surveillance enhances vulnerability. Defined as the intentional use of exotic, highly contagious pathogens to produce death or disease in humans, livestock and crops, bioterrorism could yield substantial impact on the U.S. economy (Franz 1999).

1.1 Motivation and objectives

Although the U.S. has enjoyed freedom from major animal disease outbreaks for a number of decades, this does not necessarily suggest that U.S. agriculture and the food supply chain are safe, especially in the presence of biological threats by terrorists. Consequently, an appraisal of the impacts of such incidents may help policy makers make better decisions regarding protection from and management of disease-related

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This dissertation follows the style of the *American Journal of Agricultural Economics*.

bioterrorism attacks. This study will undertake such an investigation examining the impacts of BSE discoveries and hypothetical outbreaks in North America on the U.S. beef market and welfare.

The main objective of this dissertation is to analyze the impacts of animal disease outbreaks on the U.S. agricultural sector focusing on market conditions and trade. This investigation will be presented through three interrelated components. The first component is a review and summarization of the issues, methodologies, and research in the biosecurity area. The second provides an econometric analysis of the impact of the trade disruptions caused by the two North American BSE cases in 2003 to examine how they affected U.S. markets. Using a simulation model, the third component investigates social welfare effects of the BSE induced beef trade disruptions with Canada and the U.S.

1.2 Organization of the dissertation

This dissertation consists of six chapters. The first chapter provides a general introduction to the problem addressed in this study, including the objectives and organization of the dissertation. The second chapter will brief on the biosecurity risks and related background. The third chapter will review the related literature on the studies of the impact of biosecurity risks, and summarize the research methodologies and research areas on biosecurity and food safety risks. This chapter will also cover the issues of handling biosecurity risks domestically and internationally. The fourth chapter will be an empirical study on the impact of BSE outbreaks on the U.S. beef market. The fifth chapter will be the simulation model of the impact of trade disruptions on welfare due to animal disease outbreaks. Decomposition of the change in welfare among consumers and producers will be discussed. The last chapter will conclude the dissertation with managerial and policy implications. Future research areas will be discussed as well.

CHAPTER II

BACKGROUND OF BIOSECURITY RISKS AND FOOD SAFETY ISSUES

This chapter reviews the economic issues of biosecurity and food safety risk, especially focusing on the impacts of these risks on agriculture and the food supply chain.

2.1 Biosecurity

Biosecurity issues have long been the subject of academic, industrial and governmental agency study particularly regarding "the introduction and spread of harmful non-indigenous invasive species" (Sumner 2003). In the context of livestock and poultry sector, it refers to the introduction and spread of infectious diseases. Biosecurity risks more generally include the risks that threaten the health of humans, livestock and plants.

2.2 Sources of biosecurity risks

Biosecurity risks can arise via deliberate or natural occurrences of animal and plant diseases along with introduction and spread of invasive species and foreign pathogens. Natural occurrence of animal disease virus has been commonly observed among livestock heard and poultry flocks. Outbreaks of severely contagious diseases have resulted in rapid disease spread and may affect humans (e.g., avian influenza).

After the terrorist attack to the World Trade Center in New York on September 11, 2001, the likelihood of deliberate terrorist attack by means of biological and chemical weapons was commonly felt to have increased. Any such threat posed to the health of livestock, plants and humans through biological and/or chemical carriers can be viewed as biosecurity risks. Such attacks could bring about catastrophic consequences to agriculture and food system and put human health at risk.

Although biosecurity risks pose threat mainly to livestock and plant health, along with the ecosystem, the risks could be passed on to the food supply chain. And such biosecurity threats can also pose food safety risks to humans. In particular, zoonotic animal diseases can be transmitted from livestock to humans, such as BSE and avian influenza. More generally foodborne pathogens constitute the principle risks to human health (MacDonald and Crutchfield 1996). Over 200 known pathogens that can be transmitted to humans via food consumption and in turn threaten human health (Mead et al. 1999). Foodborne diseases are estimated to cause 76 million illnesses and 5,000 deaths in the United States annually (Mead et al. 1999). Mathews et al. (2003) state that meat and poultry are the most likely sources of foodborne disease outbreaks.

Regardless of their sources biosecurity risks pose threats to the health of livestock, plants and humans with the human health risk arising through the food supply chain. That chain could be disrupted at any stage from farm to table and when affected could produce severe consequences such as shortages in food supply, food scares, economic losses and even political instability (Bruemmer 2003).

The World Organization for Animal Health (OIE, the International Office of Epizootics) identifies a number of highly contagious diseases, including BSE, foot-and-month disease (FMD), threatening the health of livestock, plants and humans (called List A and B pathogens). A number of these such as BSE, FMD and avian influenza (AI) are animal diseases that could bring disastrous impacts to agriculture and even the economy (Kitching, 2000).

The U.S. has been free from widespread and highly contagious animal disease outbreaks for decades. The 2003 two BSE cases confirmed in the North America increases the concern over the potential animal disease outbreaks in the future. This drew attention from the government and industry regarding prevention. The United States Department of Agriculture (USDA) and other government agencies have made efforts in enhancing surveillance and increasing funding for animal disease related research (Coffey et al. 2005).

2.3 Importance of agriculture and the food system

U.S. agriculture accounts for 13% of the U.S. gross domestic product (GDP) and provides 18% of the domestic employment (Dyckman 2003). U.S. exports about 18% of its agricultural products. About 9% of the food consumed domestically is imported from other countries (Blandford 2002).

The meat industry is the largest component of the U.S. agriculture. U.S. beef and veal production in 2003 was 12.04 million metric tons of carcass weight equivalent with 35 million head cattle slaughtered annually, which makes the U.S. the largest beef producer in the world. Its pork production was 9.06 million metric tons in 2003, of which 9% was exported. The U.S. is also the largest producer and exporter of broilers in the world with 2.2 million metric tons (15% of production) exported in 2003.

Prior to the BSE discovery in Washington State in 2003, the U.S. exported about 10% of its beef production amounting to 1.14 million metric tons in 2003. Of these exports about 80% went to Japan, Mexico, South Korea and Canada. Immediately following the confirmation of the BSE case in 2003, about 50 countries closed their borders to the U.S. beef or greatly reduced U.S. beef imports. Subsequently total beef and veal exports plummeted to 0.46 million pounds (carcass weight) in 2004 from 2.52 million pounds in 2003. U.S. retail beef price went up not long after the BSE discovery in the U.S. The increase of beef price in the latter part of 2003 and 2004 could be attributed to the reduction of imports of live cattle and beef from Canada and the tight domestic supply of beef and strong domestic demand (Jin et al. 2004). The 2003 case of BSE in the U.S. did not affect domestic demand very much.

2.4 Vulnerability to biosecurity risks

Because of its importance to the economy and the way that the livestock industry operates, it is vulnerable to terrorist attacks (Casagrande 2000). In addition, agricultural trade is vulnerable as terrorism threats exist in the form of attacks on trade shipments, port destruction, and the introduction of contagious diseases and exotic pests (Blandford 2002). These attacks could restrict quantities available or cause the need for costly actions to control the spread of diseases into the food supply and ecological system. All these could bring about immediate or even lasting severe consequences to the U.S. trade and agriculture.

The U.S. federal agencies have recognized this vulnerability. USDA and Food and Drug Administration (FDA), the two agencies for safeguarding food safety, have taken efforts of prevention and response to advert food events (Dyckman 2003). It is also recognized that more attention and efforts are needed for controlling biosecurity risks (Wells 2000).

International organizations such as World Organization for Animal Health (OIE) and Food and Agriculture Organization (FAO) also have important objectives to prevent the spread of diseases through international commodity movements (Schudel et al. 2004). The sanitary and phytosanitary standards (SPS) recognized by OIE and World Trade Organization (WTO) are the guidelines for preventing the introduction of pathogens into the food chain. However, they also stipulate that countries cannot use these standards as disguised technical barriers to trade unless otherwise justified by scientific evidence.

CHAPTER III

LITERATURE REVIEW OF BIOSECURITY RISK IMPACTS

There is rich literature on food safety risks and their impacts. Studies on the economics of biosecurity are on the rise. The object of this chapter is twofold: (a) to review the studies on the impacts of biosecurity and food safety risks and related issues; and (b) to summarize and synthesize research methodologies for these impacts.

3.1 Economic impacts and costs

One possible bioterrorism attack involves the introduction of a foreign animal or zoonotic disease (FAZD). The costs of such outbreaks could be substantial, consisting of the cost of disease control and management, forgone sale value of slaughtered animals (e.g. infected and potentially infected animals plus animals caught in quarantine zones), costs resulting from market and international trade disruptions, human related disease costs, and production, market, economy recovery costs among others. In particular, animal disease outbreaks and consequent market and trade disruptions have some spillover effects. Namely, producers in unaffected areas may suffer from market and trade disruptions; and sectors other than agriculture may suffer (e.g., tourism and other supporting industry may lose their revenue as the mass slaughter and disposal of animals on media coverage).

There are numerous outbreaks of FAZDs worldwide in recent years, including FMD outbreaks, BSE, and avian influenza. BSE, also called mad cow disease, was first discovered in Britain in 1986. Since then, it has been found in several countries in

Europe, in Canada and in the US. The link between BSE with human health was announced in 1996 by the British government, which induced great concerns over food safety and human health worldwide.

Although no evidence has been confirmed that FMD is infectious to humans, it affects animals with cloven hooves such as cattle, hogs, sheep and goats. It spreads rapidly by the movement of infected animals and by equipment, vehicles and people. The major 2001 FMD outbreak in the U.K. resulted in an estimated economic loss of between \$3.6 and \$11.6 billion (USDA-ERS 2001).

Avian influenza (AI), also called bird flu, is an infectious disease of birds. Epidemics have occurred in many Asian countries causing the slaughtering of millions of birds. Some highly pathogenic AI virus strains can be transmitted to humans. There have been 51 confirmed deaths as of January 28, 2005 in Asia. Several AI virus strains were detected in several states of the U.S. in February 2004 resulting in the slaughter of more than 400,000 infected chickens and a market closure by 37 countries and the European Union as of early March 2004.

Once there is a large-scale disease outbreak, a ban on the imports from the affected country by disease-free countries is common practice. Not only does the disease-affected country suffer from the loss in productivity and shrinking of domestic demand, it also faces a smaller export market and may in the longer run loses market share to competing disease-free exporting countries. It can take several months or even years to recover from the outbreak, re-capture the lost export market and boost consumer demand.

Generally speaking, biosecurity and food safety risks can bring about a wide range of impacts on the food and agriculture sectors. Food safety issues are among the factors that affect both supply and demand (Mathews et al. 2003).

3.1.1 Impacts on demand

Biosecurity and food safety risks could cause or enhance food scares in the public, affecting short or long run consumer demand. The impacts could be dramatic and immediate, especially after the incident is reported by the media. Buzby (2001) indicates that food safety incidents may change consumers' perceptions about food safety and their purchasing patterns. For example, beef demand was reduced by 2.9% in the wake of 1993 beef recalls (Schroeder et al. 2000). Japanese meat demand system experienced a two-month transition period since the initial BSE event, and consumer demand for all types of beef decreased (Peterson and Chen 2005).

3.1.2 Media influences

Food safety incidents most likely become known to the public through media. Media coverage may provide information about the food safety concerns, but may also escalate food scares. The effects of media coverage on animal disease outbreaks and food safety incidents have been explored in many studies, especially their role in affecting consumers purchasing pattern and demand.

Researchers have been examining media influences on consumer demand and response relative to the impact of food safety incidents and food scares (Pritchett and Thilmany 2005; Peng et al. 2004; Kalaitzandonakes et al. 2004; Dahlgran and Fairchild 2002; Verbeke and Ward 2001). A number of researchers have constructed an index of media coverage by counting major print media articles or word counts of coverage on food risks (Burton and Young 1996; Piggott and Marsh 2004; Pritchett and Thilmany 2005). Two studies on meat consumption in Belgium (Verbeke et al. 1999; Verbeke et al. 2000) find negative impact of dioxin and BSE media coverage on meat consumption in Belgium. Peng et al. (2004) show that BSE publicity in 2003 had a negative effect on Canadian demand for most beef products, but a positive effect on pork demand. Pritchett and Thilmany (2005) find that media coverage had greater negative impact on ground beef than on chuck roast; and a positive impact on pork. Smith et al. (1988) study the 1982 heptachlor contamination of fresh fluid milk in Hawaii and find that negative reports on contamination had a larger effect than positive coverage on milk purchases. Negative media coverage has also been found to dampen consumer demand for the meat affected by the outbreak and enhance demand for substitute products (Verbeke and Ward 2001; Burton and Young 1996).

Though statistically significant impacts have been found regarding media and consumer demand, the impact has generally been small and/or short lived (Piggott and Marsh 2004; Dahlgran and Fairchild 2002; Marsh et al. 2004; Burton and Young 1996; Pritchett and Thilmany 2005; Peng et al. 2004; Kalaitzandonakes et al. 2004). Pesaran and Samiei (1991) find that the shock was of short duration and did not show a long run effect in the case of salmonella poisoning on the U.K. egg market.

Vickner et al. (2006) estimate U.S. demand effects for fresh meat during May 2004 to May 2005 where three inconclusive BSE test results were announced. Unlike the previous confirmed BSE case in Dec 2003, no influences were found on the retail demand for fresh meat. This is likely because there was not much media coverage on these three inclusive tests. Also the U.S. government agencies made efforts in assuring the consumers that the beef supply was safe.

Though media indices can be used as the proxy for consumer awareness and concern over food safety risks, they require proper construction and substantial effort be used effectively. It is hard to make newspaper choices when searching for articles; it is also costly to construct the indices. It can only be used as a relative measure for consumers concern. Further research is needed to find the appropriate measure.

3.1.3 Effects on prices of agricultural products

Biosecurity and food safety risks also have impact on prices of meat products. The effect on meat prices after the BSE crisis in the U.K. was significant. Cattle price dropped by 21% in 1996 from the level in 1995 (Leeming and Turner 2004). In the event study of the effect of E. Coli on the farm and wholesale beef prices, Thomsen and McKenzie (2001) find that food recalls had negative effect on boneless beef price, no effect on live cattle futures price or cash prices, and little effect on boxed beef price.

Other studies have used time series methods to evaluate the impact of animal disease outbreaks. Sanjuan and Dawson (2003) study the price transmission between producer and retail prices for beef, lamb and pork as influenced by the 1996 U.K. BSE outbreak. They find that there was a significant price effect in the form of a structural break in the beef relationship between producer and retail prices during that event.

Lloyd et al. (2001) study the impact of food scares on the U.K. price movements in the 1990s. Beef prices at the retail, wholesale and producer levels were analyzed in a cointegration framework. A food publicity media index was set up and incorporated in the analysis. They find that media coverage during the 1996 U.K. BSE outbreak was an important factor in the movement of beef prices at the different stages of the marketing chain.

3.1.4 Impacts on trade

The impacts of outbreaks are more obvious and direct in the international trade arena. Generally it is common that importing countries reduce or even ban the imports from countries with outbreaks to protect their domestic markets (Mathews et al. 2003). Such changes in trade policy have been observed to result in significant trade disruptions. Trade bans have been implemented when FMD, BSE and AI outbreaks occur. Bans in some cases have been temporary and in other cases lasting for a long time. Under a trade ban, importing countries often switch supply sources to other disease free countries and such trade relationships can remain even after the original disease affected country regains its disease free status (Casagrande 2002). Thus, countries with disease outbreaks may lose the export market for long time. Due to the first U.S. BSE discovery in 2003, former importers of the U.S. beef switched to Australia and Brazil for beef afterwards. When Canada found BSE in May 2003, the U.S. ceased imports of live cattle from Canada. The effect on the U.S. market was somewhat small as imports of beef and cattle from Canada accounted for about 4.2% in the total U.S. beef supply in 2001 (Brester and Marsh 2002).

Subsequently over 50 countries stopped beef imports from the U.S. after the Dec 2003 BSE incident in the U.S. Unlike Canada where cattle exports accounts for about

67% of its total cattle supply, beef exports accounts for about 10% of the total U.S. beef supply. Thus, the disruption on the U.S. domestic beef market was limited.

However, researchers predicted that additional BSE outbreaks could result in more severe and significant impacts on demand and trade (Jin et al. 2004). Paarlberg et al. (2002) state that larger impacts on exports and consumer demand were expected if an FMD outbreak occurred in the U.S. that is of similar magnitude to the U.K. outbreak in 2001.

Export losses are generally greater under the outbreak of a highly contagious disease than that under a less severe disease. For example, beef exports from European Union fell by over 80% after the FMD outbreak in February 2001, while its beef exports dropped much less in the previous BSE outbreaks (Mathews et al. 2003; Mathews and Buzby 2001).

The import demand from disease affected countries can be impacted by a disease outbreak in the importing countries as events can cause a fall in consumer confidence and create supply shock. For example, the Japanese market changed after their BSE outbreak. The U.S. beef exports to Japan have not yet fully recovered (Mathews et al. 2003).

3.1.5 Other impacts

Researchers have also examined the impact of biosecurity risks on market structure. Outbreaks have led to enhanced surveillance and tightened regulations. The high cost of compliance with such developments can make it harder for small producers to survive (MacDonald et al. 1996).

Food recalls in the U.S. have been found to have a significant adverse impact on shareholder value only when the recall implies a severe health hazard (Thomsen and McKenzie 2001). The first U.S. BSE case negatively affected the stock market value of agribusiness firms associated with beef or with farm equipment, while non-beef meat-related firms benefited (Jin and Kim 2008). In the U.K., the 1996 discovery of BSE negatively affected the equity prices of twenty four companies (Henson and Mazzocchi 2002). DeVuyst and DeVuyst (2005) find that the decline of beef cattle prices would affect beef production related assets.

3.2 Market reactions and coping strategies

Once a food safety incident occurs, there can be demand-depressing food scares manifesting through changes in the consumer purchase patterns and firm management strategies. Under such circumstances, consumers may exhibit brand switching, recalled product avoidance and reductions in purchase volume (van Ravenswaay and Hoehn 1996). As to the producers and manufacturers, food companies may take a proactive role in bolstering consumers' confidence. These strategies include, but are not limited to, tighter surveillance of product quality, increased marketing efforts to boost the food safety and aggressive pricing strategies to regain the sales.

Since animal disease is a public externality rather than the fault of any individual firm, strategies that mitigate disease outbreaks as well as promote early recovery at the government and industry levels are warranted. For example, the single case of BSE discovered in the U.S. caused USDA to enhance the testing requirement. Also, governments make public statements about the disease situation and assure consumers of the safety of the products.

Measures to cope with biosecurity and food safety risks include ex-ante and ex-post measures such as prevention, preparedness, response, and recovery. Examples of these measures include detection, surveillance, and animal ID program, product tracking systems, movement ban implementations, and compensation schemes after the disease outbreaks among others.

3.2.1 Preventive measures

There are many ways to handle food safety incidents. They can be classified into two major categories: prevention and response/recovery. Government and the affected industries can minimize the probability and consequences of food safety crisis through prevention in advance, publicized information, detection, and timely response (Buzby 2001). The balancing between pre- and post-break efforts/investment is an important but challenging issue. For most food safety incidents, even though most of prevention investment is foregone regardless of whether incidents occur or not, the most cost effective way is to prevent such incidents from occurring. The benefits of preventing in advance include safeguarding the reputation of the brand for the firm and holding a solid market position.

Post event measures are effective if the event is relatively easy to recover from and there is little impact to the firms' image and sales. The choice of ex ant or ex post measures for animal disease outbreaks has to be made based on the characteristics of the disease (type and virus spread speed), the size of the affected herd and other considerations.

In terms of prevention in advance, government regulations and rules are put in place and implemented to ensure food safety. For example, to prevent further outbreaks of BSE, the U.K. government proposed “Over Thirty Month Cattle Slaughter Rule” (OTM rule) in 1996, which prohibits the sale of cattle over 30 months of age for human consumption. In addition, all meat and bone meal are banned to be fed to cattle. As a result of implementing this rule, fewer cases of BSE were found in the U.K. from 1996 to 2001. After Jan 2001, all animal feed is banned to contain meat and bone meal.

Animal tracking and traceability is one way of protecting meat product safety. Technologies are readily available to provide information on the animal before packing. Since the animal parts are further processed and packed, it is difficult to keep track of the origin of the product. It is believed that this tracking can permit rapid trace back to locate sources of food safety problems. However, who bears the cost of tracking is an issue (Pritchett et al. 2005). Country-of-origin labeling (COOL) is another measure to safeguard food safety. Labeling is designed to provide information for consumers. However, labeling is not used as a regulatory tool for food safety in most countries (Caswell 1999).

Even though many regulations are implemented, doubts also arise over the effectiveness of product labeling and regulations such as COOL and HACCP on food safety. To measure the effectiveness of such regulations, it is natural to look at the benefits they bring about. Empirically, consumers benefit from food safety regulations from the reduction of cost of illness and treatment. Methods to measure these benefits include cost-and-benefit analysis, contingent valuation methods and others (van Ravenswaay and Hoehn 1996).

Protecting trade from disruptions as well as ensuring food safety is both important to the government and industries. Researchers agree that these can be done through transparent and timely responses to food safety risks and surveillance and preventive measures (Mathews et al. 2003).

3.2.2 Recovery measures

During and after a disease outbreak, it is a challenging task to respond immediately to the incident. To do this a proper crisis management system should be in place. The greatest concern to the producers is the loss of their sales and reputation. Sometimes, it is necessary to address problems in a timely manner making product safety public statements, or product recalls. Sometimes, it is even necessary to pay compensation to the affected consumers. All the necessary actions to regain consumers' confidence in their products are needed.

In this case, information about the incident and the response of the producers should be transparent and immediate. However, as pointed out by some researchers, public statement by producers or government may not be effective ways to recover consumers' confidence (Smith et al. 1988).

3.2.3 Food recalls

Food recalls can prevent further harm to consumers after safety problems are detected. Food recalls generally involve firms voluntarily removing the product from trade and consumer channels for the sake of human health and well being (Marsh et al. 2004). Recalls are maintained by USDA (for meat and egg products) and FDA (for other products except meat and most egg products).

Studies on food recalls show that meat recalls have significant negative impact on consumer demand although generally of small magnitude (Marsh et al. 2004). Marsh et al. find that meat recalls lead to reallocation of consumer expenditures among meat products as well as between meat and non-meat products. Lusk and Schroeder (2002) examine the effects of meat recalls on the live cattle and lean hog futures market prices. They find medium-sized beef recalls involved with serious health hazards negatively affected the futures prices of short-term live cattle.

Wang et al. (2002) examine the impact food recalls on stock prices. They find that the mean returns fell and the volatility increased after the initial food recalls. They also find the spillover effect of volatility across firms.

More studies are needed on the impact of food recalls on consumer confidence in food because limited studies on product recalls and consumer demand are mainly focused on drug and automobile (Marsh et al. 2004).

3.2.4 Measures for food safety and their costs

In addition to regulating domestic food production, food safety regulations and rules also regulate international trade by establishing standards for contaminants of pathogen, chemical and residues in imported food products (Mathews et al. 2003).

There is an increasing market demand for food safety. To secure competitiveness in the market, private firms have incentives to ensure safety through various means. In addition to the compliance with the government regulations and rules, private controls strategies are also taken to provide safer food through self-regulation, vertical integration, HACCP systems and third party certification (Buzby 2001).

3.2.5 SPS regulations and the impact on trade

Trade volume data for the world demonstrate great importance of trade among trading countries in their economies. Data show that there is an increasing need for nations to facilitate more trade flows of food products (Hooker 1999).

Foreign pathogens and invasive species have become more and more urgent issues in the wake of frequent and large trade flows among nations. To promote more free trade as well as protecting the health of human, livestock and plants, there is an increasing need for the regulations and rules, or standards.

The Sanitary and Phyto-sanitary (SPS) agreement is intended to enhance the protection of plant and animal health and resultant food safety (Paarlberg et al. 2005; Hooker 1999). WTO requires that regulatory decisions be based on scientific evidence (Crutchfield et al. 2005). Though SPS provisions serve as the measures for safeguarding the health of human, animal and plants in a country as a general guidance, each country has its own regulations and rules. Also each has its own understanding of how to implement the rules. Some are very strict such that there are even regulations and rules for very minor process and attributes, as in Europe, Japan and the U.S. Some countries may be more flexible and lax in food safety regulations enforcement. A limited number of studies (Calvin et al. 2004; Otsuki et al. 2001; Wilson and Otsuki 2003) show that

SPS standards, if too stringent, can hamper trade flows, especially exports from developing countries.

Regulations on food safety attributes are more or less as non-tariff barriers to international trade of agricultural products (Hooker 1999). The countries with more stringent regulations apply more pressure on imported products. Although bilateral and multilateral trade agreements reduce trade barriers and promote more free trade flows among the agreeing countries, non-tariff trade barriers in the form of food safety regulations can reduce or even ban the inflow of products in the event of potential health threatening incidents.

There are increasingly more disputes over non-tariff trade barriers such as food safety regulations. Different countries have different views and standards. Since it is mostly the action of the importing countries that raises food safety related import standards and enforce them, it is the exporting countries for which these pose a difficulty. Although WTO opposes the use of food safety regulations as disguised trade barriers, it is very difficult to determine the necessity of such regulations.

3.2.6 Harmonization of regulations and regionalization

WTO requires that nations that refuse to accept products due to the non-compliance with their food safety regulations provide sound scientific evidence. Nevertheless, it is hard to find out the true motivations when these procedures come into play (Hooker 1999). Data show an increasing number of SPS standard related trade disputes. These disputes are believed to have disruptive impact on international trade (Mathews et al. 2003).

Researchers and policy makers have recognized the need to consider the issues about SPS standards such as the differences in them as applied to domestic and imported commodities. Efforts have been made in facilitating trade, solving disputes and enhancing mutual understanding. Various trade agreements incorporate regulatory rapprochement approaches such as harmonization, mutual recognition and coordination as means of standardizing food safety regulations, recognizing regulatory diversity and narrowing significant differences (Hooker 1999).

In addition to the harmonization efforts, proposals have been made that rather than restricting trade from a whole country, one might restrict trade from affected regions pursuing what is called regionalization. Such an approach recognizes the areas in a country of high vs. low risks and implements selective trade restrictions so as to reduce trade disruption and associated welfare loss (Seitzinger et al. 1999). Regionalization would reduce the negative impacts of severe trade disruption/termination on the commodity markets but increase the risk of an outbreak.

3.2.7 Technical trade barriers and quantifying their impacts

International trade organizations and agreements attempt to protect plant and animal health while promoting more trade by stipulating the health rules. However, some of these rules are overused to be trade barriers. It is hard to evaluate whether the rules are not used as disguised trade protection (Paarlberg et al. 2005).

As there is an increasing need for freer trade among nations, and with the removal of tariff barriers, countries may resort to technical trade barriers to safeguard its domestic products and consumers. These barriers are not transparent in their nature and are subjective in terms of its necessity to be implemented. They cause trade disputes among nations. In the survey study by Roberts and DeRemer (1997), respondents to the survey identified 303 barriers in 62 countries that brought about U.S. exports loss of about $5 billion in agriculture, forestry and fishery. These losses accounted for about 7% of the total value of U.S. exports in these industries (Crutchfield et al. 2005).

Some researchers attempt to measure the costs of trade barriers and estimate the tariff equivalent that would achieve an appropriate level of protection. Paarlberg and Lee (1998) use FMD as an example to illustrate how the proper trade tariff can be determined to allow imports without imposing animal disease risk to the U.S. Their framework allows the connection of potential risk in the imported commodity with the tariff to be levied accordingly. It can be used to determine the appropriate tariff-type barrier given the risk of importing infected products and disease outbreak. More research attempts should be made in this regard.

Since technical trade barriers are not transparent and can be used as protective measures easily, how to quantify their impact is an issue. Among the limited studies on this, Maskus et al. (2000) summarize the methodologies for quantifying the impact of trade barriers. The most often used methods include surveys, econometric techniques, partial equilibrium and computable general equilibrium (CGE). Surveys glean the firms' responses to regulations and the costs of compliance with these regulations. Econometric analysis is used to investigate the effect of standards imposed on imported commodities. Partial equilibrium models analyze tariff-rate equivalents of standards and technical regulations, and associated welfare changes. CGE models help us to understand the effect of standards and technical regulations on trade and various industries (Maskus et al. 2000).

3.3 Research issues and methods on the impacts of biosecurity and food safety risks

Since it provides crucial information for policy makers, producers and consumers, the analysis on the impacts of animal disease outbreaks is the subject of many studies. Previous research has been conducted for a wide range of issues using a number of methods. The research objectives include examining the business loss, welfare impacts and changes in risk (Pritchett et al. 2005). Benefits of complying with food safety regulations and costs of potential food safety risks are also examined (Crutchfield et al. 2005). The level of analysis ranges from producers to consumers at the local, regional, national, and even international levels (Pritchett et al. 2005). One of the challenges is to quantify the impacts of animal diseases rather than simply conceptually identifying those effects (Pritchett et al. 2005). The analysis of the impacts consists of the effects on welfare, trade, prices, and production among other measures. Studies have been conducted at the levels of farm producers, meat processors, consumers, regions, nations and global levels. Various models have been used for this purpose.

As reviewed by Rich et al. (2005), methods used in animal heath related studies can be grouped into five categories. They are benefit-cost analysis, linear and mathematical programming models, partial equilibrium analysis (single-sector and multi-market models), input-output/social accounting models, and computable general equilibrium models. Each approach has its advantages and disadvantages. Rich et al. (2005) indicates that the selection of approach depends on the objective, data availability, information desired, scale of analysis, considerations in time, space, and risk analysis needs.

As reviewed by Pritchett et al. (2005), the most often used methods for studying the impacts of animal disease outbreak include the input-output model (Caskie et al. 1999; Ekboir 1999), partial equilibrium model (Paarlberg and Lee 1998; Paarlberg et al. 2005; Roberts et al. 1999; Eenoo et al. 2000), simulation models (Jin et al. 2004), event studies (Thomsen and McKenzie 2001), and combinations of epidemiological and economic models (Mangen and Burrell 2003; Zhao et al. 2006).

3.3.1 Input-output model

Based on the links between beef sector and other sectors in the economy through input purchases and output sales, Caskie et al. (1999) use a regional input-output model to quantify the effects of the reduction in beef demand due to BSE on the economy of Northern Ireland with the countervailing substitution effects in pork and poultry sectors considered. It was estimated to have an income loss of 0.5% of regional GDP and job losses of 0.6%, while the majority of the income and job losses were in the beef sector. Ekboir (1999) estimates there would be losses of about $13.5 billion if there were an FMD outbreak in California.

Input-output model has obvious limitations, including (a) it only produces economic effects at the regional level; (b) the quantification relies on the multipliers in the model; and (c) it also assumes fixed prices and that the economy produces under a short term disruption in the same manner as it does from year to year (Pritchett et al. 2005).

3.3.2 Partial equilibrium model

Partial equilibrium models are often used to investigate welfare effects. Paarlberg et al. (2005) use such an approach to estimate the revenue impact and welfare changes. They decompose welfare of both producers and consumers into two categories: Producers in and out of disease regions and consumers who switch or do not switch consumption shares. For the producers, those in the affected regions suffer from sales loss while the producers in the disease-free regions face higher prices and gain surplus. For the consumers, those who switch from consuming red meat realize a welfare loss while those who are not concerned about meat safety gain from the lower meat price (Paarlberg et al. 2005).

A number of other studies have used partial equilibrium models. Paarlberg and Lee (1988) use a partial equilibrium model of beef trade to determine the optimal tariff level given the risk of importing infected products. Roberts et al. (1999) analyze trade and welfare effects of technical barriers. James and Anderson (1998) examine the Australian ban on imported bananas via a partial equilibrium model, finding that the gains to consumers may outweigh the losses to the domestic producers from removing the ban on the imports. They show that more assessment of quarantine policies is needed for animal disease risks considerations such as welfare gains and losses from importing risky commodities.

3.3.3 Simulation model

Simulation models allow the stochastic nature of market prices for final product and inputs to be incorporated such that a more realistic picture for business owners and managers for better decision making is provided. Jin, Skripnitchenko and Koo (2004) use such a model to study the scenarios of BSE outbreaks in the U.S. and estimate the effects. The scenarios in their study include the magnitudes in demand decrease (5% to 20%) and beef export reduction (50% to 100%).

3.3.4 Event study

McKenzie and Thomsen (2001) study the impact of recalls of E. Coli on wholesale and farm beef prices using an event study. They find that beef recalls decreased beef prices and public traded food companies suffered from significant shareholder losses in the event of series food safety hazards.

3.3.5 Combination of epidemiological and economic models

Though difficult, and requiring more cross-disciplinary efforts, attempts have been made to integrate economic and epidemiological models. Disease epidemiology has been gradually used in economics. In the study by Mangen and Burrell (2003), they use a five-part modeling framework which includes a spatial, dynamic, stochastic, epidemiological component implemented at the farm level to simulate the impacts of classical swine fever (CSF) outbreaks in the Netherlands.

3.4 New research areas mentioned in literature

3.4.1 Food safety regulations

Due to the importance and vulnerability of agriculture and the food system, regulations and strategies and their effectiveness are critical in maintaining food safety. The role of food safety regulations as risk management strategies on food trade needs to be further examined (Hooker 1999). Empirical studies are needed to examine the impact and effectiveness of rapprochement efforts of food safety regulations on trade flows by means of the latest methodology. Analysis, especially at a case study level, is needed to examine any particular rapprochement effort for specific products. Much more detailed analysis is required for the overall impact of rapprochement efforts on trade flows and food safety (Hooker 1999).

The requirement that developing countries comply with the developed country food safety regulations brings about other research needs (Hooker 1999). An important question is whether harmonization and transparency can actually improve trade and welfare. Difficulty in the research on trade and economic impact of food safety regulations includes, but not limit to, the generalization of various regulations, and the incorporation of risk assessment information into economic models poses another challenge (Wilson 2002). Hooker (1999) also suggests that studies on the impacts of rapprochement efforts on trade flows, firm strategies and development issues are needed.

3.4.2 Managerial implications at the business level

As pointed out by Pritchett et al. (2005), agribusinesses need to encourage more research on the managerial implications of animal disease threats to help policy making and agribusiness function. This work would stress the interpretation of research results and their implications for agri-food firms, along with the study of managerial coping strategies with these incidents.

Quantifying the losses along the meat marketing channel (from slaughter houses, through wholesalers on to retailers) is challenging due to the limited data availability. But opportunities exist for event studies and econometric models (Pritchett et al. 2005).

3.4.3 Effect decomposition of animal disease outbreaks

Paarlberg, Lee and Seitzinger (2002) suggest the need to decompose the gross effects of disease outbreaks among producers directed affected by the disease and those being affected indirectly. In addition, it may be also necessary to examine the effects on the substitute meats and the shift of consumer preferences. As mentioned by Pritchett et al. (2005), producers of unaffected meat may benefit from the disease outbreak, or consumers who are insensitive to the food scares may be able to buy affected meat commodities at lower prices.

3.4.4 Market structure

Market structure should be given more attention when studying animal disease outbreaks. As agribusinesses become more integrated vertically in operation, disease outbreaks could have different impacts on firms with different market structures (Pritchett et al. 2005). The impacts on firms may also vary across different marketing levels. The elasticities at different marketing level should be investigated after the event. Price transmission along the marketing chain before and after the disease outbreak could also be an interesting area.

3.4.5 Methodologies

Spatial economics can be used in animal disease analysis. The analysis needs to incorporate outbreak location, geographic distribution of production facilities and animal movement (Pritchett et al. 2005).

Animal disease models need to set up the links to the magnitude of the outbreak, the epidemiological work, vertical and horizontal stages in supply chain, and sectors other than food and agricultural industries by means of general equilibrium models. The models need to reflect product differentiation. Consumer response to animal disease outbreak need to be further examined (Paarlberg et al. 2005).

Other research issues mentioned in the existing studies include the expansion of the analysis scope to a wider area in subjects as well as geographical regions (Wilson 2002). Uncertainty and risk management in disease control, and related strategies should be further investigated.

CHAPTER IV

IMPACT OF ANIMAL DISEASE-RELATED TRADE DISRUPTIONS ON THE U.S. BEEF MARKET

4.1 Introduction

Two North American BSE (Bovine Spongy Encephalopathy) cases in 2003, which were confirmed in Canada on May 20th and the U.S. on December 23rd respectively, give rise to great concerns over food safety and biosecurity along with market consequences in the United States and Canada.

Canada and the U.S. have maintained a long term trading relationship in beef and cattle products. About 90% of Canadian beef exports entered the U.S. market in 2002 (USDA-ERS 2006). Immediately after the 2003 Canadian BSE case was confirmed on May 20th, many countries including the U.S. stopped importing cattle and beef products from Canada. The import ban at least caused two changes in the U.S. market. First, the import ban exerted some pressure on the beef supply in the U.S. since cattle and beef imports from Canada represented 4.2% of the total U.S. beef supply in 2001 (Brester and Marsh 2002). Second, beef and veal exports from U.S. to other countries increased by a monthly average of 18% in the subsequent five months from June to October 2003, compared with the level in April 2003, which filled in Canada's former export markets (USDA-ERS 2006). The increased beef exports further tightened the domestic beef supply.

Seven months after the Canadian BSE discovery, the first U.S. BSE case was confirmed on December 23rd 2003. Prior to this BSE discovery, U.S. exported approximately 10% of its beef production (1.14 million metric tons) in 2003. Of these exports about 80% went to Japan, Mexico and South Korea. Immediately after the BSE discovery, more than 50 countries either closed their borders to U.S. beef products or greatly reduced U.S. beef imports. Subsequently, the U.S. beef exports plummeted to approximately 20% of the total exports in the previous year. The loss of overseas beef markets increased supply in the domestic market al.ong with the loss of domestic consumer confidence of consuming beef products. Table 1 presents the events related with the BSE discoveries in Canada and the U.S.

The objective of this study is to directly investigate the impacts of trade disruptions caused by the Canadian and the U.S. BSE discoveries on the U.S. beef market. In particular, this study examines the impacts of the import ban to Canadian cattle and beef imposed by the U.S. and the restrictive exports of the U.S. beef products on the beef prices at the farm, wholesale and retail levels as well as beef consumption. The results show that the ban on Canadian beef exports to the U.S. increased beef prices, but the restricted U.S. beef exports did not have significant impact on the U.S. beef prices. Per capita beef consumption has negligible response to the supply shocks induced by trade disruptions.

The reminder of this chapter is organized as follows. Literature is briefly reviewed highlighting previous studies on the impacts of animal disease outbreaks on trade and meat markets. Then, the data and methodologies are presented. The empirical results and discussions are reported with a summary concluding the chapter.

4.2 Literature review

The impacts of animal disease outbreaks and food safety risks have been investigated on demand, meat prices, price transmissions, and international trade.

Burton and Young (1996) find the negative media coverage on BSE significantly decrease beef demand. Immediately after the 1996 UK announcement of a possible link between BSE and it's human version, vCJD, sales of beef products decreased by 40% and household consumption by 26% (Leeming and Tuner 2004). McCluskey et al. (2005) find that Japanese beef consumption dropped by 70% immediately after the 2001 Japanese BSE discovery. Schlenker and Villa-Boas (2007) find a beef sales reduction lasted for three months following the first US BSE discovery.

Animal disease outbreaks also affect meat prices and change price margins along the supply chain and across meat types. Leeming and Turner (2004) report that during the 1995-1997 U.K. BSE outbreaks the cattle price fell by 21% while sheep and pig prices rose by 19% - 21%. Lloyd et al. (2001) show that U.K. beef prices at retail, wholesale and producer levels fell by 1.7, 2.25 and 3.0 pence per kilogram following the 1996 U.K. BSE discovery. Marsh et al. (2008) find minor price effects of North American BSE events on U.S. cattle prices. They also argue that U.S. beef consumption did not suffer from the BSE event on an annual basis and more effects were present on the import demand for U.S. beef in the importing countries. Several studies differentiated price adjustments at farm, wholesale, and retail levels and the retail price margin relative to the farm and wholesale levels increases in response to the occurrence of BSE (Lloyd et al. 2001, 2006; Saghaian 2007; Sanjuan and Dawson 2003).

Trade disruption is well expected if there are animal disease outbreaks and biosecurity risks. There are some studies investigating the relationship between trade and prices of agricultural products in general. Eenoo et al. (2000) find that an increase in export demand results in an increase in domestic beef prices. Mattson et al. (2005) find that beef exports reduction caused a decrease in beef price. Marsh (2001) shows that an increase in the import shares of feeder cattle could lead to a $0.60/cwt decrease in the feeder cattle price. Wachenheim et al. (2004) find that increases in Canadian exports of beef, pork and hogs cause small reductions in U.S. domestic prices of these products, but no evidence to support the influence of Canadian live cattle exports on the U.S. cattle prices.

In the case of BSE outbreak, export ban has dramatic effects on the beef industry of the country with BSE discoveries, especially when it is highly export dependent (Moss et al. 2000). In the case of the first U.S. BSE case, Marsh et al. (2005) show that the prices of U.S. fed cattle and feeder cattle are expected to drop by $1.22 and $2.11 per hundred weights in 2005 assuming that Japan and Korea still ban the U.S. beef exports, and by $4.10 and $7.05 per hundred weights if Japan and Korea resume beef trade with the U.S. Mattson and Koo (2005) show that cattle and beef prices would decrease if there is an increase in the net cattle imports from Canada, assuming constant beef imports. But beef prices decrease less if beef exports from the U.S. resume at the previous level.

To the best of our knowledge, there is thin literature directly investigating trade disruptions caused by animal disease outbreaks and their impact on the meat market. Marsh et al. (2008) is one of few studies in this regard. Using simultaneous equation estimation, they analyze the effects of the 2003 BSE discoveries in Canada and the U.S. on prices of the U.S. fed and feeder cattle. This study explores the impacts of both the 2003 Canadian and U.S. BSE cases on the U.S. beef market with a focus on trade disruptions.

4.3 Data

This study uses monthly time series data representing the U.S. beef market and trade, including prices at the farm, wholesale, and retail levels, per capita beef consumption, beef imports from Canada, beef imports from the rest of the world, cattle imports from Canada, cattle imports from the rest of the world plus domestic cattle supply, U.S. beef and veal exports., The data range spans from January 1983 to December 2006.

All series except the per capita beef consumption are collected from various Red Meat Yearbooks and Agricultural Outlook published by ERS of USDA. To calculate the monthly per capita consumption of beef, we divide the total consumption of beef measured by the retail disappearance by population that is collected from the Population Division of the U.S. Census Bureau. In particular we follow the formula below:

$$\frac{\lambda(\text{commercial meat production} + \text{net imports} + \text{beginning stock - ending stock})}{\text{population}},$$

where λ is the conversion factor used to convert livestock carcass to retail weight equivalent. We use $\lambda = 0.7$ as suggested by the USDA reports from 1982 to 2006.

We distinguish between beef and cattle imports from Canada. Immediately after Canada announced that a beef cow in the Province of Alberta was tested positive for BSE on May 20 2003, the U.S. imposed an import ban on live cattle, beef, and related products from Canada. Less than three months later the U.S. partially reopened the border by allowing the imports of boneless beef from cattle under 30 months old on August 8th 2003. Later on April 18th 2004 the U.S. lifted the import ban on ground beef, bone-in cuts of beef and offal from animals under 30 months old. The ban on Canadian live cattle less than 30 months old for immediate slaughtering was lifted in July 2005. The distinction between beef and cattle imports allows us to separate the impacts caused by the bans of Canadian cattle or beef imports and the lift of the bans at different timing.

We combine the rest of the cattle imports from other countries with the U.S. domestic cattle supply. In the decade from 1993 to 2002, cattle imports from countries other than Canada accounts for 2.8% of the total commercial slaughter on average. We do not separate the U.S. beef and veal exports by importing countries. When a single infected cow was officially diagnosed with BSE in Washington State on December 23rd 2003, the majority of trade countries immediately stopped the imports of both cattle and beef from the U.S., including the four top importing countries (Japan, Mexico, Canada and South Korea).

Figure 1 presents the time series plots of these nine relevant variables. Beef prices at farm, wholesale and retail levels have a similar pattern over the data range. These prices reached a peak in early 1990s, another higher level in early 2000s followed a downward trend in the late 1990s, and were at their highest peak in October 2003, right before the BSE outbreak in the U.S. Immediately following the U.S. 2003 BSE discovery, farm and wholesale beef prices dropped sharply in the first two months of 2004, and retail beef price also decreased in the same period with a smaller magnitude.

Cattle and beef imports from Canada plummeted to a negligible level right after the Canadian BSE outbreak in May 2003. Beef imports from Canada recovered to the previous level before the Canadian BSE event. But cattle imports from Canada remained at the negligible level until July 2005 when the U.S. lifted import ban by allowing imports of Canadian live cattle under 30-mont old for immediate slaughter and feeding in the U.S. Beef exports from the U.S. reached the historical record level in June 2003. After that, U.S. beef exports began to increase gradually, but not up to the level before the BSE event in December 2003. Per capita beef consumption maintained relatively stable over time, except a slight decrease in February 2004. Cattle supply from other countries plus domestic supply, and beef imports from countries other than Canada remain relatively stable.

4.4 Methodologies

We will use time series methods, mainly the vector error-correction model (VECM) and innovation accounting techniques, to identify and quantify the dynamics and changes of the U.S. beef market induced by the BSE discoveries in North America, especially through trade disruptions. Directed acyclic graphs will be also used to uncover the contemporaneous causal relationships embedded in the U.S. beef market, which helps better understand the interaction of the important variables concerning the U.S. beef market and how it response to the animal disease outbreaks.

4.4.1 Vector error correction model

Time series data usually exhibit nonstationarity as different moments of the observed data are time variant. If the data are not stationary in level, but are stationary in the differences (usually in the first differences), the data generating process can be modeled with a vector autoregressive model or an error correction model in the differences depending on whether there is cointegration among the data series. Cointegration is the concept of co-movement or long run relationship among the series even though the individual series drift apart in the short run.

We denote total number of series by *p* and the time period by *t*. Given the *k* lags in the vector autoregression (VAR) with the existence of cointegration, the vector of variables, X_t, which is of dimension *p* x 1, can be modeled in vector error correction model (VECM) with *k* - 1 lags,

(1) $$\Delta X_t = \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Pi X_{t-1} + \mu + e_t \quad \text{for } t = 1,...,T,$$

where Δ is the difference operator such that $\Delta X_t = X_t - X_{t-1}$, Π is $p \times p$ coefficient matrix indicating long-run relationships among variables, Γ_i is a $p \times p$ coefficient matrix measuring the short-run effect of ΔX_{t-i} on ΔX_t, μ is a vector of constants, and e_t is a $P \times 1$ vector of innovations with zero mean and variance-covariance matrix Σ. The rank of Π determines the cointegration rank, *r*, such that $0 \le r \le p$. A zero rank of Π implies that there is no cointegration among the data series and a VAR in differences is appropriate; $r = p$ suggests that the data series are stationary and a VAR in level is appropriate; and $0 < r < p$ suggests that the data series are cointegrated with rank *r*, and an error correction model is appropriate.

The difficulty of interpreting the coefficients in the VECM leads to alternative techniques such as innovation accounting analysis to account for the dynamics embedded in the estimated parameters (Sims, 1980). We then express the VECM in a VAR at level,

(2) $X_t = \sum_{i=0}^{\infty} H_i e_{t-i}$,

where H_i is a *p* x *p* matrix of moving average parameters and e_{t-i} for $i \in [0,\infty)$ are innovations estimated from the VECM estimation that are not necessary orthogonal. Hence, a structural factorization is needed to convert the innovations e_t into the orthogonal contemporaneous innovation. Researchers traditionally use a Choleski factorization of the contemporaneous innovation matrix. However, the Choleski factorization allows researchers to arbitrarily choose one causal ordering among many others that may not reveal the true causal relationship (Demiralp and Hoover 2003). An alternative to the Choleski factorization is Bernanke factorization. It requires an auxiliary matrix A such that orthogonal innovations are generated by $v_t = \mathrm{A}\, e_t$. Equation (2) can be rewritten as

(3) $X_t = \sum_{i=0}^{\infty} \theta_t v_{t-i}$.

The Bernanke factorization uses the contemporaneous causality determined by the data themselves. Recently developed technique of directed acyclic graphs also helps to identify the causal pattern among the innovations of the series.

4.4.2 Directed acyclic graphs

Directed acyclic graph (DAG) is a graph composed of directed edges connecting a set of variables. The directed edges are arrows representing the causal flow among the variables based on the observed correlation and partial correlation (Pearl 2000). No arrow is allowed to direct from one variable all the way back toward itself. DAG starts with undirected edges connecting the variables. The concept of d-separation (Pearl 2000) implied by the correlation and partial correlation determines the assignment of the directions to the edges. The notion of d-separation is conceptualized by causal chain, causal forks, and inverted causal forks. Consider a case of three variables, X, Y, and Z. Potentially, there are three types of causal relationships among them (not including cases of non-causality). First, a causal chain such that X→Y→Z suggests that X and Z are dependent. But Y opens up the information from X and Z so that X and Z are independent conditional on Y (X and Z are d-separated). Second, a causal fork, X←Y→Z, suggests that X and Z are dependent, but independent conditional on Y. The common cause, Y, screens off the relationship between X and Z. Third, an inverted causal fork, X→Y←Z, implies that X and Z are independent, but their correlation conditional on Y is non-zero. The common effect Y does not screen off the relationship between X and Z.

The concept of d-separation is incorporated into the PC algorithm developed by Spirtes, Glymour and Scheines (1993) and GES (Greedy Equivalence Search) algorithm by Chickering (2002) to generate the DAG. Unlike the PC algorithm requiring a prior knowledge of the significance level, the GES algorithm is based on Bayesian information criterion approximation form Schwarz loss. The GES algorithm involves a two-stepwise search procedure to minimizing the corresponding Schwartz loss,

(4) $\mathrm{S}(\mathrm{G}, \mathrm{D}) = \ln p(D \mid \hat{\theta}, G^h) - \frac{d}{2} \ln m$,

where S is the SIC scoring function for the DAG graph *G* based on data *D*, $p(\cdot)$ is a probability distribution, $\hat{\theta}$ is the maximum-likelihood estimate of the parameters, *d* is the number of free parameters of *G*, and *m* is the number of observations in *D*. This Baysian information criterion balances the trade-off between fit (the first term on the right hand side of equation (4)) and parsimony (the second term). The GES algorithm always moves in the direction that increases the Bayesian score the most. The GES algorithm proceeds from an undirected graph consisting of a set of variables. All graphs of possible single edge addition, along with the initial graph, are scored by Bayesian scoring criterion. The graph with the highest score is chosen for the next step. The second phase begins by removing a single edge and comparing the scores. This backward procedure repeats until the local maximum is reached. The final causal pattern is thus determined.

4.4.3 Innovation accounting analysis

We use innovation accounting analysis such as impulse response functions, forecast error variance decompositions, and historical decomposition to identify the effects of the BSE discoveries on the U.S. beef market and trade.

The response of the system in a VAR-type model to a one-time shock in the innovations is to show the magnitude and direction of the dynamic relationships in the model (Featherstone and Baker 1987). As in equation (3), the responses of each series at time $t + j$ to the one-time shock in the innovations at time t is given by the columns of θ.

For each variable, contributions of all the variables to the variance of forecast error of this variable are accounted for as a percentage of the total variance. Therefore, the sum of all the decomposed variance contributions (in percentage) is equal to 1. Thus, forecast error variance decompositions illustrate the importance of a selected variable in explaining the forecast error variance of another variable.

Historical decomposition is useful in studying data in the neighborhood of a historical important event. Based on equation (3), the vector of X at any period $t = T + k$ can be partitioned into two parts,

$$(5)\ X_{T+k} = \sum_{s=k}^{\infty} \Theta_s v_{T+k-s} + \sum_{s=0}^{k-1} \Theta_s v_{T+k-s}.$$

The first term in equation (5), called “base projection”, gives the position of the vector X that is due to the information known up to period T. In this study, this gives the forecast for each series based on the information before the BSE event. The second summation term utilizes the information from T + 1 to T + k, which incorporates the information of market fluctuation after the BSE event in this case. Each series at the period of T + k can be expressed as a linear combination of historical innovations from each other series, which represents the contribution of each other series to the movement of the selected series. Such a partition allows us to infer which innovations are most important in moving each series at a particular time. The variable with more influence tend to drive the series under consideration farther apart from its base projection.

4.5 Empirical results and discussions

4.5.1 Diagnosis testing

We first test for non-stationarity of each data series. The commonly used tests are the Dickey Fuller (DF), Augmented Dickey Fuller (ADF), and Phillips-Perron (PP) tests, which examines the null hypothesis of a unit root against the alternative of a constant deterministic trend. These traditional unit root tests do not consider potential structural break(s) in the data series, which may lead to forecast failure (Hendry 2000). We also conduct the Zivot-Andrews unit root test that allows for one possible shift in mean, trend or both (Zivot and Andrews 1992) and Clemente unit root test that allows for one or two breaks in mean (Clemente et al. 1998). Table 2 presents results of the unit root tests at both levels and the first differences.

The DF and PP tests suggest that the beef prices series, beef imports from Canada, and beef exports are nonstationary while others are stationary at level. The ADF tests also show another unit root in cattle imports from Canada in addition to the five nonstationary series found in the DF and PP tests.

Allowing for one possible structural break, the Zivot-Andrews test results suggest that the prices series and cattle and beef imports from Canada are nonstationary while others (beef export, beef consumption, other cattle supply, and beef imports from countries other than Canada) are stationary in level. Clemente test shows that all series are non-stationary except beef import from Canada.

Based on the unit root tests, we find that the beef prices in levels are nonstationary, but others have mixed results depending on tests. We conduct the same tests for the first order differences and the results suggest that the first order differences of these series are stationary in all tests except for retail price in Clemente test.

The optimal lag length (*k*) in a VAR model is determined by various information criteria including Akaiki information criterion (AIC), Schwartz information criterion (SIC), Hannan and Quinn (HQ), and Hacker and Hatemin-J (HJ) information criterion. The VAR model employed for this study incorporates seasonality since cattle and beef production exhibits seasonal pattern. As shown in Table 3, the optimal lag length is one based on SIC, HQ, and HJ information criterion and three based on AIC. Since AIC may have tendency to over-penalize additional regressors in contrast to other information criteria (Geweke and Meese 1981), we conclude a level VAR of one lag. However, a level VAR of one lag suggests no short-run effect of ΔX_{t-i} on ΔX_t (see equation (1)), Furthermore, we conduct Ljung Box Q test (Ljung and Box 1978) for autocorrelation in the residuals after the VAR estimation and reject the null hypothesis of no autocorrelation. Therefore, we use the optimal lag of two instead.

Given a VAR model with two lags, the Johansen trace test is conducted to test the rank of cointegration vectors. We test two model specifications where both account for seasonality, one with a linear trend and another with no linear trend. As shown in Table 4, we reject the null hypotheses of rank $r = 0$, $r \leq 1$, $r \leq 2$, $r \leq 3$, and $r \leq 4$, but fail to reject the null hypothesis of rank $r \leq 5$. Therefore, we conclude that there are five cointegration vectors among the nine series. In other words, there exist five long run relationships among the nine series.

To further characterize the cointegration space, we conduct exclusion tests to investigate whether any of the data series does not belong to these five cointegration vectors and exogeneity tests to examine whether the conintegrated data series respond to the perturbation in the long run relationships. Results in Table 5 suggest that all the nine series belong to the conintegration space and each of them responds to the perturbation in the long run relationships.

The data in this study span more than two decades during which structural changes may exist. We then employ the time varying rolling and recursive coinegration methods (Hansen and Johansen 1999) to endogenously detect any structural change. The null hypothesis of cointegration rank r is rejected at the 5% significance level if the value of the normalized trace statistics is greater than one. Since the cointegration rank is five if using the complete observations, we only present the rolling and recursive cointegration trace tests for the null hypothesis $r \leq 4$. Figure 2 suggests that we fail to reject the null hypothesis of four cointegration vectors before the second half of 2003 but reject it after that time. The instability of the cointegration suggests a structural break in the second half of 2003, which was likely induced by the 2003 BSE discoveries in both Canada and the U.S. The Clemente unit root test conducted earlier also validates this finding as it identifies a structural break in June 2003 for the wholesale price, December 2003 for the farm price, and January 2004 for the retail price. Given the detected structural break, the ideal case is to analyze the data before and after the break. However, we do not have sufficiently long data series to conduct analysis for the post-break periods. Thus, we use the whole sample to analyze the impacts of BSE cases.

4.5.2 Contemporaneous causalities in the U.S. cattle and beef markets

Based on the correlation matrix from the VECM estimation, we generate a DAG using the GES algorithm in TETRAD IV [1] and present the contemporaneous causalities in Figure 3. Farm price causes wholesale price, which is consistent with the literature (Goodwin and Holt 1999). Retail price causes farm price, which may suggest the market power of the beef retail sector resulting from increasing concentration at the retail level (Sexton 2000). Both beef imports from Canada and the U.S. beef exports cause retail beef price, which suggest a possible channel that the BSE and the resulting trade disruptions could affect the retail beef price through supply changes. Beef consumption is the receiver of information from wholesale price, cattle imports from Canada, beef imports from Canada, beef exports, and beef imports from countries other than Canada. Retail price does not directly cause beef consumption, but it passes information to beef

1 Source: www.phil.cmu.edu/projects/tetrad.

consumption through farm and wholesale prices. These contemporaneous causal relationships will be incorporated in the innovation accounting analysis later.

4.5.3 Impacts of the Canadian and U.S. BSE cases on the U.S. cattle and beef markets

Are beef prices and consumption responsive to trade disruptions?

Figure 4 plots impulse response functions for the prices at farm, wholesale and retail level and per capita beef consumption.

Figure 4(a) and 4(b) show that (a) the U.S. beef prices at farm, wholesale and retail levels increase if there is a decrease in the cattle and beef imports from Canada. Hence, we expect the import ban from Canada immediately following the 2003 Canadian BSE case would likely increase the beef prices, which is consistent with Marsh et al. (2008); and (b) the price responses to beef imports from Canada is larger than that to the cattle imports from Canada, and the responses also last longer. Figure 4(c) suggests that beef prices at farm and wholesale levels respond negatively to the U.S. beef exports in very small margins in the first four months and restore to stability later. A temporary positive response is observed in retail price in the first two months. Either no obvious or low response of beef prices to the U.S. beef exports may be explained by the small share (10%) of the U.S. beef exports of the total supply. Figure 4 (d) shows that per capita beef consumption has negligible response to the supply shock induced by trade disruptions.

Can trade disruptions partly explain the forecast error variance of the U.S. beef prices and consumption?

Figure 5 shows forecast error variance decomposition results. For each series, we decompose its variance of the forecast error into the innovations of all the series in the 24-month horizon. The forecast error variance of farm beef price is largely explained by itself and beef imports from Canada and other countries. Beef imports play an increasing role over time.

The forecast error variance of wholesale price is mostly explained by farm beef price, while retail price and beef imports have relatively more important role in explaining the uncertainty of the wholesale price over time. As suggested by DAG, beef imports from Canada have impact on retail price, and this impact passes to farm price and then to wholesale price.

In addition to the small contribution share from farm and wholesale price, the forecast error variance of retail beef price is largely explained by itself and other cattle supply. Although cattle imports from Canada reached 1.69 million head in 2002, this only accounted for about 4.7% in the total commercial cattle slaughter in that year. The majority of the U.S. cattle supply comes from the domestic market. It plays a greater role in affecting the retail price. Forecast error variance of per capita beef consumption is largely explained by itself.

Can the BSE discoveries and the sequential trade disruptions explain the change in beef prices and consumption?

We further conduct historical decomposition to demonstrate the contribution of each series to the change of the selected series around the time of the 2003 Canadian and U.S. BSE cases. Since we focus on the impact of the BSE-induced trade disruptions on the

U.S. beef market, only the historical decomposition graphs for beef prices and beef consumption are presented in Figures 6.

We use all the observations one month before the event to forecast the data series of seven months ranging from one month before the event and six months after the event. The forecasted data series utilize all the information up to one month before the event, i.e., excluding the impact of the BSE case. The actual data series are influenced by all the current information including the BSE case. The difference between the actual and forecasted data series suggests the impact of the BSE case, which is represented by the solid line in each plot in Figure 6. The stacked bars in Figure 6 represent the contributions of each series to the deviation of the forecasted series from the actual series in the selected series over the decomposition periods. By comparing the segments in each stacked bar, we are able to identify the variable that is the most important in influencing the movement of the series under investigation. Graphically, the largest segments in the stacked bars have the greatest influence on the difference in the series value with and without the animal disease event.

The left panels in Figure 6 illustrate the impact of the 2003 Canadian BSE discovery. The comparison of the prices deviations illustrated by the solid line shows the following findings: (a) the Canadian BSE discovery and the sequential import ban imposed by the U.S. increase the prices at farm, wholesale, and retail levels by 10 to 80 cents per pound; (b) the impact is differentiated along the supply chain: increasing sharply after July 2003 and reaching the highest level in October 2003 for farm and wholesale prices, and November 2003 for retail price; and (c) the impact on beef prices is stronger and longer than on beef consumption.

Furthermore, the left panels of Figure 6 also suggest the following findings. First, beef imports from Canada and other cattle supply made the greatest contribution to the price deviation at the farm level due to the Canadian BSE discovery. The U.S. beef imports from Canada had maintained an average level of about 90 million pounds from May 2002 to April 2003. But it dropped to 88,000 pounds in June 2003, which was almost a 100% reduction. The low level of beef imports from Canada did not improve in July and August 2003. The impact of this huge reduction began to reflect in the farm price in August, September and November 2003. Another large contributor to the great increase in farm beef price is other cattle supply that includes the U.S. domestic cattle supply and cattle imports from countries other than Canada. The tight cattle and beef supply could contribute to the higher farm and wholesale beef price after the Canadian BSE discovery.

Second, the increase in the retail beef price is partly attributable to the rise of beef exports, especially after July 2003. Since many countries imposed the import ban on Canadian cattle and beef products, the U.S. beef were likely on the greater demand by these countries. The U.S. beef exports reached 258.55 million pounds in June 2003, which was a 28% increase compared with the level in June 2002. The increased exports of the U.S. beef exerts more pressure on the already tight cattle and beef supply in the domestic market since the U.S. also imposed an import ban on the Canadian cattle and beef products. We also find large contribution of other cattle supply to the retail price increase, which substantiates the tight cattle supply claim. Beef consumption did not exert much influence on the retail price within the two months after the BSE event in Canada. Even though the U.S. consumers responded greatly to the 1996 U.K. BSE, especially to the announcement of the possible link between the BSE and its human version, vJCD, the 2003 Canadian BSE case did not have dramatic impact on the U.S. beef consumption.

Overall, we conclude that the 2003 Canadian BSE discovery caused the increase of the U.S. beef prices at farm and wholesale levels through the reduction in beef imports from Canada and the increased U.S. beef exports to other countries. However, the import ban on Canadian cattle and beef do not affect the retail price that much. Instead, the increase of the retail beef price is likely attributable to the increased U.S. beef exports. Overall, the import ban to beef products from Canada, the increase in U.S. beef exports, and the already tight domestic beef supply pushed beef prices to a higher level after the Canadian BSE event. The impact of the Canadian BSE discovery on beef prices demonstrated mostly through supply shock induced by trade disruptions. The U.S. beef demand did not show much impact on the rise of the beef prices. The impact of the Canadian BSE discovery on per capita beef consumption is limited.

The right panels in Figure 6 illustrate the historical decomposition on the U.S. beef prices and consumption from November 2003 to June 2004. The solid line, which represents the difference between the forecasted and actual data series, suggests that both beef prices and consumptions decrease immediately after the confirmation of the first U.S. BSE case. The adverse impacts of the U.S. BSE discovery on beef prices at farm and wholesale levels dissipated by March 2004, three months after the event. However, the negative impacts had a longer duration for the retail beef price and it eventually dissipated by June 2004, six months after the event. This BSE case affected the wholesale price more than the farm and retail prices. The longer duration of the impact on the retail price and the larger impact on the wholesale price could be explained by the fact that the banned beef exports were in the form of processed beef products and would not return to the feedlots but sold to the retailers or further processed into beef cuts.

Furthermore, the right panels of Figure 6 relating to the first U.S. BSE case also have the following findings. The wholesale price increased starting from March 2004 following a three month reduction after the BSE event, which could be attributable to the rise in retail and wholesale prices. Farm beef price exerts the greatest influence on the decrease of farm and wholesale prices after the U.S. BSE event until March 2004. After March 2004, the increased retail price and strong beef demand contributed to the rise in farm price. The first two right panels of Figure 6 suggest that the ban on the U.S. beef exports did not exercise much influence in decreasing farm and wholesale prices. The excess supply as a result of the export ban to the U.S. beef slightly decreased farm and wholesale prices in January and February 2004. It did not contribute much to the increase in the actual farm and wholesale prices after March 2004, either. The reason of its limited influence of trade disruptions on farm and retail prices could be due to the fact that the banned U.S. beef exports were sold in the retail market instead of entering feedlots.

The actual retail price fell from December 2003 until March 2004. It was lower than the forecasted price until June 2004, i.e., the retail price recovered in June 2004, seven months after the U.S. BSE case. The U.S. beef exports exerted a downward pressure on the retail price and this effect was larger than that on farm and wholesale prices. Excess beef supply, which would be exported to other countries if there was no import bans, diverted to the U.S. retailers, which caused the reduction of retail price for these three months. In addition to the great contribution by the retail price itself, the rise in retail price was more attributable to the strong beef demand than other factors after March 2004.

Per capita beef consumption decreased following the U.S. BSE case. However, it recovered on March 2004, three months after the BSE event. The strong consumer demand played a role in pushing the retail price up after March 2004. This may indicate that consumers did not have much concern over the U.S. beef safety following the holiday season. The export ban to U.S. beef after the BSE event in 2003 did not constitute a large supply shift for a long time. It had limited effect on the farm and wholesale prices. Its temporary downward pressure on the retail price lasted for only three months. Due to the strong demand for beef in the U.S., retail price increased three months later.

The impact of the Canadian BSE event on beef prices is different from that of the U.S. BSE event. Farm, wholesale and retail beef prices all increased after the Canadian BSE until the U.S. BSE discovery in December 2003. Price along the supply chain all decreased after the U.S. BSE event until March 2004, four months after the confirmation of the U.S. BSE case. The magnitude of the price change after the Canadian BSE event was larger and lasted longer than that after the U.S. BSE event. The positive price impacts of the Canadian BSE event can be partly attributed to the reduction in beef imports from Canada (for farm and wholesale prices), and the increase in beef exports (for retail prices). The Canadian BSE discovery had negligible impact on beef consumption. For the case of the U.S. BSE event, the negative impact on retail price lasted longer than farm and wholesale prices, but the negative impact on wholesale price had the larger magnitude in the short run. Beef consumption after the U.S. BSE event dropped slightly but rose even higher later.

4.6 Summary

Using a time series approach, this study examines the impact of trade disruptions induced by the Canadian and U.S. BSE discoveries in 2003 on beef prices at farm, wholesale, and retail levels as well as beef consumption. Empirical results show that these two BSE events caused a structural break in the U.S. beef market and trade.

The innovation accounting analysis summarizes the dynamic properties of the nine series. The impulse response function analysis shows that the reduction of cattle and beef supply increases beef prices at farm, wholesale and retail level. The shock in beef exports causes slight response in beef prices for just a very short time. Beef consumption hardly shows any response to the trade shock. The forecast error variance decomposition also reveals the contribution of beef imports to the uncertainty in the farm and wholesale prices. The BSE events in Canada and the U.S. had impact on the U.S. beef prices. These BSE events caused changes in the U.S. beef and cattle supply through trade disruption. The effects of trade disruption were shown in the deviations of beef prices after each event, with beef imports from Canada and beef exports as the major contributors after the BSE events. The impact of the Canadian BSE event is different from that of the U.S. event. The impact of the Canadian event is positive on beef prices and also of a larger magnitude, while the impact of the U.S. event is negative of a smaller magnitude. Beef consumption was not significantly affected by the trade disruption. Instead, the strong beef demand exerted certain effects in pulling up the retail price three months after the U.S. BSE event.

CHAPTER V

SIMULATING TRADE-DISRUPTION IMPACTS OF BSE OUTBREAKS IN THE U.S. AND CANADA

5.1 Introduction

5.1.1 Introduction of the problem and literature review

Countries trade commodities based on comparative advantage and gain from that trade. Countries may enforce certain trade policies that may distort trade patterns for various reasons. Trade distortion can result in the reduction of trade volume, trade disputes, and even trade termination. Commonly used trade barriers include tariffs, quotas, and tariff equivalent barriers. There are also technical barriers to trade (TBT) which include nontariff barriers such as required compliance with the technical standards and regulations imposed by importing countries along with International Sanitary and Phyto-sanitary (SPS) standards.

According to results in Oyejide et al. (2001), Australia, the European Union and the United States are the three countries where SPS requirement constitute the largest obstacle to trade. It is challenging and costly to the developing exporting countries to meet the technical requirements and quality standards set forth by the developed countries such as national animal health standards (Oyejide et al. 2001). In turn, these limitations affect welfare, employment, output, and commodity prices in potential exporting countries that face these barriers.

Quantifying the impact of trade policies has been the subject of a lot of research. However, there are limited research studies that relate to the impact of biosecurity risk-induced trade disruptions/barriers as they impact agriculture and the food system. Studies have investigated the impacts of SPS and TBT, animal welfare, plant health, security of domestic ecosystem, and invasive species. This research will fill in the gap.

In the analysis of the impact of biosecurity risks, some studies use partial equilibrium models. Ekboir et al. (2002) use a simulation model to estimate the effect of beef market shocks on beef imports, exports and equilibrium prices for FMD-endemic and FMD-free markets. Their model includes many countries and regions in depicting world beef trade. They examine the impact of FMD eradication of FMD in Argentina and Uruguay and the entry of their beef exports to FMD-free markets showing impact on the beef prices.

James and Anderson (1998) use a partial equilibrium model to assess the effect of quarantine policies on consumers as well as producers in the case of Australian ban on imports of bananas. They find consumers may gain from lifting the ban on the products that are competing with domestic products.

The conceptual bioeconomic framework presented by Zhao et al. (2006) investigates how the introduction of invasive species affects decision making in the livestock sector. Incorporating the epidemiological forecasts of disease event, production, consumption and international trade, they examine optimal mitigation policy based on welfare comparison across different scenarios.

5.1.2 Objectives and contributions

Rich et al. (2005) indicate that there are generally five major economic impact measures that need to be examined when conducting economic analysis of animal disease outbreaks, including costs, prices, international trade, national welfare, and employment. Rich et al. (2005) also indicate that there are many important questions that have not been addressed and many economic methods to answer those questions are not fully utilized.

Due to the importance and vulnerability of the U.S. agriculture and food sector, it is interesting to see the potential impact of biosecurity risks brought by international trade disruptions on the U.S. livestock and meat industry and to examine welfare changes for the U.S. agriculture producers and consumers and its trading partners. Producers and consumer surplus are useful in determining the impact of policy changes and disease shocks (Rich et al. 2005).

This chapter will examine the effect of animal disease related trade disruptions on the U.S. agriculture. It will utilize the mathematical programming based Agricultural Sector Model (ASM) of McCarl and associates[2] to simulate the effects of BSE relate trade disruptions. The analysis will generate results that may be beneficial in assisting decision making for government policy makers, business professionals, farmers and ranchers.

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2 See Adams et al. 2005 for a description and model history.

This study offers the following contributions to the literature. First, it utilizes a sector wide model that is integrated with international trade to examine welfare changes within the country and between trading partners. It will also produce estimates of the national and regional changes in prices and quantities in agricultural products. Second, this study examines the effects of BSE on internal livestock movement and shows how transport adjustments may mitigate disease impacts. Since biosecurity risks reside in the movement of extensive livestock across borders between the U.S., Canada and Mexico, transportation costs have to be considered in the model as an indispensable part for calculating the costs of livestock production and distribution. The inclusion of transportation cost also facilitates the simulation if we need to consider the scenario where there is livestock movement ban.

Since there have been no large scale FMD outbreaks in the U.S. of the similar size of the U.K. outbreaks, or any bioterrorism attack in the form of highly pathogenic epidemic, the best way to estimate the market impact and welfare effect of such events is to use the simulation models. Adapting ASM to this purpose is such an attempt. In the following sections, we will first discuss the U.S. livestock and meat industry. After discussing the ASM assumptions, simulation scenarios and results will be presented. Finally, we will conclude the chapter with limitations and future research areas.

5.2 The U.S. livestock and meat industry

The U.S. is renowned for its highly developed agriculture and food system. It has comprehensive livestock, crop and byproduct production, plus large associated processing and distribution industries. This highly integrated system provides an abundance of food and agricultural products for domestic and overseas markets. The trade flows between the U.S. and its trading partners also play a great role in maintaining competitive prices and benefiting domestic and international consumers. However, the extensive trade flow, complicated with the agricultural production and transportation, is vulnerable to bioterrorism attacks and/or naturally occurred animal and crop diseases outbreaks.

Agriculture is an important sector in the U.S. economy. Beef cattle production is the largest segment in the U.S. agriculture. There are 97.1 million cattle in the U.S. in January 2006. More than one million businesses, farms and ranches are involved in beef related operations[3].

Beef cattle production consists of several stages. Cow-calf operations are usually family owned businesses where calves are raised until weaned. Weaned calves are fed in stocker or backgrounders until they reach 12 to 18 months. They are moved to feedlots where the cattle live in pens and are fed with grain. The fed cattle will be sent to packing plants for slaughtering and processing after they reach 20 months or weigh about 1100 pounds.

There are extensive transportation activities involved in cattle production, especially the movement of calves to feedlots and of cattle from feedlots to packers. In case of animal disease outbreaks, a movement ban is likely to be imposed to prevent the

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3 Source: www.beefusa.org.

spread of disease. Since fed cattle cannot move out while feeder cattle cannot move in, the beef cattle supply chain in the affected region is disrupted. This will impact the beef cattle supply and meat market accordingly. In addition, an export ban will likely be imposed on the affected products regionally or nationally. Because of feed interrelationships, it is likely that all sectors in agriculture will be affected. Plus, consumer demand may also be impacted because of food safety concern. The shifts in the supply of beef cattle and the demand for beef will lead to new market equilibrium and sequential changed welfare distribution.

Transportation of calves and fed cattle between regions (including Canada and Mexico) is explicitly depicted in this model. Movement of other livestock species or meat products is not modeled. ASM is extended to include such movements in the following ways. First, for countries that move calves or fed beef into the U.S. (Canada and Mexico), only calf-to-stocker operation, calf-to-feedlot, stocker-to-feedlot interregional movement are modeled as well as Canada-US movement of slaughter animals. Live animals from Mexico are divided equally to east and west Mexico as this division is established in the ASM. Livestock imports from Mexico and Canada come from the border cities. The distance and cost are based on the starting points on the border. The distance in mileage from source to destination of movement is determined[4]. Constant transportation cost is assumed regardless of the volume shipped. The unit cost

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4 The distance was calculated by the online distance finder at www.freetrip.com.

of transportation is a result of multiple interviews with experts in cattle industry. A 5000-pound truck load of livestock is assumed. The final transportation pattern is determined based on the above assumptions, calculations, and experts' opinions. Interregional and cross-border cattle movement routes are presented in Table 6 and Table 7 respectively.

5.3 Concept of ASM

Many approaches can be applied to conduct agricultural sector analysis to estimate welfare effects of policy changes or events. One of them is the mathematical programming approach in the partial equilibrium model as used in ASM. Mathematical programming models can be very useful for policy assessment. They can be applied in the analysis of direct or indirect impacts of alternative policies on a sector in the economy (McCarl and Spreen 1980). One of the prominent features is that production factor uses and outputs levels are endogenous along with the prices of these items. The model can be easily expanded and extended for various policy alternatives. In this study, we will use the Agricultural Sector Model (ASM). The ASM incorporates all crops, livestock, production and processing activities. It enables the modelers and analysts to find out the welfare effects of any policy changes. Various versions of ASM have been used in studies of farm programs, climate change, environmental policies and trade policies (Chang et al. 1992; Schneider et al. 2007).

ASM is a nonlinear, price endogenous model which models the production, processing and consumption of more than 70 commodities in 63 US regions along with international trade. It incorporates agricultural activities and generates the commodity quantities, input prices and welfare measures. The 63 regions are grouped into 11 larger regions if we prefer the results at the aggregated level. The 11 regions are listed in Table 8. Production and processing technologies are specified in ASM. Livestock and crop budgets are included in the model too. It has 19 types of variables (e.g. land, crop and livestock production, resources supply, inputs, demand, supply, farm policy) and 19 equations (one objective equation and 18 constraints) (McCarl et al. 1993). The model reflects the market equilibrium under perfect competition when the total social welfare is maximized. The supply and demand functions for all the commodities in the model endogenously determine the prices and quantities of all the production factors and outputs (Schneider et al. 2007).

The objective of ASM is to maximize the total welfare composed of consumer surplus and producer surplus. It is presented by the total area under the demand curve less the area beneath the supply curve up to the point where supply and demand curves intersect (Schneider et al. 2007). Figure 7 shows the welfare representation.

The supply and demand curve intersects at point E, which is the equilibrium point. The price level is P, and quantity level is Q at the equilibrium. The area underneath the demand curve up to point Q is the approximation of the total revenue (area OAEQ). The area underneath the supply curve up to point Q is the approximation of the total cost (area OBEQ). The difference between these two areas (triangle BAE) is the total welfare, which can be decomposed into consumer surplus (triangle PAE) and producer surplus (triangle BPE). The objective function is to maximize the total welfare.

5.4 Model assumptions and specification

The ASM version used in this study is a static equilibrium model depicting sectoral economic activity. Perfect competition for factors and output markets is assumed as discussed in McCarl and Spreen (1980). Constant elasticities for the demand and supply curves are assumed for the commodities. Homogeneous commodities are assumed in each region. Perfect substitutes of commodities are also assumed in each region. Consumers are indifferent to the sources of supply.

5.5 Simulation results

5.5.1 Scenarios description

Six scenarios along with a base scenario will be examined in this study depicting different trade and animal disease situations and demand shift.

- A **base** scenario where there are no major animal disease outbreaks, no trade disruption or demand shift.
- A **Canada BSE short run scenario** where there are BSE outbreaks in Canada and import of beef and cattle commodities from Canada is completely banned. Also there is no short run livestock adjustment in the herds and anticipating the import ban would not last long. Another assumption in this scenario is the U.S. beef exports are not affected, which means they are maintained at the historical level as in the base scenario. U.S. beef demand is assumed unchanged.
- A **Canada BSE long run scenario** where there are BSE outbreaks in Canada and there is adjustment in cattle production due to the anticipation of the long

lasting status of the trade ban. No change in the U.S. beef exports is assumed. U.S. beef demand is assumed unchanged.

- A **U.S. BSE short run scenario** where there are BSE outbreaks in the U.S. and there is no short run livestock adjustment in cattle production. Exports of U.S. beef and cattle commodities are banned. We assume beef exports are banned or reduced by 90%. U.S. beef demand is assumed unchanged.
- A **US BSE long run scenario** where there are major BSE outbreaks in the U.S. and there is adjustment in cattle production due to the anticipation of the long lasting status of the export ban of U.S. beef. We also assume that the reduction in beef exports is 80% and there is no change in the U.S. beef demand.
- **A Canada and U.S. BSE short run and a 15% demand reduction scenario** where both Canada and the U.S. have major BSE outbreaks coupled with a 15% reduction of the U.S. beef demand. It is assumed that cattle and beef imports from Canada are completely banned and U.S. beef exports are reduced by 90%.
- **A Canada and U.S. BSE long run and a 40% demand reduction scenario** where both Canada and the U.S. have major BSE outbreaks. Cattle and beef imports from Canada are completely stopped and U.S. beef exports are reduced by 90%. Livestock adjustment is assumed in the long run. Also, a 40% reduction in U.S. beef demand is assumed.

5.5.2 Welfare for agriculture

Table 9 presents results of these six scenarios. In the base scenario, U.S. consumer surplus is $1,398,029 million. In the first two scenarios where BSE outbreaks occur in

Canada, there is a reduction in consumer surplus due to decreased imports. The magnitude of the reduction is about $200 million greater in the short run scenario than in the long run scenario. The U.S. producers gain in these two scenarios. The increase in the producer surplus is $614.56 million and $496.86 million, respectively. The total social welfare decreases by $236.08 million and $75.41million in the short run and long run scenario, respectively.

In the U.S. BSE scenarios, consumers gain and producers lose. Compared with the base scenario, the consumer surplus is $1710.84 million and $662.95 million larger in the short run and long run scenario respectively. But the producer surplus is $1666.73 million and $681.6 million less, respectively. The magnitude of the increase in the consumer surplus and the reduction in the producer surplus are larger in the short run scenario than in the long run scenario. The total social welfare increases in these two scenarios. In the 2001 BSE outbreak in Canada, the U.S. stopped cattle and beef imports from Canada. About 67% of Canadian fed cattle enter the U.S. market. The ban on cattle imports reduced the cattle and beef supply in the U.S. market. Other things assumed unchanged, the price of cattle and beef price would increase which leads to the decrease of the consumer welfare. In the two scenarios of the U.S. BSE outbreaks, the reduction in the U.S. beef exports by 90% results in larger increase in the U.S. consumer surplus than in the scenario of only 80% reduction in beef exports. The almost complete ban to the U.S. beef exports in the U.S. BSE short run scenario makes the extra beef stay in the domestic market. This could reduce the beef price and increase the consumer welfare. But the producers lose in this case.

In the scenarios, where both Canada and the U.S. have BSE outbreaks coupled with a reduction in beef demand, the changes in welfare are the greatest for both consumer and producer domestically and internationally. The 15% and 40% reduction of beef demand in these scenarios result in a loss of consumer surplus of $6,023 million and $22,452 million and a loss of producer surplus of $4311 million and 5482 million. Table 9 shows that the total welfare in these two scenarios decreases by $10,245 million and $27,530 million respectively. When BSE outbreaks in both Canada and the U.S. where cattle and beef sector is highly integrated, coupled with the reduction in the U.S. beef demand, both consumers and producers lose and the total social welfare suffers from a huge decrease. This simulation results also indicate that 40% reduction of the U.S. beef demand brings about a greater loss of the U.S. consumer and producer surplus than the 15% reduction in the U.S. beef demand. If there are severe BSE outbreaks in Canada and the U.S., international markets will restrict cattle and beef products from these two countries. Given the importance of cattle and beef industry and trade in Canada and the U.S., the trade ban results in severe economics loss. In addition to that, the BSE outbreaks would trigger consumers' negative reaction to the events. Therefore, it is well expected that consumers would change beef consumption pattern and reduce beef demand. Coupled with the trade ban, which suggests the supply shift, the total welfare of the U.S. deceases by the greatest amount compared with less severe scenarios.

The lower panel of Table 9 presents the welfare changes in the rest of the world. Foreign consumers lose in all scenarios, with the huge loss in the scenarios where there are BSE outbreaks in the U.S., and where both Canada and the U.S. have BSE outbreaks coupled with reduction in the U.S. beef demand. The foreign consumers and producers lose from $5,972 million to $7,179 million in total. Also, the U.S. beef ban brings about much greater loss in foreign welfare than the Canadian cattle ban only. This may be attributed to the fact that Canada exports its cattle mostly to the U.S. and only a small percentage enters other markets. But U.S. beef is exported to many countries. Thus, the ban to U.S. beef exports brings about larger negative impact to foreign consumers. The total global net welfare decreases in all cases.

Generally speaking, in the Canadian BSE scenarios, either with or without short run adjustment, U.S. consumers lose but producers gain. The society as a whole loses. This is the opposite in the U.S. BSE scenarios where the society gains as a whole. But when both Canada and the U.S. have BSE outbreaks and also when there is a large reduction of U.S. beef demand, the total welfare of the U.S. and the rest of the world decline by a great margin. The impact on welfare is huge if cattle and beef trade of Canada and the U.S. is interrupted and the U.S. beef demand is reduced by a great margin.

5.5.3 National price and production for slaughter cattle

As a result of the import ban to Canadian cattle, the price for slaughter cattle in the U.S. goes up by 2.0% compared with the base price without trade disruption. But price goes down by 7.8% and 3.1% respectively in the U.S. BSE scenarios. In the U.S. BSE short run case, the price falls by a larger margin. But with the adjustment in cattle production, the long run price effect from the ban is buffered. However, beef price would fall by

17.1% and 25.9% in the scenarios where cattle from Canada are banned, the U.S. beef exports are restricted and domestic demand falls by 15% and 40% respectively.

The national production of slaughter cattle would fall by 0.1%, 0.2%, 0.2%, 1.5%, 1.5%, and 15.6% in the six trade disruption scenarios respectively. Table 10 presents the results. It shows that when Canada and the U.S. both have BSE events and the U.S. demand for beef reduces by 40%, the effect on price and quantity of beef is the greatest among the six scenarios.

5.5.4 National production, price, imports and exports

Table 11 presents production, price, import and export indices for all farm products, all livestock and meats. Except in the Canadian BSE long run and U.S. BSE short run scenarios, production of all farm products and livestock are lower than the base scenario. Meat production in all scenarios is lower than the base scenario except when Canadian beef and cattle is banned and there is no livestock adjustment in the U.S. The reduction in all farm products, livestock and meats is the greatest when there is BSE outbreaks in Canada and the U.S. coupled with a 40% reduction in the U.S. beef demand. In the short run after Canadian BSE, cattle imports from Canada is banned and there is reduction in the production of beef which gives the downward pressure on the total production of all meats in the U.S. Anticipating the lasting ban to Canadian cattle imports, there is adjustment in cattle production. Thus the meat production goes up in the long run scenario. In the two cases of the U.S. BSE outbreak, the production of meats goes down because of the extra supply for beef diverted from exports. The index for meat production shows that meat production falls by the greatest margin among all scenarios when both Canada and the U.S. have BSE outbreaks and beef demand falls by 40%.

The price index for all farm products drops by a small margin in all scenarios. However, the impact of BSE outbreaks on the prices of all livestock is more significant. Livestock price increases in the scenarios of Canadian BSE cases while it decreases in the other four scenarios where there are BSE outbreaks in the U.S., especially in the scenarios where the U.S. beef demand drops by 40%. Livestock price index falls to 69.63, which indicates a dramatic impact related with the consumers' response to major BSE outbreaks in Canada and the U.S.

The meat price index increases in the scenarios of Canadian BSE outbreaks and decrease in the scenarios of the U.S. BSE outbreaks as well as in the scenarios of BSE outbreaks in both Canada and the U.S. Because of the tight cattle supply resulting from the cattle ban to Canadian imports and the short supply of U.S. cattle, it is well expected that meat prices would go up after the imports ban. On the other hand, the meat prices fall after the U.S. BSE outbreaks due to the extra supply of beef that would have exported but has to be absorbed by the domestic market because of import ban imposed by trading partners of the U.S. These indices are 98.05 and 98.46 respectively for the scenarios with and without production adjustment. Meat prices fall by a greater margin in the scenarios when there are BSE outbreaks in Canada and the U.S. coupled with the reduction in the U.S. beef demand, especially when U.S. beef demand drops by 40%.

Imports of all farm products and all livestock imports are lower than the base scenarios. All livestock imports index is much lower in the scenarios of beef demand reduction of 15% and 40% respectively. The index for livestock imports is 81.35 and 57.69 in these two scenarios respectively. Although meat imports changes slightly compared with the base scenario, the magnitude of change is not very significant. With BSE outbreaks in Canada and the U.S., the impact of the trade ban to cattle and beef imports and exports offset each other, which results in minor changes in meat imports.

The export index for all farm products increases slightly in all scenarios. The export indices for meat in the Canadian BSE cases remain the same as the base scenario. However, it is much lower than the base in other scenarios. Meat exports are restricted after BSE outbreaks in the U.S., especially beef and related meat products. This shows the severe impact on U.S. meat exports caused by animal disease outbreaks in the U.S.

5.5.5 Agricultural regional production

The U.S. is divided into 11 large regions in this study. There are no agricultural activities in the Pacific Northwest-west side. The percentage changes in agricultural production of calf and finished beef for the other 10 regions are summarized in Table 12.

There is no change in cow calf and beef production in the Canada BSE short run scenario. In the Canadian BSE long run and U.S. BSE short run scenarios, Lake States and Northeast have the largest change in cow calf production. Cow calf production increases by 17% in Lake States, but reduces by 14% in Northeast. The largest change is found in the scenario where there are BSE outbreaks in Canada and the U.S. coupled with a 40% reduction in the U.S. beef demand. With the long run adjustment, the cow calf production increases by 30% and 2% in Northeast and Southeast respectively. It remains unchanged in Pacific Northwest-east side. However, cow calf production drops from 2% to 18% in all other regions. The biggest decline in cow calf production is in Grain Plains and South Central. With the ban to the U.S. beef exports and the 40% reduction in the U.S. beef demand, the BSE outbreaks in Canada and the U.S. result in the great impact on cow calf production among all scenarios.

Beef production follows the same pattern. The simulation results in the lower panel of Table 12 shows that there is no change in beef production for all regions in the Canadian BSE short run scenario. Except in the last scenario of both Canada and the U.S. BSE coupled with 40% demand reduction, most changes in beef production in all regions are not significant. Beef production in Lake States increases by 17% in the Canadian BSE long run and the U.S. BSE short run scenarios. Beef production in Northeast decreases by 14% in these two scenarios. Like the cow calf production, there are great changes of beef production in most regions in the scenario where there are BSE outbreaks in Canada and the U.S. coupled with a 40% reduction in the U.S. beef demand. In this scenario, beef production increases by 29% and 3% in Northeast and Southeast respectively. It remains unchanged in Pacific Northwest-east side. Beef production falls in all other regions, ranging from 1% to 35%, where the largest decline is in South Central.

Generally speaking, the impact on cow calf and beef production varies across the regions and across the scenarios. But the great impact is found in the scenario of the Canadian and the U.S. BSE long run with 40% beef demand reduction for all regions except Northeast. The production of cow calf and beef increases by 17% in the Canadian short run and the U.S. long run scenarios, while it declines by 12% in the scenario of both Canadian and the U.S. BSE long run with 40% reduction in beef demand. Cow calf and beef production in Pacific Northwest-east side is not affected at all in all scenarios.

5.5.6 All livestock production index

Table 13 presents the results of all livestock production indices. This table summarizes the changes in the production of all livestock in all the regions. It shows that all livestock production is not affected in all regions. Except for the scenario of both Canada and the U.S. BSE long run with 40% reduction in beef demand, all indices are not quite different from the base scenario, with minor increase or decrease in some regions and in some scenarios. In the Canadian BSE long run and the U.S. BSE short run scenarios, all livestock production in Late States increases by 14.5%, while it decreases by about 88%. All livestock production indices increase to 129 in Northeast, 101 in Pacific Southwest and 103 in Southeast. It remains unchanged in Pacific Northwest-east side. Livestock production decreases in all other regions, where the decline is the biggest in South Central.

5.6 Summary

The simulation study shows that the trade disruption from BSE outbreaks in Canada and the U.S. had impacts on the U.S. agriculture. Since Canada and the U.S. are trade partners in meat and many other agricultural commodities, BSE outbreak in either country could bring about the changes of the U.S. prices, quantities and welfares for consumers and producers. However, the impacts from the ban to Canadian cattle imports and from the ban to the U.S. beef exports vary across the scenarios. Without cattle production adjustment in the short run, there would be negative impacts from the ban to

Canadian cattle imports on the consumers. But with adjustment, the negative impacts are smaller in the long run. The U.S. producers gain in these scenarios. However, it is the opposite in the U.S. BSE scenarios. The U.S. consumers gain while producers lose. Generally speaking, the whole society would gain in the scenarios of the U.S. BSE outbreak. This result indicates that, in terms of total social welfare, the U.S. is more vulnerable to the ban to the Canadian cattle imports than to the ban to the U.S. beef exports. In the other two scenarios where there are BSE outbreaks in Canada and the U.S. along with a reduction in the U.S. beef demand, both consumers and producers lose by a large magnitude. When the U.S. beef demand reduces by 40%, the negative impacts on consumer and producer surplus are the greatest, totaling a social welfare loss of $27,530 million. Slaughter beef price and production are also negatively affected. The impact on slaughter beef price and production is also the greatest in the scenario of 40% reduction of the U.S. beef demand. Since Canada is the one of the most important suppliers of cattle to the U.S., and there is a time lag for cattle production adjustment in the short run, it would experience a reduction in slaughter cattle in the short run.

Production, price, imports and exports of all farm products, all livestock and meat change by a larger margin in the scenario of both Canadian and the U.S. BSE outbreaks with a 40% beef demand reduction. All livestock imports and meat exports are much lower than the case without trade disruption and demand shift.

Furthermore, the impacts from the trade disruption induced by Canadian BSE and US BSE outbreaks vary across the regions. However, the great impact is found in the scenario of both Canadian and the U.S. BSE with a 40% beef demand reduction for most regions. Cow calf and beef production changes slightly in other scenarios.

This study can help us identify the regions that are more vulnerable to trade disruption in terms of the producer surplus or consumer surplus. From the Canadian lessons after the BSE outbreak in May 2003, it is necessary to better prepare risk management strategies at the firm level and government level. Government also needs to consider the compensation and insurance mechanism. For future research, incorporating the severity of biosecurity risks and other animal disease outbreaks such as foot-and-mouth disease and avian influenza would provide more information about the impact on the U.S. welfare as well as the livestock and poultry industry.

CHAPTER VI

CONCLUSION

Since the terrorist attack on September 11, 2001, there has been an increasing awareness of and concern over the possible bioterrorism attacks. Terrorism attacks in the form of biosecurity risks pose great threat to the safety of agricultural product and food supply. Many studies have examined the economic issues of biosecurity and food safety risks in terms of economic impacts. However, not a great amount of work has explored how markets are affected by trade disruption associated with biosecurity and food safety incidents. This study contributes information on the market effects of animal disease using data from the 2003 BSE discoveries in both Canada and the U.S. We find that the 2003 events contribute had a definite market effect in the U.S. beef market and altered trade. The U.S. beef prices at farm, wholesale and retail level were found to respond to the outbreak and associated trade events, but per capita beef consumption was not much affected. The uncertainty alteration in farm and wholesale prices was partly explained by the U.S. beef imports from Canada. The U.S. beef prices increased after the Canadian BSE event, but decreased within the three months after the U.S. BSE event. The decomposition of these impacts shows that the associated trade affects were partial drivers. In particular the ban on Canadian beef exports into the U.S. contributed to the subsequent U.S. increase in beef prices after the Canadian BSE event in May 2003. Similarly the restrictions placed on U.S. beef exports after the U.S. event contributed to the subsequent decrease in U.S. beef prices after the U.S. BSE event. The trade disruptions did not greatly affect per capita beef consumption.

This dissertation further simulates the effects of BSE outbreaks on U.S. agricultural markets and welfare by using Agricultural Sector Model (ASM). Six scenarios of trade disruption and demand shift are examined along with a base case where no trade disruption or demand shift is assumed. The impact on social welfare and markets vary across the magnitude of trade disruption and the magnitude of the U.S. beef demand shift. Simulation results show maximum welfare loss occurs with the BSE outbreaks and associated trade in both Canada and the U.S. where the U.S. beef demand reduces by 40%. The impact of trade bans to Canadian cattle imports and the U.S. beef exports also vary across the U.S. regions.

The economic analysis of the impacts of BSE outbreaks and the associated trade disruptions has implications for the U.S. beef industry. Since the U.S. has the largest beef production and consumers market in the world, given the importance in its beef trade, understanding how trade disruption would affect the U.S. beef and cattle industry will benefit the policy makers and the beef business to better regulate and protect the industry from being affected by market fluctuation and trade disruption.

There are some limitations in this study. For the time series study of the U.S. beef market, although a structural break was found across whole sample range, it would be ideal to study the subsamples before and after the break point. But the whole data set was used due to data availability. For the simulation study, if the model could incorporate the severity of the animal disease outbreaks, it would provide more information about the impacts. Furthermore, this study could provide more information if other major disease outbreaks are incorporated such as foot-and-mouth disease and avian influenza. These limitations should be pursued in future research.

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APPENDIX A

TABLES

Table 1. BSE Events in Canada and the U.S. and Consequent Changes in Trade

Time	Country	Event	Trade Changes
5/20/2003	Canada	CFIA announced a BSE case in Alberta.	Other countries including the U.S. imposed Import ban of live cattle, beef and related products from Canada.
8/8/2003	U.S.		The U.S. allowed the imports of boneless meat from cattle younger than 30 months old from Canada.
12/23/2003	U.S.	USDA announced a positive BSE test result from a single cow in Washington State.	Japan, South Korea, Mexico, Canada, Russia, China, Australia, Brazil, and many other countries banned imports of the U.S. cattle and beef products.
3/4/2004	Mexico		Mexico opened its border to the U.S. boneless beef less than 30 months old.
4/18/2004	U.S.		The U.S. lifted the import restrictions on beef products from cattle younger than 30 months old from Canada.
5/4/2004	Canada		Canada allowed the U.S. pet food containing ingredients derived from cattle with certain restrictions.
1/2/2005	Canada	CFIA confirmed a BSE case in an eight year old cow in Alberta.	
1/11/2005	Canada	CFIA confirmed a BSE case in a beef cow under the age of seven in Alberta.	
2/9/2005	U.S.		The U.S. announced its delay in allowing imports from beef less than 30 months old.
6/24/2005	U.S.	USDA confirmed a BSE case in a 12-year-old beef cow born and raised in Texas.	
7/18/2005	U.S.		The U.S. allowed the imports of Canadian live cattle less than 30 months old for immediate slaughter and feeding.

Table 1. Continued.

Time	Country	Event	Trade Changes
1/20/2006	Japan		Japan has suspended import of all beef from the United States.
1/23/2006	Canada	CFIA confirmed a BSE case in a six-year-old in Alberta.	
2/28/2006	Mexico		Mexico allowed the U.S. imports of bone-in beef and bone-in beef products from animals under 30 months old.
3/13/2006	U.S.	USDA confirmed a BSE case in a cow in Alabama.	
3/16/2006	Canada	CFIA confirmed a BSE case in a cow from British Columbia.	
6/29/2006	Canada		Canada reopened its border to all classes of the U.S. cattle.
7/4/2006	Canada	CFIA confirmed a BSE was in a cow from Manitoba.	
7/13/2006	Canada	CFIA confirmed a BSE case in a 50 month-old dairy cow from Alberta.	
7/27/2006	Japan		Japan announced that it would resume accepting U.S. beef from animals 20 months of age or younger.
8/23/2006	Canada	CFIA confirmed a BSE in a mature beef cow from Alberta.	

Table 2. Non-stationarity Tests for the U.S. Beef Prices, Consumption and Supply Series

data series	DF	ADF	PP	ZA a	CLEM b
	level				
farm beef price	-2.35	-1.73	-2.42	-4.39	-3.34
wholesale beef price	-2.19	-1.51	-1.96	-4.56	-2.09
retail beef price	-0.13	-0.24	-0.15	-3.91	-1.00
cattle imports from Canada	-3.88*	-2.28	-3.43*	-4.74	-3.20
beef imports from Canada	-2.45	-1.67	-2.16	-4.75	-4.17*
beef exports	-2.49	-2.27	-2.25	-5.54*	-2.51
beef consumption	-8.67*	-4.08*	-9.18*	-8.99*	-1.96
other cattle supply	-10.45*	-6.31*	-11.23*	-9.20*	-1.81
beef imports from other countries	-10.80*	-4.23*	-11.35*	-8.29*	-1.69
	first difference				
farm beef price	-11.43*	-11.49*	-10.69*	-10.60*	-4.68*
wholesale beef price	-12.33*	-13.41*	-11.74*	-10.48*	-3.57*
retail beef price	-13.22*	-12.39*	-12.86*	-9.46*	-2.10
cattle imports from Canada	-14.90*	-13.36*	-15.35*	-13.48*	-4.95*
beef imports from Canada	-16.10*	-12.99*	-16.37*	-13.07*	-6.78*
beef exports	-18.94*	-13.02*	-19.23*	-19.00*	-13.84*
beef consumption	-32.31*	-11.20*	-38.37*	-10.21*	-8.61*
other cattle supply	-31.27*	-12.07*	-35.56*	-10.01*	-5.79*
beef imports from other countries	-28.25*	-12.80*	-36.66*	-12.14*	-8.62*

The critical values for Dickey-Fuller (DF), Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Zivot-Andrews (ZA), Clemente (CLEM) tests at 5% significance level are -2.89, -2.89, -2.89, -4.80, and -3.56, respectively. The asterisk indicates that the null hypothesis is rejected at the 5% significance level.

[a] For the ZA tests, we only report non-stationary test results assuming there is a possible structural change in the mean. The results are robust if assuming a structural change in trend or in both mean and trend.

[b] For the Clemente tests, we only report non-stationary test results assuming there is one possible structural change. The test results assuming two structural changes are similar.

Table 3. Tests for Optimal Lag Length for VAR Model with Seasonality

lag	Schwarz information Criterion (SIC)	Akaike information criterion (AIC)	Hannan and Quinn (HQ)	Hacker and Hatemin-J (HJ)
0	35.3003	33.4157	34.3235	34.7593
1	24.2893*	20.2414	22.5800*	23.3426*
2	25.1751	19.9638	22.7332	23.8226
3	26.1128	19.7382*	22.9383	24.3546
4	27.4162	19.8782	23.5091	25.2523

The asterisk indicates the smallest SIC, AIC, HQ and HJ.

Table 4. Trace Test on the Order of Cointegration for the Nine Series

rank	without linear trend			with linear trend		
	trace statistics*	critical value*	decision	trace statistics	critical value	decision
r = 0	461.929	208.27	R	457.139	197.22	R
r = 1	303.122	169.41	R	298.396	159.32	R
r = 2	207.324	134.54	R	202.676	125.42	R
r = 3	136.336	103.68	R	132.312	95.51	R
r = 4	77.361	76.81	R	73.633	69.61	R
r = 5	40.813	53.94	F#	37.102	47.71	F

The null hypothesis in this test is that the order of cointegration (i.e. the rank) is less than or equal to *r*. The decision “R” and “F” refer to “reject” and “fail to reject” the null hypothesis respectively. The decision “F#” indicates the first “fail to reject” in this sequential test. Critical values are taken from Jonathan Dennis CATS in RATS manual (Table C2 for critical value* and Table C3 for critical value).

Table 5. Exclusion and Weak Exogeneity Tests for the Nine Series

	Exclusion Test		Weak Exogeneity Test	
data series	Test Statistics	Test Decision	Test Statistics	Test Decision
farm beef price	91.66	Reject	48.68	Reject
wholesale beef price	85.22	Reject	54.38	Reject
retail beef price	63.54	Reject	28.76	Reject
cattle imports from Canada	39.96	Reject	14.13	Reject
beef imports from Canada	40.10	Reject	27.89	Reject
beef exports	45.85	Reject	41.96	Reject
beef consumption	34.15	Reject	104.74	Reject
other cattle supply	17.82	Reject	88.10	Reject
beef imports from other countries	58.37	Reject	62.98	Reject

The critical value is 11.07 at 5% significance level.

Table 6. Interregional Cattle Movement in ASM

calf to grazing				
from ASM region	source city	to ASM region	destination city	distance (miles)
Pacific northwest west				
Pacific northwest east	Burns, OR	Rocky Mountains	Gallup, NM	1016
Pacific Southwest	Visalia, CA	Rocky Mountains	Gallup, NM	738
Rocky Mountains	Alamosa, CO	Southwest	Shamrock, TX	438
Rocky Mountains	Hardin, MT	Great Plains	Dodge City, KS	889
Great Plains	Sturgis, SD	Corn Belt	Houston, MO	989
Southwest	Stephenville, TX	Rocky Mountains	Gallup, NM	730
Lake States				
Corn Belt	Bolivar, MO	Great Plains	Dodge City, KS	391
South Central	Jackson, MS	Southwest	Shamrock, TX	705
Northeast				
Southeast	Sebring, FL	Southwest	Shamrock, TX	1415
calf to feedlots				
from ASM region	source city	to ASM region	destination city	distance (miles)
Pacific northwest west	N/A			
Pacific northwest east	Burns, OR	Rocky Mountains	Greeley, CO	983
Pacific Southwest	Visalia, CA	Rocky Mountains	Florence, AZ	615
Rocky Mountains	Hardin, MT	Great Plains	West Point, NE	812
Rocky Mountains	Alamosa, CO	Southwest	Amarillo, TX	346
Great Plains	Sturgis, SD	Rocky Mountains	Greeley, CO	369
Southwest	Stephenville, TX	Great Plains	Dodge City, KS	458
Lake States	N/A			
Corn Belt	Bolivar, MO	Great Plains	Dodge City, KS	391
South Central	Glasgow, KY	Great Plains	Dodge City, KS	891
Northeast	N/A			
Southeast	Sebring, FL	Southwest	Amarillo, TX	1544
grazing to feedlots				
from ASM region	source city	to ASM region	destination city	distance (miles)
Pacific northwest west	N/A			
Pacific northwest east	Burns, OR	Rocky Mountains	Greeley, CO	983
Pacific Southwest	Bakersfield, CA	Rocky Mountains	Florence, AZ	539
Rocky Mountains	Gallup, NM	Southwest	Amarillo, TX	422
Great Plains	Sturgis, SD	Corn Belt	Orange City, IA	447
Southwest	Shamrock, TX	Rocky Mountains	Dodge City, KS	201
Lake States	N/A			
Corn Belt	Houston, MO	Rocky Mountains	Dodge City, KS	503
South Central	Richmond, KY	Rocky Mountains	Dodge City, KS	937
Northeast	N/A			
Southeast	Kissimmee, FL	Southwest	Amarillo, TX	1496

Table 7. Cattle Movement between Mexico and US, Canada and US

Mexican feeder cattle to US feedlots		
from Mexico	to ASM region	distance (miles)
West-Mexico	Southwest	597.5
West-Mexico	Rocky Mountains	876
West-Mexico	Great Plains	1037.5
West-Mexico	Pacific Southwest	480
East-Mexico	Southwest	476.5
East-Mexico	Rocky Mountains	887
East-Mexico	Great Plains	957.5
East-Mexico	Pacific Southwest	863
Mexican calf to US grazing		
West-Mexico	Southwest	687
West-Mexico	Rocky Mountains	386.5
West-Mexico	Great Plains	1096.5
East-Mexico	Southwest	516
East-Mexico	Rocky Mountains	637
East-Mexico	Great Plains	1227
Canadian feeder cattle to US feedlots		
Canada	Rocky Mountains	487
Canada	Pacific northwest east	409
Canada	Great Plains	636
Canada	Corn Belt	760
Canada	Lake States	90
Canada	Northeast	424

Table 8. ASM Region Definitions

Region	States/Subregions
Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio
Northern Plains	Kansas, Nebraska, North Dakota, South Dakota
Lake States	Michigan, Minnesota, Wisconsin
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
Pacific Northwest-east side	Oregon and Washington, east of the Cascade mountain range
Pacific Northwest-west side	Oregon and Washington, west of the Cascade mountain range
Pacific Southwest	All regions in California
Rocky Mountains	Arizona, Colorado, Idaho, Montana, Eastern Oregon, Nevada, New Mexico, Utah, Eastern Washington, Wyoming
South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Eastern Oklahoma, Tennessee, Eastern Texas (TxEast)
Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
Southwest	Western and Central Oklahoma, All of Texas but the Eastern Part -- Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, TexasTrans Pecos

Source: Adams et al. 2005

Table 9. Welfare Comparison across Scenarios (Base Value and Changes in Million Dollars)

	base	Canada BSE SR	Canada BSE LR	US BSE SR	US BSE LR	Both SR + 15% demand reduction	Both LR + 40% demand reduction
				United States			
US Consumers surplus	1398029	-758.44	-559.89	1710.84	662.95	-6023.08	-22452.82
US Processors surplus	2852.29	-92.21	-12.39	-17.23	122.78	88.85	403.93
US Producers surplus	44455.2	614.56	496.86	-1666.73	-681.6	-4311.11	-5482
Total	1445336	-236.08	-75.41	26.88	104.15	-10245.33	-27530.88
				Rest of the world			
Foreign Consumers	182773.4	-16.3	-2.19	-6626.32	-5879.12	-6589.08	-6536.79
Foreign Producers	14427.27	14.62	-37.51	-203.3	-92.98	-200.35	-643.14
Total	197200.7	-1.67	-39.7	-6829.62	-5972.1	-6789.43	-7179.93

Table 10. National Price and Production for Slaughter Cattle across Scenarios (Base Value and Percentage Change)

		base	Canada BSE SR	Canada BSE LR	US BSE SR	US BSE LR	Both SR + 15% demand reduction	Both LR + 40% demand reduction
price	$/Unit	76.14	2.00%	2.00%	-7.80%	-3.10%	-17.10%	-25.90%
production	Million Units	334.97	-0.10%	-0.20%	-0.20%	-1.50%	-1.50%	-15.60%

Table 11. National Production, Price, Import and Export Index

	base	Canada BSE SR	Canada BSE LR	US BSE SR	US BSE LR	Both SR + 15% demand reduction	Both LR + 40% demand reduction
				Production			
All Farm Products	100	99.97	100.06	100.1	99.61	97.92	96.73
All Livestock	100	99.95	100.09	100.16	99.39	97.79	94.93
Meat	100	99.78	100.1	99.92	99.43	99.04	93.35
				Price			
All Farm Products	100	99.86	99.86	99.88	99.88	99.86	99.15
All Livestock	100	103.81	102.36	87.96	95.6	93.43	69.63
Meat	100	100.61	100.37	98.05	98.46	94.86	92.47
				Import			
All Farm Products	100	94.69	93.52	89.33	96.59	85.89	69.48
All Livestock	100	93.08	91.54	85.76	95.49	81.35	57.69
Meat	100	101.65	100.95	100.72	99.65	100.67	99.35
				Export			
All Farm Products	100	100.06	100.03	100.03	100.07	100.06	101.01
Meat	100	100	100	66.21	69.88	68.28	69.97

Table 12. Agricultural Regional Production

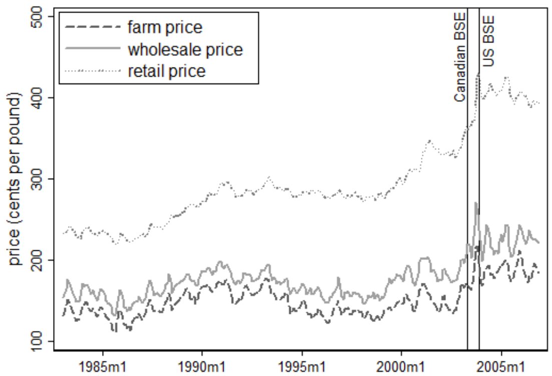
	Canada BSE SR	Canada BSE LR	US BSE SR	US BSE LR	Both SR + 15% demand reduction	Both LR + 40% demand reduction
	Percentage Change in Cow calf Production					
Corn Belt	0%	0%	0%	0%	0%	-7%
Great Plains	0%	1%	1%	-1%	-1%	-18%
Lake States	0%	17%	17%	-3%	-3%	-12%
Northeast	0%	-14%	-14%	5%	5%	30%
Rocky Mountains	0%	2%	2%	0%	0%	-2%
Pacific Southwest	0%	0%	0%	1%	1%	-9%
Pacific Northwest east side	0%	0%	0%	0%	0%	0%
South Central	0%	0%	0%	-1%	-1%	-18%
Southeast	0%	1%	1%	0%	0%	2%
South West	0%	0%	0%	-1%	-1%	-15%
Total	0%	1%	1%	-1%	-1%	-11%
	Percentage Change in Finished Beef Production					
Corn Belt	0%	0%	0%	0%	0%	-6%
Great Plains	0%	0%	0%	-4%	-4%	-25%
Lake States	0%	17%	17%	-3%	-3%	-12%
Northeast	0%	-14%	-14%	5%	5%	29%
Rocky Mountains	0%	-1%	-1%	0%	0%	-1%
Pacific Southwest	0%	-1%	-1%	3%	3%	-30%
Pacific Northwest east side	0%	0%	0%	0%	0%	0%
South Central	0%	0%	0%	-8%	-8%	-35%
Southeast	0%	1%	1%	0%	0%	3%
South West	0%	0%	0%	1%	1%	-13%
Total	0%	0%	0%	-1%	-1%	-16%

Table 13. Regional Livestock Production Index

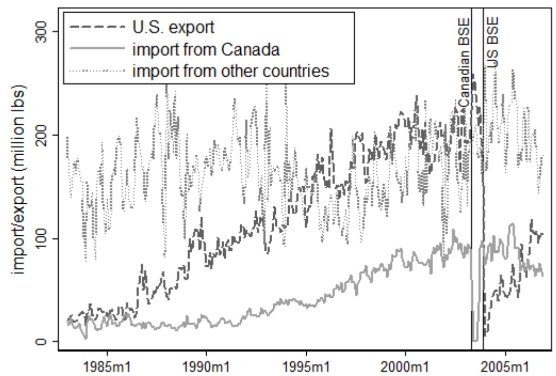
	base	Canada BSE SR	Canada BSE LR	US BSE SR	US BSE LR	Both SR + 15% demand reduction	Both LR + 40% demand reduction
Corn Belt	100	100	100	100	100	100	96
Great Plains	100	100	99	99	99	100	98
Lake States	100	100	114	115	98	98	90
Northeast	100	100	89	87	105	105	129
Rocky Mountains	100	100	100	100	100	100	88
Pacific Southwest	100	100	100	100	99	99	101
Pacific Northwest east side	100	100	100	100	100	100	100
South Central	100	100	100	100	99	99	74
Southeast	100	100	101	101	100	100	103
South West	100	100	100	100	99	99	95

APPENDIX B

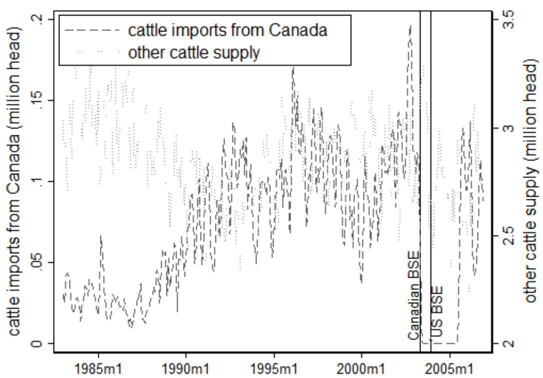
FIGURES



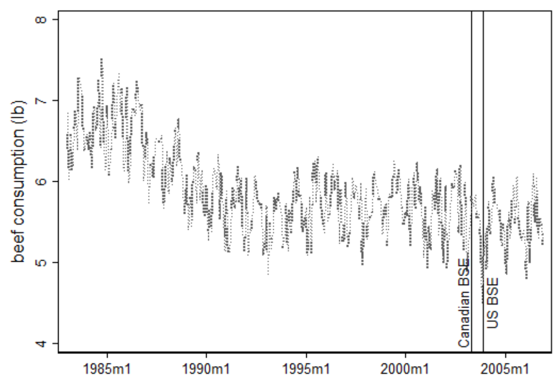
(a) Beef prices



(b) Beef imports and exports

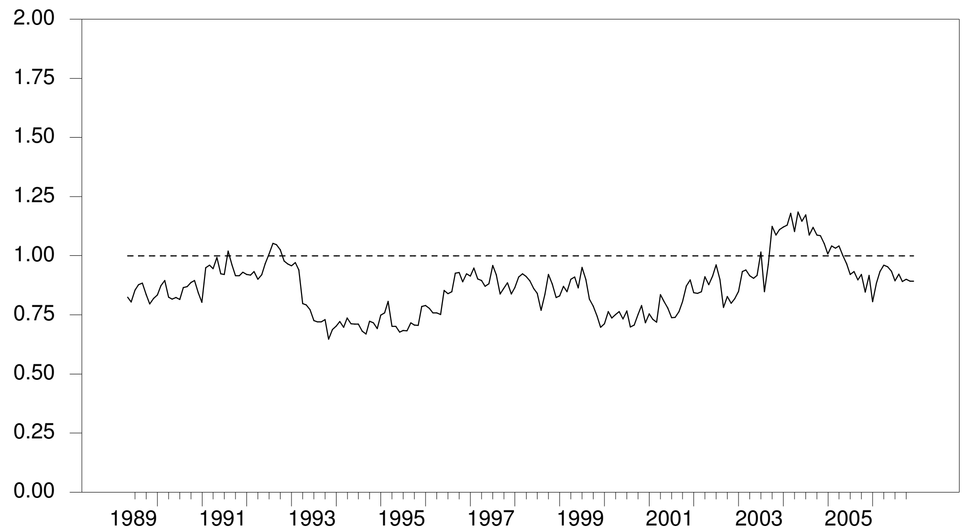


(c) Cattle supplies

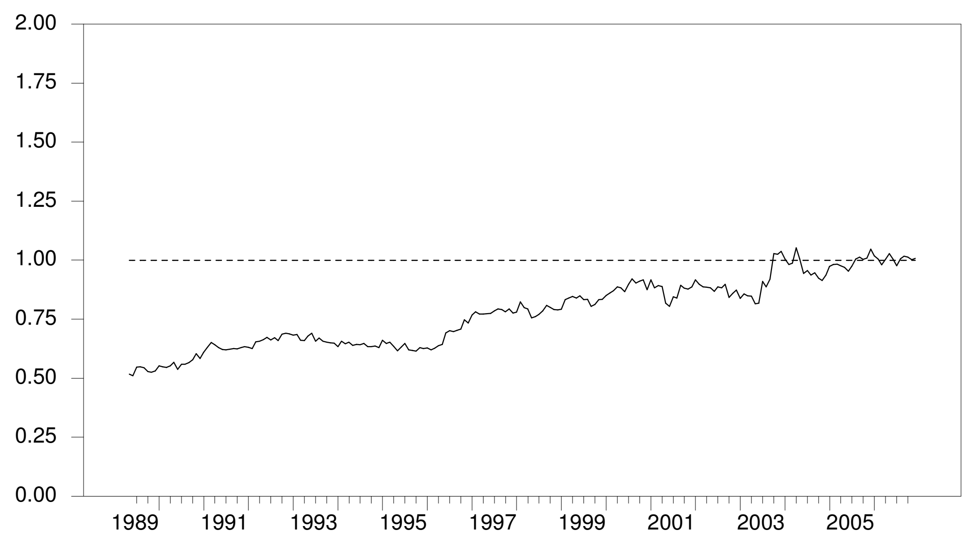


(d) Per capita beef consumption

Figure 1. Time series plots of the nine series between January 1983 and December 2006 (Solid vertical lines represent the 2003 Canadian and U.S. BSE cases)



(a) Rolling test for the null hypothesis of at least four cointegration vectors



(b) Recursive test for the null hypothesis of at least four cointegration vectors

Figure 2. Structural break tests on the nine series based on five cointegration vectors

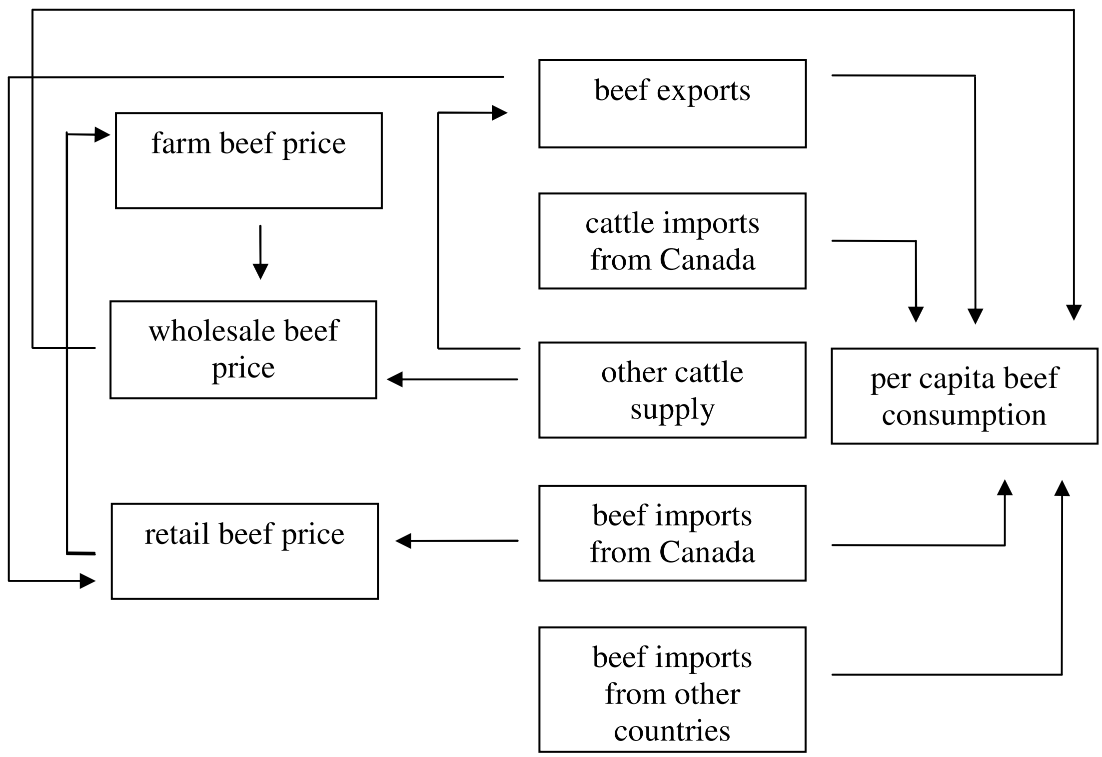
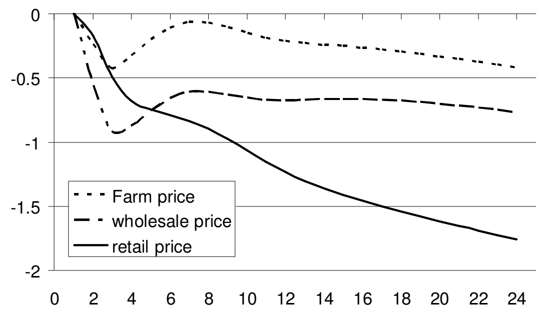
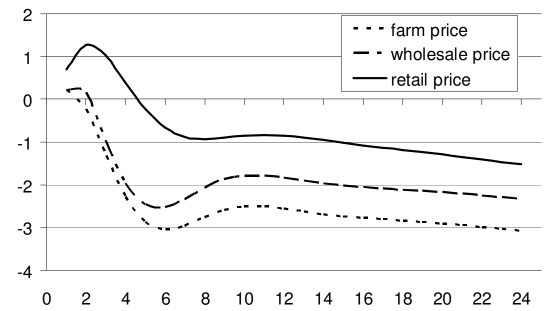


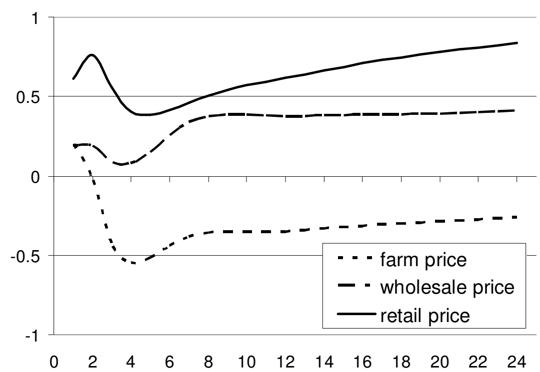
Figure 3. Contemporaneous causalities



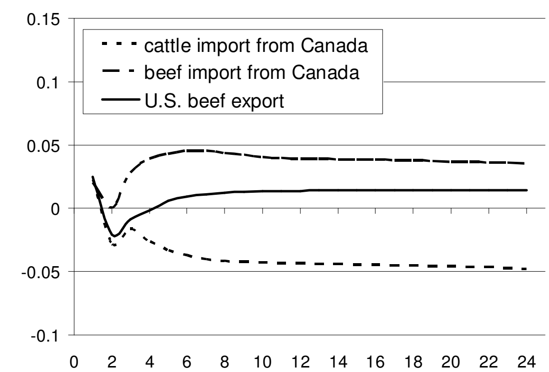
(a) beef prices responding to Canadian cattle imports



(b) beef prices responding to Canadian beef imports

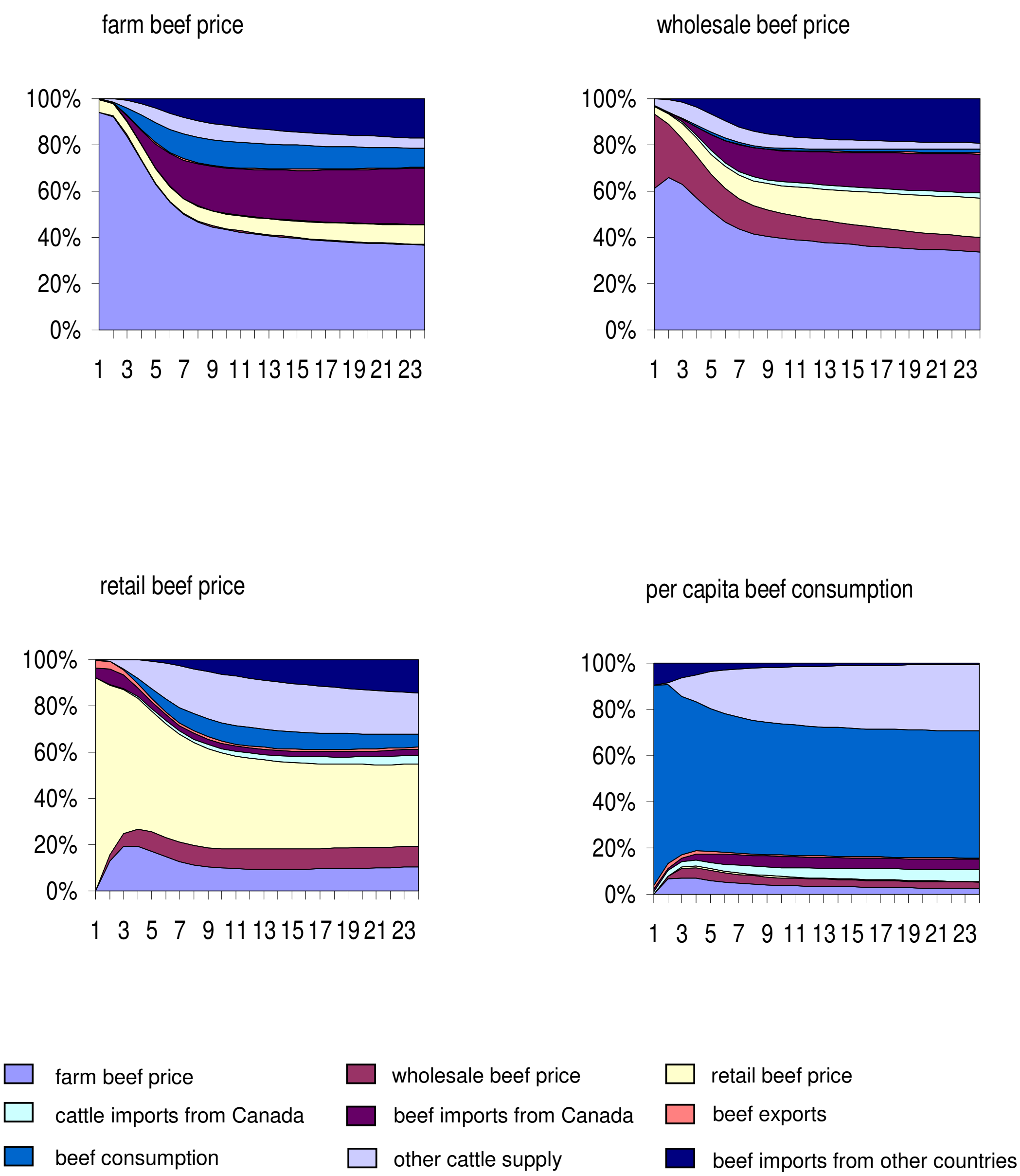


(c) beef prices responding to U.S. beef export



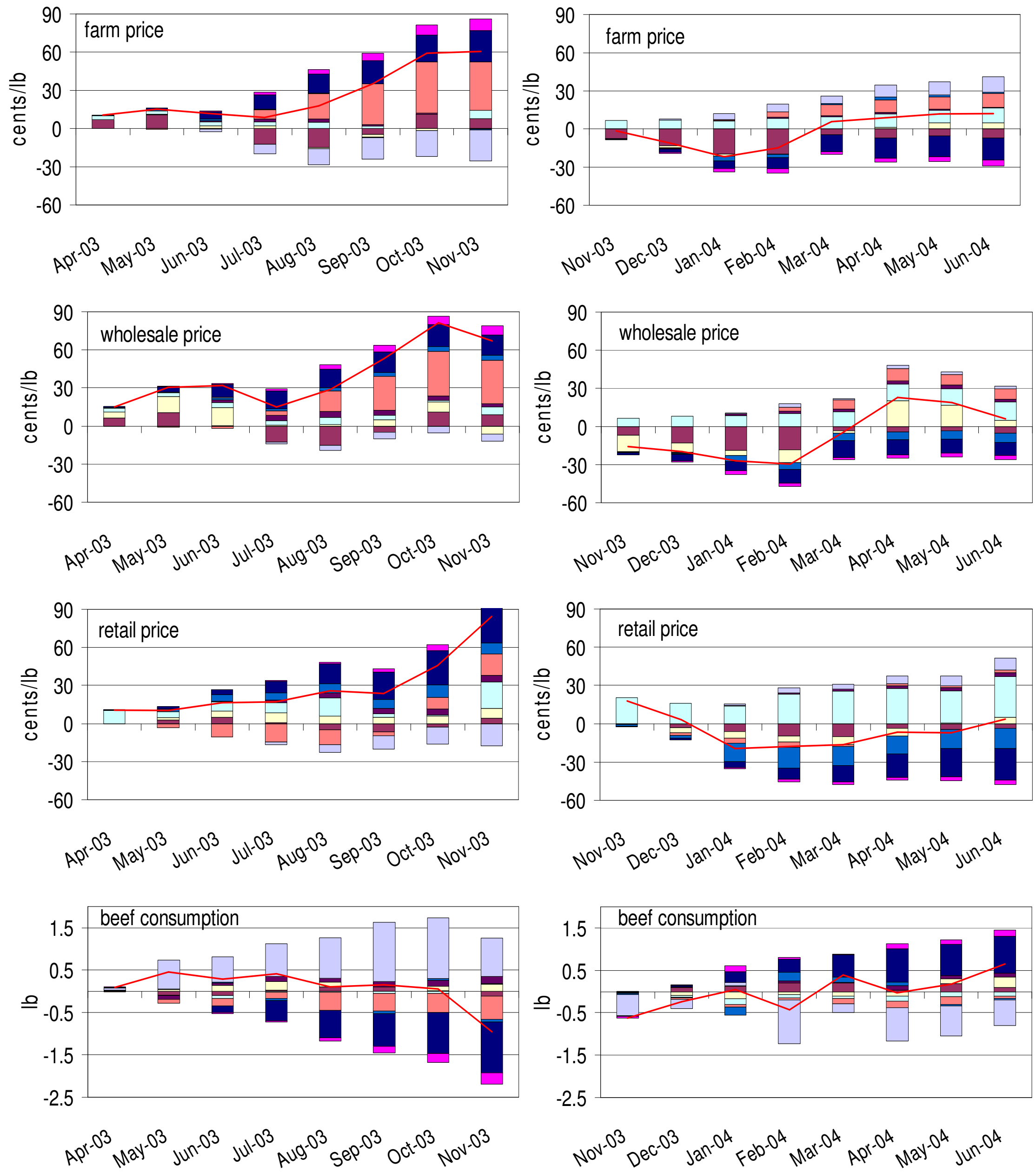
(d) beef consumption responding to trade variables

Figure 4. Impulse responses of the U.S. beef prices and consumption to a one-time-only shock in the innovations in the cattle and beef trade variables (The number on the x-axis represents the number of months since the initial shock, the y-axis is the response in standard deviation.)



Note: The x-axis is the forecast time horizon. The y-axis represents the percentage of the variance explained by each variable.

Figure 5. Forecast error variance decomposition of beef prices and per capita beef consumption



(a) responding to the Canadian BSE case (b) responding to the U.S. BSE case

farm beef price	cattle imports from Canada	other cattle supplies
wholesale beef price	beef imports from Canada	beef exports
retail beef price	other beef imports	beef consumption

Figure 6. Contribution of each series to the difference between the forecasted and actual series represented by the solid line when responding to the 2003 Canadian and U.S. BSE discoveries

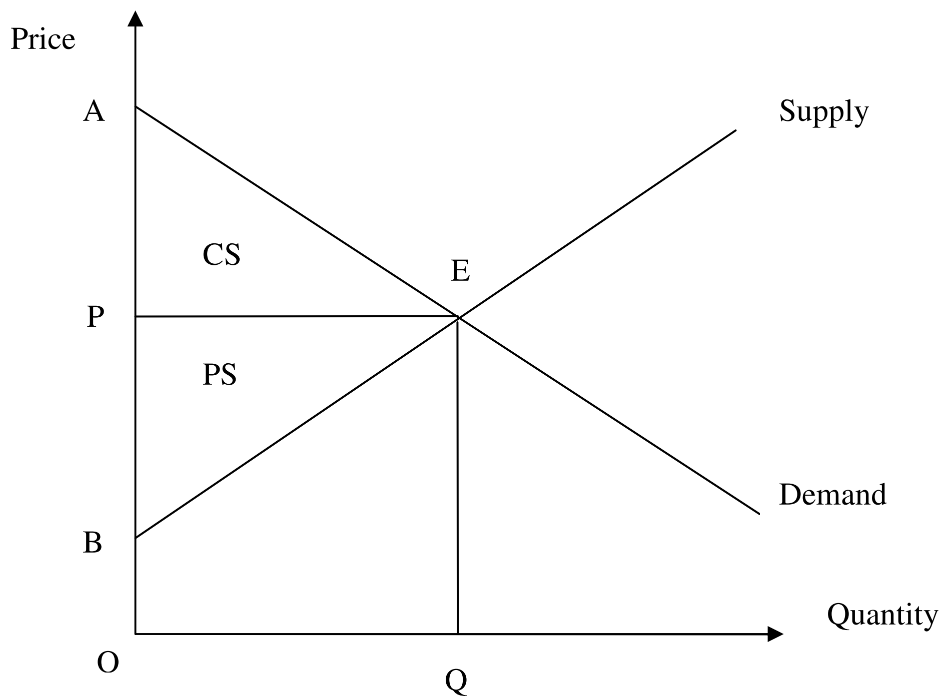


Figure 7. Welfare representation

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