ESSAYS ON MODELING THE ECONOMIC IMPACTS OF A FOREIGN ANIMAL DISEASE ON THE UNITED STATES AGRICULTURAL SECTOR

A Dissertation

by

AMY DEANN HAGERMAN

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

December 2009

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	Bruce A. McCarl
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	Yanhong Jin
	Bo Norby
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ABSTRACT

Essays on Modeling the Economic Impacts of a Foreign Animal Disease on the United States Agricultural Sector. (December 2009)
Amy DeAnn Hagerman, B.S., Oklahoma State University;
M.S., Texas A&M University
Chair of Advisory Committee: Dr. Bruce A. McCarl

Foreign animal disease can cause serious damage to the United States (US) agricultural sector and foot-and-mouth disease (FMD), in particular, poses a serious threat. FMD causes death and reduced fecundity in infected animals, as well as significant economic consequences. FMD damages can likely be reduced through implementing pre-planned response strategies. Empirical studies have evaluated the economic consequences of alternative strategies, but typically employ simplified models. This dissertation seeks to improve US preparedness for avoiding and/or responding to an animal disease outbreak by addressing three issues related to strategy assessment in the context of FMD: integrated multi region economic and epidemic evaluation, inclusion of risk, and information uncertainty.

An integrated economic/epidemic evaluation is done to examine the impact of various control strategies. This is done by combining a stochastic, spatial FMD simulation model with a national level, regionally disaggregated agricultural sector mathematical programming economic model. In the analysis, strategies are examined in the context of California's dairy industry. Alternative vaccination, disease detection and movement restriction strategies are considered as are trade restrictions. The results reported include epidemic impacts, national economic impacts, prices, regional producer impacts, and disease control costs under the alternative strategies. Results suggest that, including trade restrictions, the median national loss from the disease outbreak is as much as $17 billion when feed can enter the movement restriction zone. Early detection reduces the median loss and the standard deviation of losses. Vaccination does not reduce the median disease loss, but does have a smaller standard deviation of loss which would indicate it is a risk reducing strategy.

Risk in foreign animal disease outbreaks is present from several sources; however, studies comparing alternative control strategies assume risk neutrality. In reality, there will be a desire to minimize the national loss as well as minimize the chance of an extreme outcome from the disease (i.e. risk aversion). We perform analysis on FMD control strategies using breakeven risk aversion coefficients in the context of an outbreak in the Texas High Plains. Results suggest that vaccination while not reducing average losses is a risk reducing strategy.

Another issue related to risk and uncertainty is the response of consumers and domestic markets to the presence of FMD. Using a highly publicized possible FMD outbreak in Kansas that did not turn out to be true, we examine the role of information uncertainty in futures market response. Results suggest that livestock futures markets respond to adverse information even when that information is untrue. Furthermore, the existence of herding behavior and potential for momentum trading exaggerate the impact of information uncertainty related to animal disease.

DEDICATION

For my husband: my rock and the keeper of my sanity

For my unborn child: my reason to hope for a brighter future

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I would like to thank my committee chair, Dr. Bruce McCarl, for the opportunities he has provided me and for his guidance through the past two and a half years. I have grown as a researcher and as a person under his mentorship and hope I can earn the right someday to be called his peer. I would also like the thank Dr. Yanhong Jin for her encouragement and advice throughout this journey; Dr. David Bessler for providing thoughtful and insightful guidance as to what it means to be a true researcher through both my Masters and Doctoral programs; and Dr. Bo Norby for being a voice of practical knowledge and encouragement during my crash course in epidemiology. Thanks also to Vicki Heard and Dee Cochran who have both helped me through the jungle of paperwork required to get to this point. Finally, my thanks go out to all of the other professors and support staff in our Agricultural Economics Department who have made my entire graduate experience excellent. I have truly felt a part of the departmental family.

Thanks also to the Department of Homeland Security funded National Center for Foreign Animal and Zoonotic Disease Defense at Texas A&M, for support both financially and personally. Specifically I would like to thank Gary Snowder and Neville Clark for their support of my research efforts and the opportunity to present this research to a diverse audience.

I would also like to thank the following individuals: Tim Carpenter and Josh O'Brien from UC Davis for the use of the Davis Animal Disease Spread Model and explaining its operation to me. Michael Ward of the University of Sydney and Linda Highfield for the use of the AusSpread model and repeatedly explaining basic principles of epidemiology. Monica Galli, with whom I first began exploring the issues of movement restriction impacts on dairies. Johnny Lin, who has been my co-author on the integration of risk attitude in economic analysis and Bart Fischer, who provided an experienced editing eye during my writing process.

NOMENCLATURE

FAD	Foreign animal disease
FMD	Foot-and-mouth disease
GSD	Generalized stochastic dominance
BRAC	Breakeven risk aversion coefficient
OIE	World Organization for Animal Health
FAO	Food and Agriculture Organization
WAHID	World Animal Health Information Database
IP	Infection Point

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1. INTRODUCTION

Historically the vast majority of recommendations regarding the management of animal disease have been based primarily on analyses with epidemic simulation models that minimize the time to control disease outbreaks. After the 2001 United Kingdom (UK) FMD outbreak, such modeling was termed “armchair epidemiology” and was strongly criticized (Kitching, Thrusfield and Taylor). This criticism stemmed from a post outbreak appraisal of the policy recommendations made and implemented during the outbreak (contiguous herd slaughter plus slaughter of infected and dangerous contact herds) that judged those approaches to have caused excessive, unnecessary long term damage to the livestock industry. Cited evidence includes findings that the UK exhibited a declining trend in animal agriculture following the outbreak (Bai et al.) with some producers choosing to scale down or discontinue operations (Bennet et al.). Similarly, the extensive vaccination and slaughter from the policy implemented during the Netherlands’ 2001 FMD outbreak resulted in ex post criticism by livestock industry participants who felt the amount of slaughter was not justified (Pluimers et al.).

The cost of animal disease impacts is generally broader than would arise under a simple accounting of the number of dead animals or an examination of just the length of the outbreak. Such costs include the cost of lost animals and the direct costs of disease management along with the national welfare losses, short and long term trade losses, environmental consequences, consumer demand shifts and local impacts. Epidemic model driven strategy selection based on quickly eradicating the disease may not minimize total economic impact in either the short or long run. Neither can economics be the sole criteria; rather an integrated economic/epidemic model is likely to better support the implementation and evaluation of disease control strategies.

This dissertation follows the style of the *Journal of Agricultural and Applied Economics.*

Ideally, a disease control evaluation system would be dynamic and spatial in nature (Rich and Winter-Nelson) taking into account both the time it takes to control the disease and the full economic implications of the control strategies chosen. Control strategy efficacy can be measured in terms of the lost animals, disease management, national welfare costs, short and long term trade losses, environmental consequences, consumer demand shifts and local impacts. The evaluations should consider not only average affects but also the distribution of effects. The economic portion of the analysis can capture some or all of these loss categories and integrate them into a set of measures to quantify the distribution of outcomes from an animal disease outbreak in a particular region. The reason economic models have not been more extensively used in the past is the difficulty in developing a model that can quantify those impacts that extend beyond the primary livestock markets and the more firm level and epidemic orientation of many of the studies (Rich and Winter-Nelson).

1.1. Dissertation Objectives and Procedures

The ultimate objective of this work is to improve the preparedness of the US for avoiding and/or dealing with animal disease outbreaks. This will be done in the case of FMD a disease that has not been found in the U.S. since 1929, but could occur as exhibited by recent outbreaks in other parts of the world plus increased transmission likelihood as influenced by increased international commerce and tourism along with terrorism possibilities. More operationally this work:

- Assesses the economic and epidemic consequences of select FMD related strategies and in the process
    - develops a deterministic, integrated economic/epidemic model approach that can be used in this and future assessments because it captures economic impacts more fully across the US agricultural sector by including the inter-relationships among markets

  - extends the framework into a risk setting to improve understanding of how risk and uncertainty impact FMD response policies and livestock markets.

- Examines the way that information release can influence livestock markets.

This provides a contribution to the economic/epidemic literature by assessing impacts in vertically and horizontally linked markets considering effects on consumers and producers, in both domestic and international markets. It also provides an approach to examining the role of risk and uncertainty in formulating policy for control strategy selection ex ante using the breakeven risk aversion coefficient concept. Finally a contribution is made by exploring the role of information uncertainty factors into futures market response.

In order to meet the objective, this dissertation will:

- conceptualize a linked economic/epidemic model plus develop an overall analysis framework that evaluates vulnerability and response strategies in terms of welfare, market and risk consequences.
- implement that framework in the context of the concentrated beef feeding region located in the High Plain of Texas and in the large dairy production region located in the Central Valley of California.
- evaluate ex post disease management strategies regarding vaccination, surveillance and detection, and quarantine zones in both a risk averse and a risk neutral setting
- examine the market consequences of information uncertainty about disease in the U.S. within the context of an FMD scare in Holton, Kansas in 2002.

1.2. Plan of Dissertation

This dissertation consists of five essays in addition to introductory and conclusions sections:

- Section 2 contains the first essay that sets the stage for the dissertation by providing an overview of FMD as an economic damage causing disease, the threat to US livestock industries and what the likely response strategy in the US will be.

- Section 3 contains essay 2, which develops and explains the modeling done in the study by first reviewing the literature on integrated epidemic-economic modeling in general and the economic justification for various model choices, then explains the modeling methodology used in the assessments in essays 3 and 4, and covers the methodology for linking the epidemic and economic models. The code related to the model conceptualized in this essay is provided in the appendix.

- Section 4 contains the third essay that presents an application of the model framework discussed in essay 2 and the appendix, using the economic/epidemic analysis of control to examine several standard disease mitigation strategies like detection, slaughter, vaccination and movement restrictions. Impacts will be estimated at the local affected region level and at the national aggregate level. Specifically we use a framework integrating the Davis Animal Disease Simulation (DADS) Model for the epidemic modeling and the Forestry and Agricultural Sector Optimization Model (FASOM) for the economic modeling. These models are used to examine the impacts of an FMD outbreak in the dairy producing areas of California, and discuss briefly the value of using a national level sectoral model over input-output or cost benefit analysis.

- Section 5 contains the fourth essay that risk attitude on the part of policy makers would influence control strategy selection in the context of an FMD outbreak in the Texas High Plains. In particular alternative intensities of control strategies (i.e. enhanced versus regular surveillance of suspect premises during the outbreak) are examined. This marks one of the first study to provide economic rankings of strategies that include risk attitude, which would be expected to be a key component when faced with a large scale animal disease outbreak.

- Section 6 contains the fifth and last essay that explores another facet of the challenges the country would face in the event of an FMD outbreak. In particular, that essay examines market distortions under information uncertainty looking at whether herding behavior and momentum trading may cause mispricing when information about disease testing is uncertain. Specifically investigating whether mispricing occurred as a result of the March 12, 2002 FMD test scare and the duration of the distortion.
- Section 7 contains a general summary and conclusions.

2. ESSAY 1: OVERVIEW OF FMD ISSUE AND ECONOMICS

The FMD virus is considered to be one of the greatest foreign animal disease threats US livestock producers face (USDA-APHIS, 2007b). FMD in animals is highly contagious, hardy in various climates and can be carried on almost any surface (Musser). Currently the US is FMD free, but the threat of this disease has made it a top priority in the nation's bio-security plan[1].

Although FMD can cause animal deaths, the danger from FMD is not due to the mortality rate the disease imposes but rather from the economic consequences. Most adult animals survive infection and the young animal death rate is approximately 50% (USDA-APHIS, 2007b). Adults often recover in 2-3 weeks. Death rates are higher in very young animals, animals with compromised immune systems, and newborns. Its primary natural threat is in reduced meat and milk productivity (James and Rushton). However, FMD results in almost a 100% morbidity rate (Musser). Its contagiousness and hardiness have led to a policy of strict trade regulations against a country where the disease is present. Thus, FMD has been labeled an "economic disease" because the motivation for its eradication comes from trade and economic reasons rather than the threat posed to livestock or human beings (Anthony; James and Rushton).

This essay sets the stage for the FMD analysis showing the danger presented by FMD through both its impact in other parts of the world and the potential damage it could cause in the US. First, an illustration of FMD's threat as an economic disease using the 2001 UK FMD outbreak as an example is presented. Then an overview of the disease

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[1] Bio-security is "the series of management steps taken to prevent the introduction of infectious agents into a herd or flock" (Hutchinson et al., pg. 1). Often the process of bio-containment is included in this term. Bio-containment is the set of management practices used to prevent the spread of infectious disease once it has entered the herd. When an infectious agent is purposefully spread to cause damage to a group or country, it is termed bio or agro-terrorism.

itself, its historical presence in the US, and its potential threat to US agriculture today will be discussed. Finally the control strategies prescribed under current US policy will be described as well as alternative strategies that could be used in the event of an outbreak.

2.1. FMD as an Economic Disease: The 2001 UK Outbreak

To illustrate the economic dangers of an FMD outbreak, we consider the 2001 FMD disease outbreak in the United Kingdom, which resulted in the destruction of over 6 million animals. Only 20% of slaughter was due to slaughter of animals with the actual infection. Welfare slaughter (animals killed because of feed or space limits) accounted for about 35% (2 million animals) of the total, and the rest (45%) were slaughtered for dangerous contact or other disease control purposes (Anderson, 2002; NAO). In addition, a little over 500,000 young sheep were slaughtered under the Light Lamb Scheme (Thompson et al.). The Light Lamb Scheme slaughtered very young animals soon after birth as a disease preventative. Figure 1 provides a breakdown of the number of animals destroyed to control the disease.

The event was also costly. Total direct costs to the public sector as estimated by the U.K. Cabinet Office were £3 billion (British pounds) or almost $5 billion (US dollars using 2009 exchange rate). Compensation paid out to farmers and ranchers for their lost livestock totaled £1.4 billion ($2.3 billion) and payments to contractors providing goods and services used in eradication of the disease totaled £1.3 billion ($2.14 billion). At the height of the outbreak in mid-April 10,000 personnel including veterinarians, soldiers and support staff were employed in the effort and 100,000 animals were being slaughtered per day (Anderson, 2002).

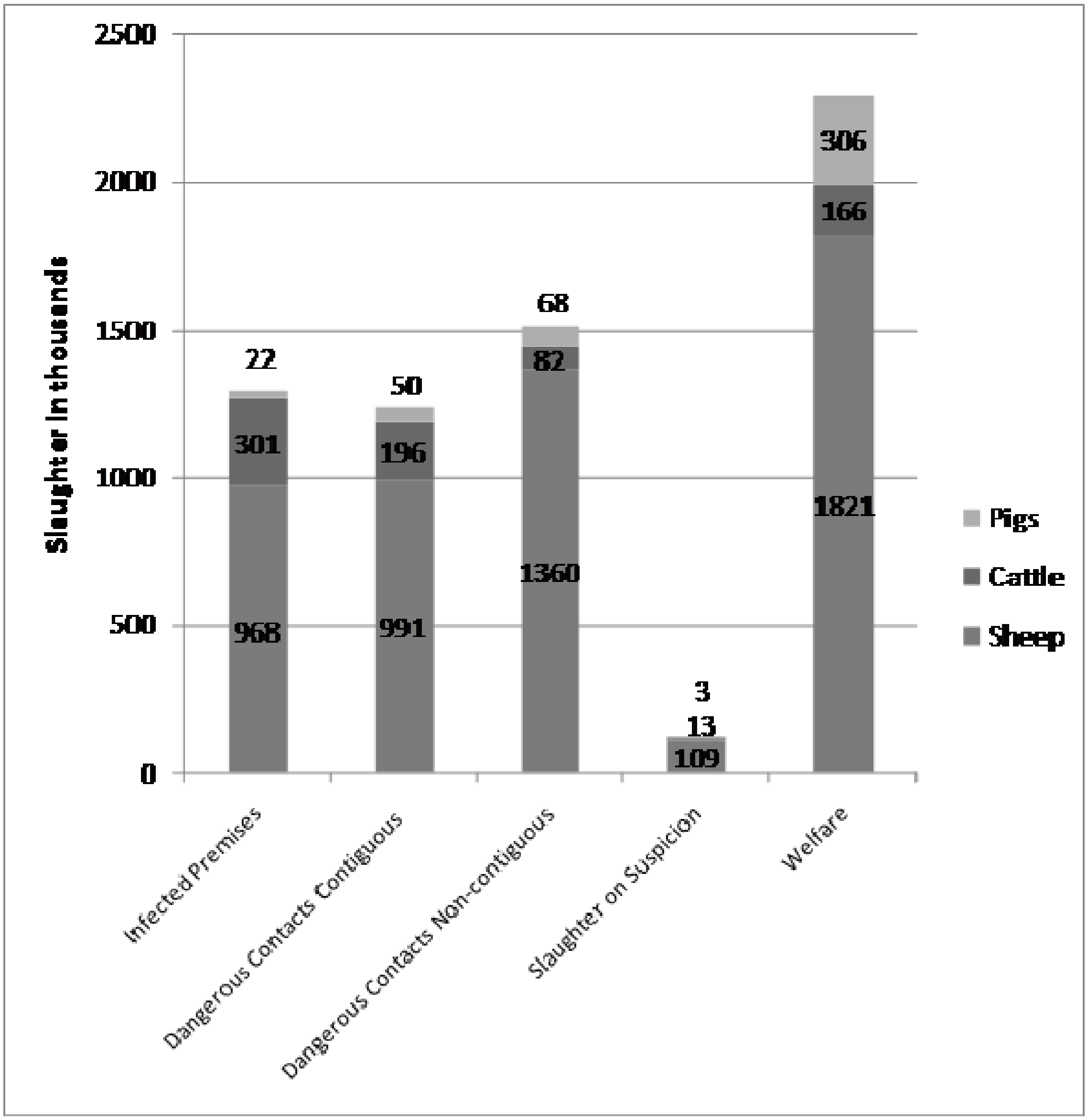

Figure 1. Slaughter of Animals in the 2001 UK FMD Outbreak by Purpose and Species (Anderson, 2002)[2]

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[2] Tables and figures are original unless a source is cited directly in the title.

The losses were found to extend well beyond the animals slaughtered and direct costs. During the outbreak, which lasted from February 20 to September 30, borders remained closed to exports of live animals and animal products. Such trade barriers would be expected to cause significant losses to society, harm commercial trade, and hamper competition (Evans) both in the short and long run. In the time frame from 2000 to 2003, cattle and sheep exports from the UK were reduced by 72%, meat and processed meat exports were reduced by 45%. If the 1999 BSE trade losses still in place as of 2001 are also taken into account, the trade loss was estimated to increase to 92% from a “no ban” baseline (Phillipidis and Hubbard). It is estimated that trade markets in the UK will not recover until 2020 at least (Philippidis and Hubbard), perhaps longer after the 2007 outbreak.

In terms of secondary losses, the government estimates £4.5 to £5.4 billion ($7.4 to $8.9 billion) were lost in tourism. Visitors were deterred by the blanket closures of footpaths and the media images of pyres used in mass carcass incineration (NAO). Figure 2 illustrates the tourism losses during the outbreak period. From 2000 to 2001, March shows an increase but this may be because the height of the outbreak occurred in April. Tourism turned out to be the largest loss category of the entire disease outbreak (NAO).

The UK was not the only country that experienced an FMD outbreak in 2001, but may be the best documented. The world community saw many previously FMD-free countries become contaminated in 2001. Figure 3 shows a map of the countries (darker areas) that reported a 2001 FMD outbreak to the World Organization for Animal Health (OIE), FAO or the World Reference Laboratory.

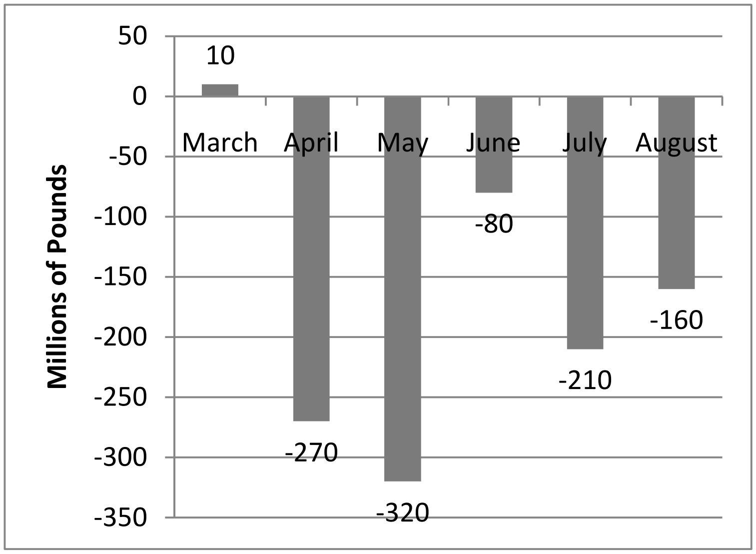


Figure 2. Change in Tourism in the UK from 2000 to 2001 (NAO)

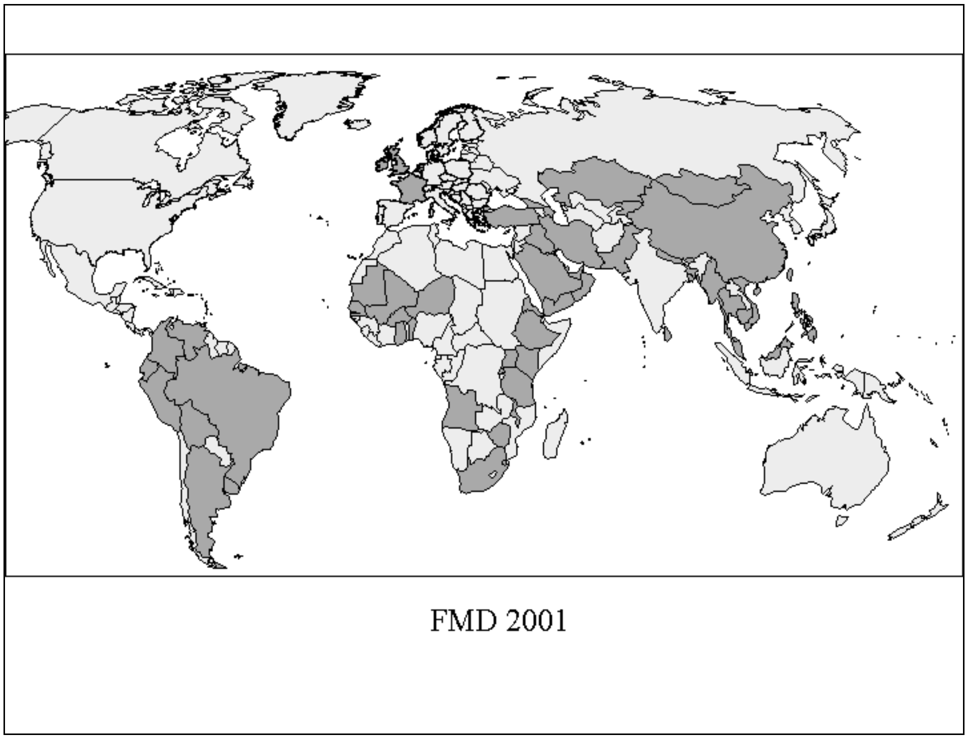


Figure 3. FMD Events Reported in 2001 (WAHID)

Clearly there is valid concern over the consequences of FMD coming to the United States. In particular, given the current state of preparedness for such an event—or lack thereof—concerns have been raised over the country’s ability to quickly and effectively control an FMD outbreak. In the UK example, a post-event analysis revealed the country's lack of preparation led to both higher monetary costs and larger animal losses than anticipated (Anderson, 2002). With pre-planning for such a disaster, the infrastructure would support a more rapid, effective response. The U.K. FMD outbreak in 2007 was less severe because there was a plan in place and consequently response was swift with the outbreak was rapidly controlled; however, severe and long lasting damage has been done to the country’s animal agriculture sector (Anderson, 2008).

2.2. Background on FMD

Any even-toed, split-foot ungulate is susceptible to FMD—including cattle, sheep, swine, bison, goats, deer and elk. There are 7 serotypes of FMD and more than 60 sub-serotypes (USDA-APHIS, 2007a). Once an animal is infected, the virus can be spread through any secretion, excretion, or tissue including the animal's breath, milk, semen, saliva, urine, feces and blood. Animals shed the disease for days or weeks after initial infection. It is transmitted primarily via inhalation or the ingestion of materials containing the virus. It can also be spread via contaminated organic and inorganic materials such as trucks, cloths, hay or people (Ekboir). Finally, under certain conditions, the disease can be spread through wind. Wildlife can also contribute to disease spread.

The primary mode of FMD entry into a disease free country is through the import and subsequent use in feeding of materials contaminated with the virus or the import of live animals (Musser). Swine can excrete large amounts of the virus but are not highly susceptible. In the U.S., swine operations are largely centralized, making containment and tracing easier. Sheep, goats and exotics make up only a small portion of the overall livestock sector, so their primary threat is as carriers of the disease. Cattle populations are largely de-centralized and highly susceptible to the disease. Animal movements are large and complex making tracing difficult. Also wild deer, feral hogs and other susceptible wildlife populations are particularly effective as carriers since FMD could go undetected for long periods of time and these animals range over large areas, often grazing with susceptible domesticated herds. In 2001 FMD outbreaks in Africa, the African Buffalo played a pivotal role in the spread of the disease (Bengis, Kock and Fischer).

FMD has an incubation period of 1 to 8 days (3 days on average), after which clinical signs of the disease will present themselves. Signs include blisters on the mouth and feet, lameness, and excess salivation (USDA-APHIS, 2007a). These signs can be quite subtle. In the 1997 Taiwanese outbreak, FMD was found only in hogs, whereas the 2000 Taiwanese outbreak included cattle and goats (Musser). The goats did not have lesions in the mouth but the cattle did (Musser). In the 2001 U.K. outbreak, sheep showed very few signs of the disease but were the primary method of transmission and the largest category of slaughter (Anderson, 2002). In addition, the blisters, lameness and excess salivation could indicate a more benign problem; for example, burrs or mold in feed could cause similar symptoms (Cattle Buyers Weekly, 2002a). Only lab tests can identify the true cause. Even if farmers see clinical signs of the virus, it is possible they will not run the appropriate tests in a timely manner, either because they do not recognize the danger or because they do not wish to be the epicenter of an FMD outbreak.

In summary, FMD can spread over large distances fairly quickly. It takes only a small amount exposure for infection to occur, and the incubation period is relatively short. Detection is difficult, and the infected animal can become contagious before visible signs of infection (Ekboir). For these reasons, FMD is very dangerous and costly.

2.2.1. <u>Disease Spread</u>

A vulnerable animal could go through six possible states: susceptible, latently infected, sub-clinically infectious, clinically infectious, immune (either naturally or through vaccination) or dead. An animal does not have to move through all states, but every animal begins in the susceptible state. Most epidemic models are built based on simulating the movement of animals through states and for this reason are called "state transition models". Figure 4 provides a flow of the disease states (adapted from Bates, Thurmond and Carpenter).

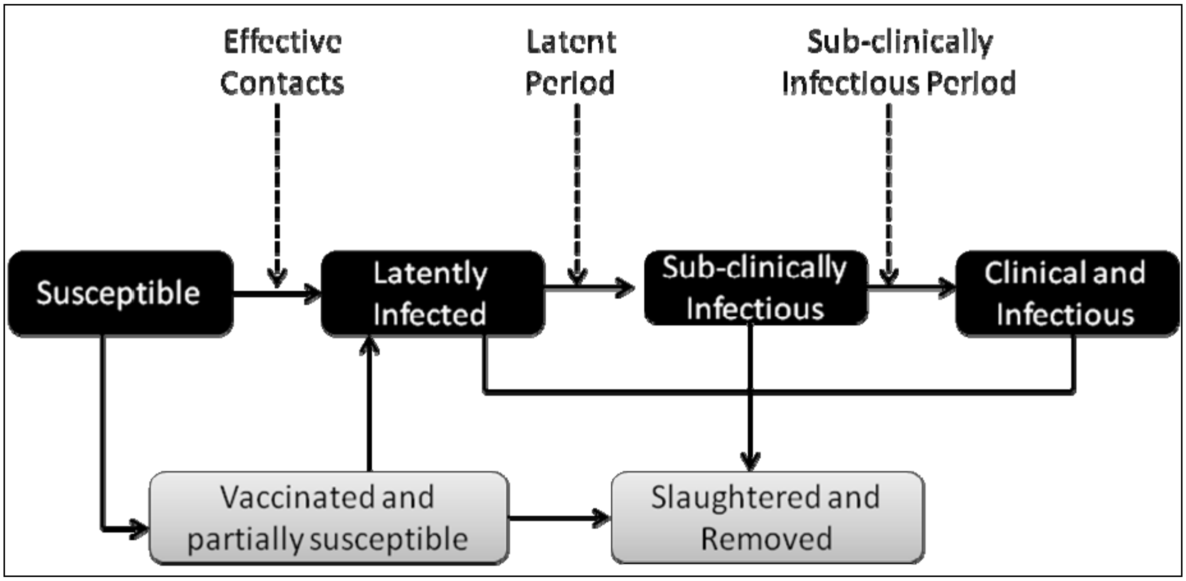


Figure 4. Illustration Depicting the Model States and Pathways for Progression of FMD (Bates, Thurmond and Carpenter)

Once a single animal has the virus, the movement through states begins. There may be a short period in which the animal is infected but not excreting the disease (latently infected) after which the infected animal will start excreting the virus but not showing signs of the disease (sub-clinically infectious). These two stages are sometimes simply called the sub-clinically infectious or latent period. During this time anything that comes in contact with the infected animal can become a carrier, including trucks, feed, clothes, non-susceptible species, and other fomites. The latent stage is estimated to last an average of 3.7 days; during this stage no virus is detectable (Thurmod and Perez). How an animal moves through the states is largely dependent on the control strategies put in place. For example, a susceptible animal that is vaccinated is still partially susceptible, but will have some immunity. Under current policies, which will be discussed later, that animal is then moved directly to slaughter and thus the probability of spread from that animal is eliminated upon proper carcass disposal. Live animal exports cannot take place from an FMD infected country (James and Rushton).

Only very rarely have humans contracted a mild form of FMD, so it is not considered a zoonotic disease. Symptoms in humans are mild headache, fever and small sores on the hands/feet accompanied by a tingling sensation. Blisters heal within a few days, and full recovery occurs within a week. Only serotypes O and A have been shown to infect humans. Forty reported cases have been recorded since 1921, these were all in Europe, Africa and South America (Bickett-Weddle et al.).

Meat from animals that have been slaughtered as a result of the FMD outbreak is still of human consumption grade. However, livestock products and humans exposed to the virus can still carry it for a period of time and cause contamination to other areas. In humans the virus can live in the nose and lungs for up to 48 hours and consequently spread it to any susceptible animal they come in contact with during that period (Musser). Bone and lymph nodes products are particularly adept at carrying the disease (Paarlberg and Lee). For this reason livestock product import bans are a standard response from trading partners when a previously FMD-free country becomes infected. A country that has allowed FMD to become endemic would need to produce processed/cooked meat products in order to still participate in international trade. Other impacts from FMD that are captured using economic estimation would be the impact of FMD on trade of other products from the infected region (e.g. fruit and vegetable exports from an area under movement restrictions), local veterinary service interruptions, market losses from slaughter ready animals being held past their prime, and restrictions of movements of people (James and Rushton).

2.3. FMD in the United States

FMD has been recorded in the US eight times since 1870. The most devastating outbreak was in 1914 where it spread across 22 states, leading to the destruction of 172,000 cattle, sheep, swine and goats. Cattle populations are considered to be at particular risk due to the comparative ease with which they can be infected by the airborne virus and their ability to excrete the virus up to four days before detection (Ekboir); however, severe damage could be done in multiple livestock industries.

2.3.1. Threat to the US

Although FMD has not been seen in the United States since 1929, it has occurred in 52 other countries since March 2000 (Musser) increasing the risk of infection today. US livestock production shares characteristics with other developed countries that make it particularly vulnerable to a foreign animal disease attack (Jin, Elbakidze and McCarl). First, it is highly concentrated both in terms of firm numbers and geographic spread. Meatpacking is a segment of the supply chain that poses a risk as a supply bottleneck. In the US, four firms accounted for 67% of meat packing in 2005 (GIPSA). In Figure 5 each dot shows the location of a meat packing plant for either Cargill, Tyson, Smithfield, National or Swift.

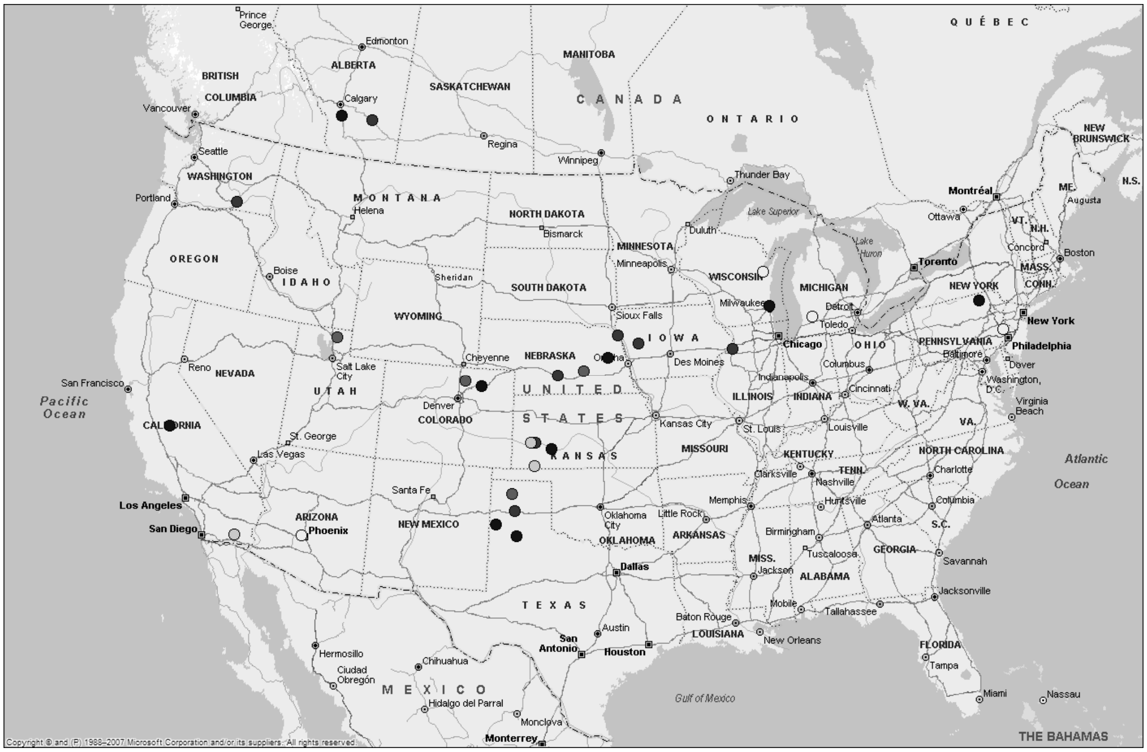


Figure 5. Major Meat Packing Plant Locations in the US and Canada (Peel)

Geographically, large scale animal feeding is concentrated in particular regions due to land and feed availability. The area enclosed by the box shown in Figure 6 represents 80% of the fed beef production in the US (Wilson). Iowa alone accounted for 28% of pork production in 2008 (USDA-NASS, 2009). Furthermore, the pork and poultry industries are centralized into a few firms operating many contract concentrated feeding operations.

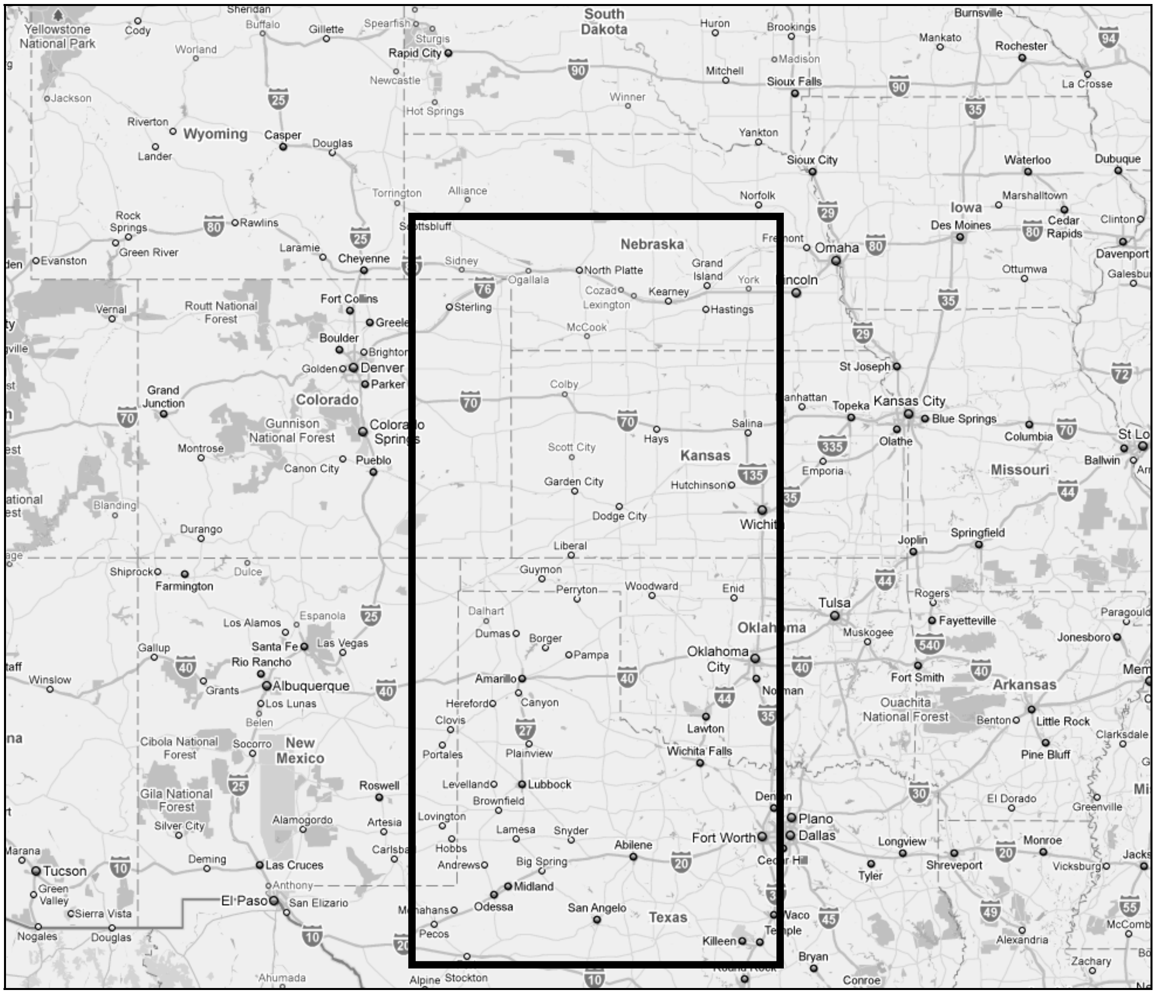


Figure 6. The Concentrated Beef Feeding Region of the United States (Wilson)

Second, the US is a large scale producer and consumer of meat and meat products. Consequently, livestock are routinely moved over long distances, changing hands several times throughout the supply chain (Jin, Elbakidze and McCarl). One study contends that, from farm to table, meat travels on average 994 miles (Cupp et al.). In simulations of FMD, current patterns of animal movement could spread the disease to 25 states in five days (Chalk).

Other characteristics that make the US livestock sector vulnerable to FMD are:

- the high levels of livestock and personnel movements to and from other countries and South American countries in particular;
- limited experience of farmers and veterinarians in identifying the disease;
- limited adherance to biosecurity protocols in areas of high animal movements like salebarns; and
- lack of incentives for farmers to report signs of the disease.

The remainder of this section will provide a brief overview of US livestock production, broken down by susceptible livestock type. This gives the reader an understanding of the scope and scale of livestock production as well as provides a context for results presented in later sections.

2.3.2. Beef Cattle

The US is the largest producer of beef in the world (USDA-ERS, 2009a) with 11.9 billion metric tons of production, about 22% of world production (USDA-FAS). In 2008, the US produced a retail equivalent of $76 billion in value for 26.56 billion pounds of beef, or a cattle and calf production value of $34.9 billion (USDA-ERS, 2009a).

The US is also the top consumer of beef in the world (USDA-FAS) consuming 27.3 billion pounds in 2008 (USDA-ERS, 2009a). As a consequence, the US is a net importer of beef. Imported beef is typically lower value, grass fed beef destined for processing and ground beef, whereas exported beef is typically of the higher value, grain finished cuts (USDA-ERS, 2009a). In 2008, a little over 7% of the total US beef production was exported (USDA-ERS, 2009a) so most beef is processed or consumed domestically. US beef imports primarily come from countries that have a comparative advantage in producing beef inexpensively. As shown in Figure 7, Australia is the main source of US beef imports followed by Canada (USDA-ERS, 2008).

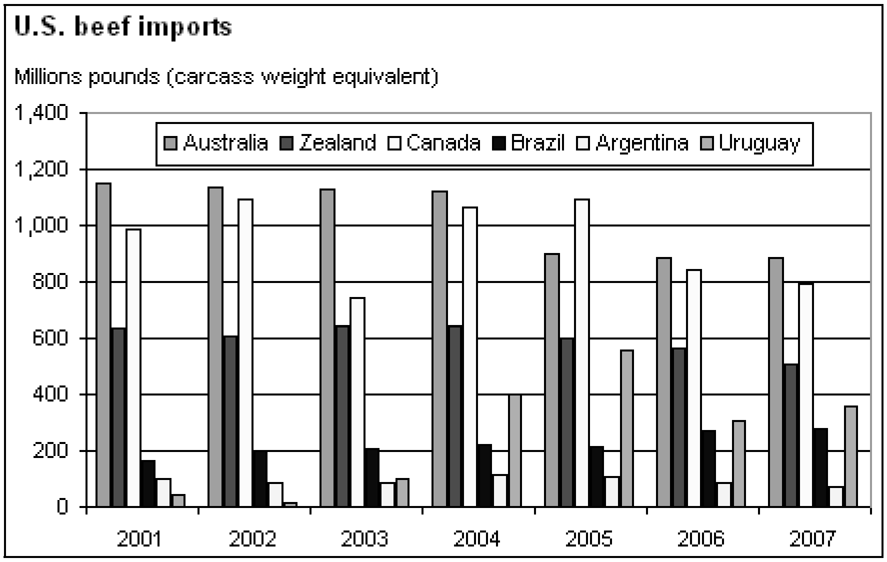


Figure 7. US Beef Imports 2001-2007 (USDA-ERS, 2008)

At this juncture, the impacts three US cases of BSE have had on beef trade is warranted. In December, 2003 a Washington state dairy cow was identified as having been infected with BSE prompting a total ban on US exports to major beef trading partners. Two other confirmed cases of BSE were identified in Texas (2004) and in Alabama (2006), slowing the ability of those markets to recover. Of the four major US trading partners prior to 2003-Japan, Canada, Mexico and South Korea-trade with Mexico and Canada has largely resumed, but Japan and South Korea continue to be restricted with both having limits on animal age at the time of slaughter to protect against BSE (Mathews, Vandeveer and Gustafson) although these limitations began to ease as of 2008 (Bloomberg News). Figure 8 illustrates US beef exports to these major trading partners from 2001 to 2007.

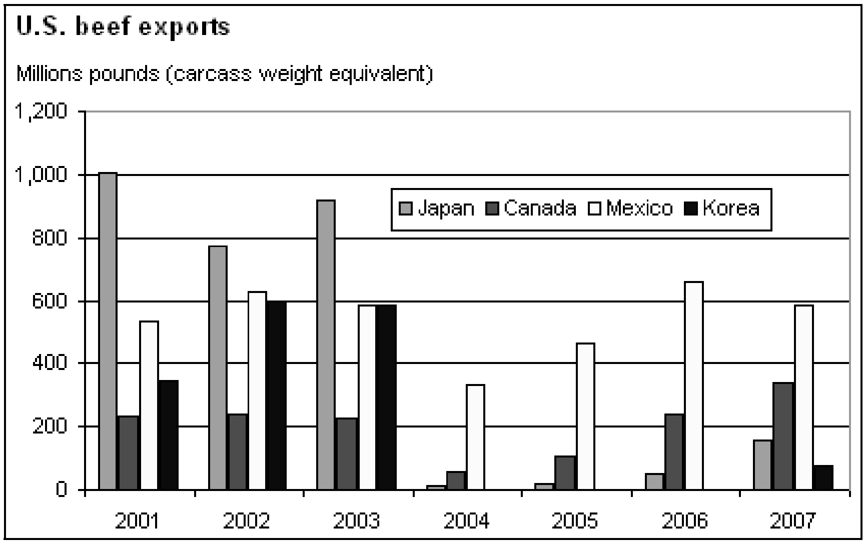


Figure 8. US Beef Exports 2001-2007 (USDA-ERS, 2008)

There is also trade in live cattle, primarily with Canada and Mexico due to geographic proximity and similar production practices. As the largest live cattle trading partner, 65% of live cattle imports come from Canada compared to only 33% of beef imports (USDA-ERS, 2009a).

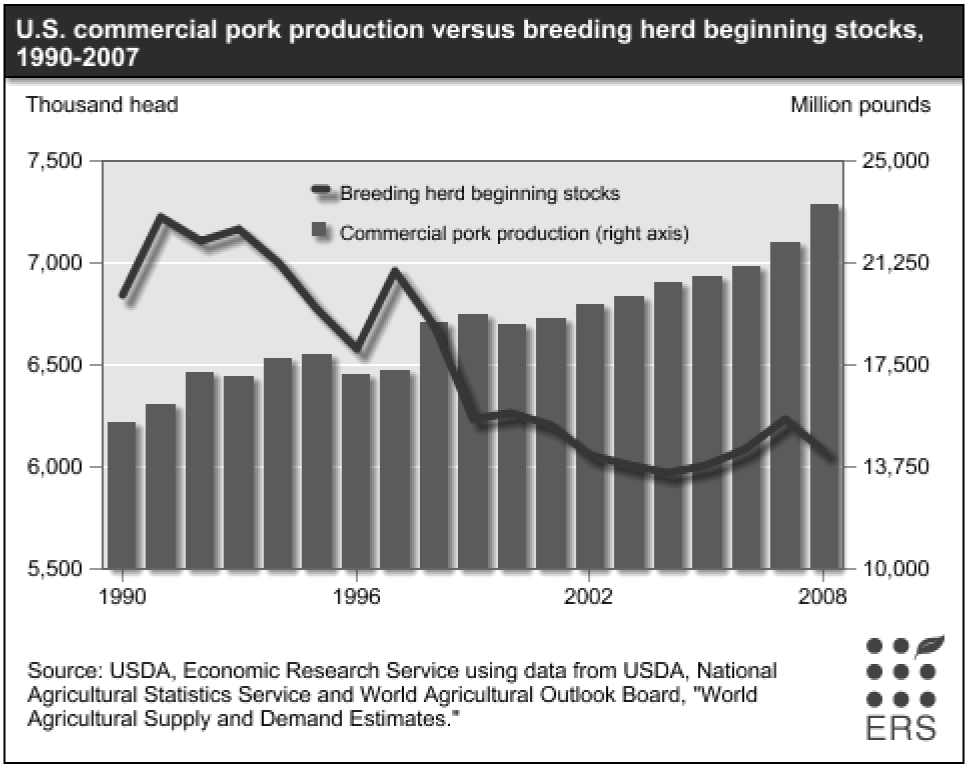
2.3.3. Dairy

The 2008 US Dairy cow inventory was 9.3 million head, producing almost 190 billion pounds of milk (USDA-NASS, 2008). The dairy industry is highly de-centralized, primarily made up of family-owned farms, but products are generally marketed through producer cooperative associations. The trend on these farms is to use improved genetics for more milk production per cow and an increased number of cows per farm. This has led to an increasing trend in milk production that more than offsets the declining trend in the number of operations and total number of milk cows in the US (USDA-ERS, 2009c). The largest dairy producing states are California, Wisconsin, New York, Idaho, and Pennsylvania (USDA-NASS, 2008).

US International exports of dairy products have historically been small, particularly when compared to other products like beef and pork. Trade is primarily based on butter, cheese and dried milk. The years 2007-2008 saw an increase in dairy exports that could mean an increased importance of trade for the dairy industry in the future (USDA-ERS, 2009c). Export categories include American cheese, other cheeses, condensed milk, evaporated milk, and non-fat dry milk. Imports have mostly been limited to cheese, but the levels of imports are somewhat large. Total dairy product imports for the US were 5.3 billion pounds in 2004 (USDA-ERS, 2009c). The US is a net importer of cheese, with the exception of American cheese, which is a net export.

2.3.4. Swine

As of 2008, the US was second only to China in pork production with 67.4 million head (USDA-FAS), and is the leading pork exporter in the world. The value of pork exports alone in 2008 was $4.675 billion (Meyer). The US has been a net exporter of pork and pork products since 1995 with net exports increasing eleven fold in the eight years since 2000 (USDA-ERS, 2009b). This is primarily the result of advances in the efficiency of pork production through drastic structural changes away from small, independent producers to large commercial operations organized through contracting and vertical coordination. This structure reduces production risk (e.g. lower death rate in sows and offspring) and allows for optimal year round production regardless of weather conditions. Technological advances are not limited to the way the hogs are raised; other advances have been made in genetics, feeding and management techniques to obtain more pork per sow as shown in Figure 9 (USDA-ERS, 2009b).



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service and World Agricultural Outlook Board, "World Agricultural Supply and Demand Estimates."

Figure 9. US Commercial Pork Production and Breeding Herd Beginning Stocks 1990-2007 (USDA-ERS, 2009b)

The primary export markets for pork are Japan (28%) followed by Mexico, Hong Kong, Russia and Canada. The US primarily exports fresh chilled pork (e.g. loin), which is a higher value product. Mexico's US pork demand has fluctuated over time and Canada's has dropped with expanding Canadian pork production (USDA-ERS, 2009b). Canada and Denmark are the primary sources of US pork imports. Although imports represent a small share of total pork usage in the US, these two countries have represented about 80% of imports since 1985 (USDA-ERS, 2009b). This is primarily represented by imports of low-cost cuts like ribs.

Live hogs, like live cattle, have been traded with Canada and Mexico. The largest portion of US live hog imports occurs with Canada, but US live hog exports have primarily gone to Mexico (USDA-ERS, 2009b).

2.3.5. Sheep and Small Ruminants

The final major category of susceptible animals, which includes sheep and goats, has been losing prevalence in the US livestock sector since the 1940s. In 2007, only 6.2 million head of sheep were on inventory. There are two major types of sheep operations: large rangeland flocks and small farm flocks. Sheep and goats have historically been a source of meat and wool, but as the industry transitions there is an increasing niche market for cheeses, yogurts, organic and specialty wool, and sheep for youth stock shows (National Academy of Sciences). The US is not a major player in the world sheep, lamb and mutton markets. Imports of lamb and mutton primarily come from the major world players in the industry, Australia and New Zealand, where exports of lamb go to Bermuda and Mexico and mutton goes to Mexico and Canada (USDA-ERS, 2009d).

2.3.6. Summary

Whether accidental or intentional, a FMD outbreak would make a significant impact on the U.S. economy. Domestic losses from FMD can run into the billions in the short term, but international trade restrictions put in place as a consequence of an FMD incident could have longer lasting impacts, particularly for pork producers who have a significant presence in the world market. The introduction of animal disease can lead to stiff trade barriers by non-infected countries.

Further, if importing countries find another stable source of goods, they are likely to maintain this new relationship even after the original trading partner is disease free. One example of this is Japanese pork imports. Prior to 1982, Denmark was the leading exporter of pork products to Japan. However, following the outbreak of FMD in Denmark, Taiwan became Japan’s leading supplier until 1997 when they experienced a devastating FMD outbreak. Since that time, the US has become the leading exporter of pork to Japan (Casagrande). Given prior history, there seems little doubt that should the US contract FMD, current trading partners will seek another disease-free source of product with little hesitation.

2.4. Strategies for Eradicating FMD

The current US policy for FMD is enforced by the Animal and Plant Health Inspection Service (APHIS). This policy is outlined in a fact sheet that was published by APHIS in April 2007. After a suspected infected animal is identified, then tests are taken with animals in the same herd or on the same premises put under quarantine. Upon confirmation of an FMD outbreak by an APHIS diagnostician, which usually takes only 24 hours after samples are taken, APHIS and state agencies will immediately take steps to secure the area surrounding the infected premises including setting up an initial quarantine zone, tracing the movements of infected animals and alerting officials in neighboring states, countries and the OIE. At this point prescribed response policies would be put in place. Namely, all animals on the premises or in dangerous contact would be slaughtered as discussed below; however, this slaughter could be combined with other policies. After the outbreak is eradicated, or at least regionalized, the goal of APHIS would then be to help producers recover from the outbreak (USDA-APHIS, 2007c).

2.4.1. Detection

Many strategies have been suggested for eradicating FMD should it occur in the US; however, there is not universal US level agreement on the "best" strategy. The most common, and most common-sense, strategy is to catch the disease early. Here detection refers to the identification of the first confirmed case of FMD. Early detection is not always a simple matter, particularly in a country such as the US that has not had an FMD outbreak in almost 80 years, and is not a costless activity. There must be an ex ante investment in resources and education to encourage early detection. It is unlikely that the disease will be caught very early in the US given the similarity of symptoms to more benign problems, the time since the last case of FMD, and the dependence on farmers and local veterinarians to report the disease. If, or when, the disease is found in the US the eradication process will be costly both in monetary terms and in terms of animal lives lost. Simulation studies have shown these losses can be reduced significantly through early detection of the disease (Schoenbaum and Disney; Paarlberg, Lee and Seitzinger; Ekboir; Ward et al.,2007). In the 2001 UK outbreak delayed detection contributed to the vast magnitude of the outbreak (Anderson, 2002). The later the disease is identified, the more aggressive the response will have to be in order to eradicate the disease.

2.4.2. Stamp Out

The current policy of the US relating to FMD is an aggressive eradication policy that relies on the slaughter of all infected and disease-exposed animals called “stamp out”. “Stamp out” involves the destruction of all adult and young animals contracting the disease as well as the destruction of any dangerous contacts, indirect contacts and sometimes contiguous slaughter. A dangerous contact is any animal that has come in contact with an infected animal (NAO). In addition, an animal that is an indirect contact, which occurs through exposure to a person, feedstuff, or other fomite that has been on infected premises, can be slaughtered as well. Feedstuffs on infected premises are destroyed, and buildings are cleaned then left uninhabited for a defined length of time to assure the virus is no longer active. Humans should wear protective clothing that is changed between premises. Contiguous slaughter involves the slaughter of any animal on a property bordering an infected property despite the fact that no direct or indirect contact occurs. This particular policy was used in the 2001 UK outbreak, but received a backlash of negative response from farmers and residents in the country (Anthony). This portion of the response policy is termed “depopulation”.

Stamping out has proven to be the most epidemiologically effective way to eradicate the disease in as short a time as possible. Indemnity payments are paid to producers equal to the fair market value of the depopulated animals. This can be used in conjunction with contiguous slaughter, ring or targeted vaccination to reduce disease spread, expanded testing or surveillance. Some countries have opted to rely on vaccination and a policy of phasing out the disease over time rather than the more aggressive stamp out policy; this will be discussed in more detail below.

2.4.3. Surveillance

Another option is the investment in enhanced surveillance both ex post and ex ante. Surveillance for FMD is conducted almost entirely by producers and veterinarians (Musser). *Ex ante* surveillance includes checking randomly for the initial case of disease and port of entry surveillance. *Ex ante* investments can also be made in systems to speed response and recovery *ex post*. This would include investments in vaccines and diagnostics, increased diagnostic laboratory capabilities, and the National Animal Identification System. *Ex post* surveillance includes the use of additional personnel to increase the number of visits or tests run in the surveillance zone.

2.4.4. Movement Restrictions

Response zones are another tool for eradicating FMD. Response zones typically mean that within that zone, the movement of animals, equipment, feedstuffs, and people is severely restricted. These zones consist of multiple layers of protection. The restrictions on movement vary by the type of zone and often the disease strategies utilized do as well.

There are three primary zones: the control area (the infected zone and the buffer-surveillance zone), the surveillance zone and the free zone. Table 1 provides a summary for each area. Within the response zones, USDA officials will seek to prevent further spread of the disease through restricting unnecessary movements of animals, people and equipment. Commercial traffic will be re-routed, and local traffic will be ranked by their risk level. A permit system will be put in place for all low to moderate risk local traffic. Within the response zones all premises will be given one of four classifications: infected premises, contact premises, suspect premises, and at-risk premises as shown in Table 2.

Table 1. Response Areas Defined by the USDA-APHIS

Zone	Size	Purpose
Control Area	Entire state, tribal nation, or territory at minimum	All animal movement will be stopped until the scope of the outbreak can be determined.
Infected Zone	6.2 miles around each infected premises	This will be the area of concentrated stamping out of the disease. Within this area all movement of animals and carriers will be completely halted except by special permit.
Buffer-Surveillance Zone	No minimum size	Surveillance of all susceptible animals with a minimum of 2 inspections every 14 days until the disease is eradicated
Surveillance Zone	Minimum size is 6.2 miles beyond the perimeter of the control area	Surveillance of high risk herds with movement allowable using permits
Free Zone	Surrounds the surveillance zone and extends to the boundaries of the U.S.	Surveillance continues according to standard animal health code practices.

Source: USDA-APHIS, 2007c

Table 2. Premises Designations Defined by the USDA-APHIS

Premises Type	Status	Action
Infected	The FMD virus has been identified or is presumed to exist	All infected premises are located within the infected zone. An individual level quarantine is imposed on each infected premises and all susceptible animals are euthanized and disposed of.
Contact	Premises has been exposed either directly or indirectly to FMD virus carriers	All contact premises must be inside the control area. All susceptible animals are euthanized and disposed of except in special exceptions. Animals exempted from slaughter are placed under intensive surveillance for not less than 28 days.
Suspect	Premises with susceptible animals located in any response zone, but not classified as infected or contact.	Premises are placed under quarantine and intensive surveillance for not less than 28 days, passing three inspections every 14 days, and possibly additional surveillance after removal from the surveillance zone to the free zone.
At Risk	Premises in the buffer surveillance zone with susceptible animals, but no clinical sign are present.	Movement is allowed within the buffer zone, but not into the free zone. Non-susceptible animals may move in and out of the free zone with a permit.

Source: USDA-APHIS, 2007c

Current APHIS guidelines call for a "stamp out" policy in conjunction with response zones. The response zones control the spread of the disease while the "stamp out" procedure eradicates the disease within the response zones. Figure 10 provides a timeline for the outbreak. This timeline is based on the October, 2007 version of the APHIS response guidelines. The series of response zones are put in place as soon as the Foreign Animal Disease Diagnosticians (FADDs) receive the positive test result back from Plum Island. Prior to this, the FADDs will use their best judgment to put temporary quarantine areas in place.

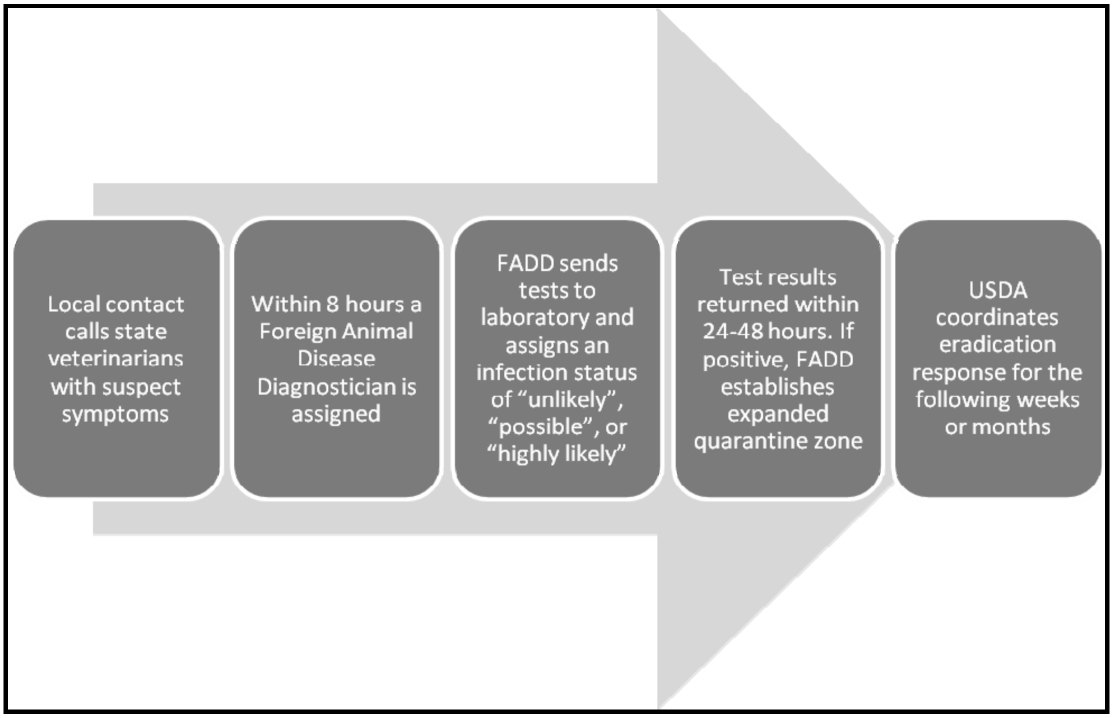


Figure 10. Timeline for Outbreak

2.4.5. Vaccination

Stores of FMD vaccine are required to be stockpiled under the Homeland Security Presidential Directive 9 established in 2004. While vaccination is not the first step, it could be considered by APHIS as a way to provide a protective barrier around the infected area, potentially reducing disease spread and regionalizing the disease (USDA-APHIS, 2007c).

FMD vaccines are produced by growing live virus in laboratories. There are four foreign animal disease research facilities located in the US, UK, Australia and Canada that study FMD vaccines to protect their own livestock industries and global livestock markets (Kitching et al.). Animals are typically vaccinated twice, with protective immunity occurring 4-5 days later. The vaccine does not last, and must be re-administered every 4-6 months. Another challenge of vaccination for FMD is the number of sero-types and sub-serotypes since the vaccine must cover the strain present in a particular outbreak. FMD vaccines must be kept cool throughout their life, and they do not have a long shelf life (Kitching et al.). For these reasons, vaccination has not been proposed to prevent disease entry into the US but has been proposed as a means of slowing the spread of the disease.

Economically, there are two sides to the vaccination issue in the case of an FMD incursion. First, vaccination has shown in some instances to be useful in acting as a retardant for disease spread (Randolph et al.; Kitching et al.). The policy is to slaughter vaccinated livestock because the vaccines currently in use are not differentiable (DIVA): post-outbreak, it is difficult or impossible to determine if an animal with FMD antibodies was infected and recovered or if it has antibodies from vaccination. Second, vaccination has trade recovery implications. Countries utilizing vaccine are given a status of "FMD Free with Vaccination" which may result in greater trade barriers than a status of "FMD Free without Vaccination". DIVA vaccines are currently being tested and manufactured, but it is unknown how these vaccines will be treated from this policy standpoint. Ekboir outlined several other drawbacks to the use of vaccination, namely

- Persistence of trade restrictions and movement restrictions
- Vaccinated animals are not allowed to leave the quarantined area ever

- Additional spread risk associated with the interaction of animals and those performing the vaccination
- Welfare implications of more animals being under movement restrictions for longer periods of time
- Longer disruption of processing industries
- The potential for driving down prices from additional meat supply if vaccinated animals enter the meat supply chain.

The use of vaccine is an *ex post* strategy, but the stockpiling of the vaccine in the anticipation of an FMD outbreak is an *ex ante* strategy. Consequently, currently animals vaccinated for this reason are almost always slaughtered. Also, vaccines currently in use are not differentiable (DIVA) vaccines, meaning there is no way to know if the animal has been infected and recovered or if the antibodies are from the vaccine.

Bearing in mind the current response capability, strategies that have been suggested in the literature, and historical events occurring in the U.K., Netherlands and Taiwan, this dissertation will seek to add practically and substantially to the literature on the economics of animal disease.

2.4.6. Ex Ante Investment vs. Ex Post Expenditure

There is considerable uncertainty involved in the probability of an FMD outbreak occurring in the US and whether policies are justified given these probabilities. Furthermore, the size of the event space in the US is large. If an FMD outbreak were to occur in an area with a very low susceptible animal concentration, the decision for ex ante investment would seem quite different from the decision to invest in densely populated regions because the difference in potential damages is quite large.

The US currently invests in some prevention and anticipation activities to reduce the likelihood of entry or to reduce the impact upon entry of the FMD. These activities include: restricting the importation of live ruminants and swine from FMD infected countries; checking for disease at ports of entry; implementing additional inspections on incoming international flights; asking veterinarians to heighten monitoring of domestic livestock; cleaning military vehicles and equipment prior to re-entry in the country; and implementing an educational campaign to make farmers and ranchers more aware of the disease (USDA-APHIS, 2007b). In addition, the US maintains a vaccine stockpile at various undisclosed key points, has prepared regional labs with emergency response protocols, and has provided additional training to personnel in order to rapidly respond to the disease. However, these types of activities must be balanced against the expected costs of an FMD under the various control strategies discussed above to determine whether they are good investments economically. We were unable to find a dollar figure of what is being spent on FMD at this time.

2.5. Eradicated versus Endemic FMD

To conclude this essay, the question of whether it is worthwhile to put forth the effort to eradicate FMD is addressed. The disease is typically eradicated if a country has export markets for domestically produced livestock and livestock products, has a large livestock industry with intensive production systems, or have the ability to prevent FMD introduction from neighboring countries (James and Rushton). In addition, other countries that experience a relatively small outbreak that can be quickly eradicated may choose eradication to protect markets for non-livestock goods. These characteristics would point to the North America, Europe, Australia, and parts of South America having incentive to eradicate as opposed to allowing FMD to become endemic (James and Rushton). A case where FMD is largely endemic is India, which houses nearly 15% of the world cattle population due to their use as draught animals (James and Rushton). Losses per year in India from milk production were estimated to be Rs12,520 million ($271 million) in trade losses and Rs 16,500 million ($357 million) in domestic losses. Losses due to reduced draught power and animal deaths were estimated at Rs18,130 ($392 million) (James and Ellis). In a study of FMD in the Philippines, where FMD was endemic in at least part of the country, Randolph et al. examined the tradeoff between endemic disease losses and the costs of eradication. The program in the Philippines was based on phasing FMD out using vaccination rather than quickly eradicating it using slaughter. The study found that the cost-benefit ratio of investment in eradication ranged from 1.6 to 12.0, which indicated that in this country eradication was an economically viable alternative (Randolph et al.). Based on these studies, it is reasonable to assume that the US and other major livestock producing countries would most likely benefit from an eradication program rather than allowing the disease to become endemic, despite the high cost of an eradication program.

2.6. Conclusion

This essay set the stage for the FMD analysis showing the danger presented by FMD through both its impact in other parts of the world and the potential damage it could cause in the US. It is most likely that an eradication program would be put in place, using standard control policies that have worked in other parts of the world. Thus, these control strategies should be examined in greater detail to determine their impact.

3. ESSAY 2: COMBINING EPIDEMIC AND ECONOMIC MODELS IN A SECTORAL ANALYSIS FRAMEWORK

3.1. Introduction

This essay develops a general method for achieving the objective of the dissertation, specifically developing a linked economic/epidemic model for FMD event and strategy analysis. This methodology can then be used in future combined economic / epidemic modeling work. This study is a part of the larger research and development effort of the National Center for Foreign Animal and Zoonotic Disease Defense (FAZD). That effort is designed to develop and employ an integrated, database supported economic and epidemic modeling system as a part of an overall decision support and strategy analysis system. The research is also intended to provide a quantitative approach for analyzing alternative strategies for prevention, intervention and recovery to develop information is support of planning efforts.

3.2. Economic/Epidemic Model Development

To estimate potential economic losses of agricultural contamination from infectious animal disease spread as accurately as possible, an integrated economic/epidemic model is needed. Epidemic simulation information is necessary to evaluate disease spread and strategy implications (Jalvingh et al.; Ferguson et al.). In turn, the economic model will use the epidemic output to evaluate the economic costs of a potential outbreak and the use of alternative strategies. The type of economic model used will vary depending on several factors such as the geographic scope of interest (farm, region, nation, or world), economic factor of interest (employment changes, price changes, trade changes, or welfare changes) and the extent of damages expected from a particular disease.

Such integrated models are primarily used to predict what would happen in the event of an outbreak of a specific disease in a specific region or to assess the sensitivity of an outbreak to various control strategies. Ideally, models should capture the recovery over multiple time periods from the outbreak, over the period of restocking and recovering trade relationships, through to the time of full recovery. Furthermore, they should capture the geographic implications of the disease in terms of spread to other regions or countries (Rich and Winter-Nelson). Moreover, to assess risk through both the epidemic portion of the model and the economic portion, the alternative stochastic results from the epidemic portion may be run through the economic portion as statistically independent trials. This is opposed to the standard practice of running only the averages from the epidemic model through the economic model.

The stochastic parameters in the epidemic model deal with the rate of disease spread and the effectiveness of control strategies. The spread rate of an infectious disease will determine the severity of epidemic damages, which in turn are used to estimate the economic damages and the appropriate combination of necessary prevention and response actions. The purpose of prevention activities is to decrease the probabilities of intentional or unintentional agricultural contamination incidents. Response, control and recovery policies are focused on minimizing damages by stopping the spread of a possibly infectious contamination and minimizing the scope of the outbreak, as well as fixing the source of vulnerability leading to the outbreak, restoring livestock production, replacing the lost production in the food supply chain and rebuilding consumer confidence. Figure 11 provides an illustration of how integrated economic-epidemic modeling works conceptually.

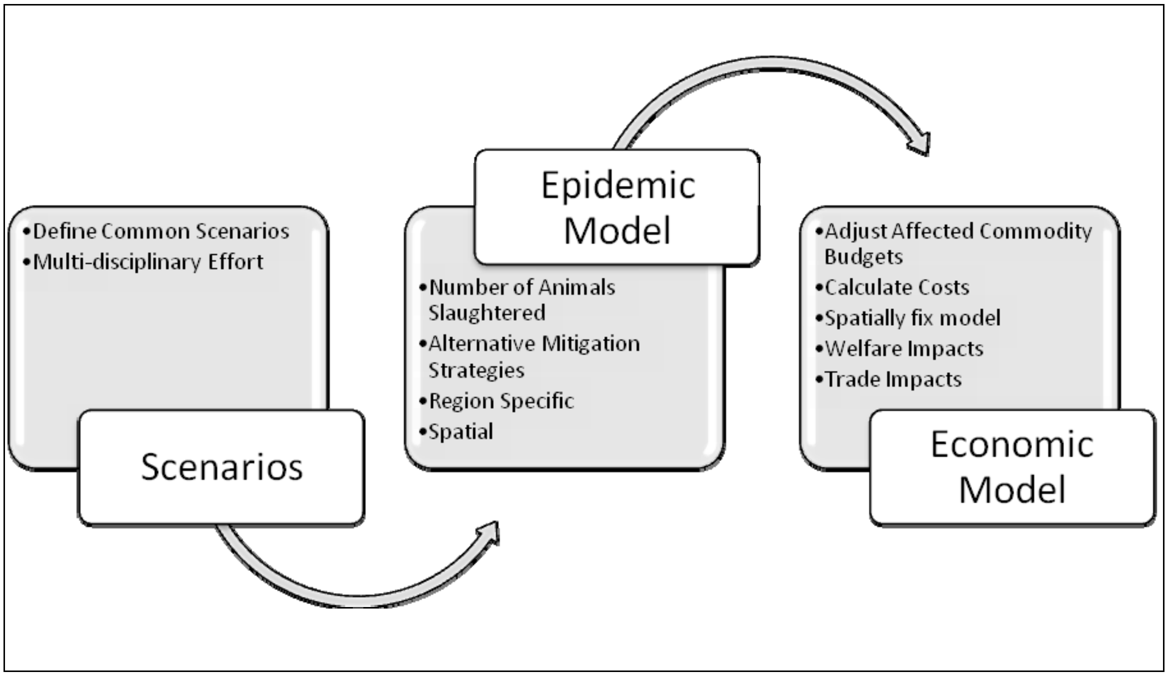


Figure 11. Conceptual Flow of an Integrated Economic/Epidemic Model

3.2.1. Epidemic Modeling

The first step in building an integrated model, assuming we have calibrated epidemic and economic models, is to determine what control strategies will be examined, and how those control strategies will impact the model input parameters. This requires in-depth knowledge of the biology of a disease, the effectiveness of control measures in slowing or halting the spread of the disease. The calibration requires a detailed survey of herd populations and compositions plus the contact rates in the region of interest. It often falls within the purview of the epidemic modeler to collect this data and collaborate with those in the biological sciences who have studied animal disease spread, prevention, and control in great detail.

The role of epidemic modeling, when used in a predictive setting, is to simulate the spread of an animal disease—given certain control strategies—until the disease is either eradicated (episodic modeling) or reaches a stable state (endemic modeling). There are essentially two ways to model epidemics: spatial models based on intensive surveys and non-spatial models using approaches such as the Reed-Frost algorithm for disease spread. Non-spatially based models provide a useful approximation of disease spread; however, the assumption that herds are spread evenly in a geographic area is usually problematic, particularly in areas of concentrated animal populations. This is because it is based on an assumption that each herd is equally likely to come in contact with every other herd (Schoenbaum and Disney). Spatial epidemic models used actual locations of premises and contact rates between those premises based on extensive survey work by epidemiologists, veterinarians and biologists familiar with the disease. These models are better able to explore the full distribution of disease impacts—particularly the highly irregular outcomes in the tails (Bickerstaff and Simmons)—under alternative control strategies. The tails are an area of concern from a risk management standpoint. This requires a stochastic, spatial model. This benefit of spatial epidemic models over non-spatial approaches is balanced against the high cost in terms of time and effort to build spatial models.

3.2.2. Economic Modeling

The economic portion of the model is concerned with assessing the ripple effects an animal disease outbreak will have on the directly infected region as well as indirectly affected regions, livestock industry and economy as a whole. The economic model uses the simulated epidemic model outcomes to determine what the distribution of disease impact would be. The type of economic model used may vary depending on the type of disease being examined—its spread rate, impacts on livestock, and control policies—because not all diseases have the same impacts. Furthermore, some diseases like FMD are classified as being more dangerous economically than others as they result in large scale consequences. Thus, the modeler should determine model choice based on the characteristics of the disease and the assumptions of the study. Four model types are discussed here: a simple cost calculating cost benefit analysis, input-output analysis, partial equilibrium and computable general equilibrium models. The various integrated models for FMD that have been done in the past can be grouped by the type of economic analysis performed. The remainder of this section will provide a theoretical justification for when each model type is most appropriate and past studies that have used them.

3.2.2.1. Cost Calculating Cost-benefit Analysis (CCCBA)

CCCBA is the most basic type of economic analysis, and it also appears to be the most commonly used (Rich, Miller and Winter-Nelson). Under this type of analysis the benefits in terms of reduced value of animal loss are offset against the direct costs of mitigation strategies used to achieve that reduction in the course of an outbreak. CCCBA is used to examine the vulnerability of an area to an event as well as examine mitigation and management policies. The strength of CCCBA is that it is relatively simple to compute, saving in man and computer hours. A criticism of CCCBA is the accuracy of the estimate. This is because certain simplifying assumptions are made, such as perfectly inelastic supply and perfectly elastic demand.

First, consider the implications of supply elasticity assumptions. The supply curve for livestock and livestock products is assumed to be perfectly inelastic. There is some justification for livestock supplies being inelastic in the short run. Livestock follow a set production cycle, so quantities cannot adjust quickly to price changes. To increase livestock inventories in a region, either animals must be imported or the population can be naturally increased over time according to the production cycle.

If this assumption is made (with no assumption made yet on demand other than the law of demand holding), then a parallel reduction in supply occurs. Referring to Figure 12, the disease response (i.e. "stamp out") would result in the quantity of livestock in the country to shift from q_0 to q_1. Consequently prices would rise from p_0 to p_1. Producers would experience a loss of area W and a gain of area T (area U cancels out), so whether they would gain or lose from the disease would be dependent on the relative sizes of those two areas. Consumers would lose area T+U.

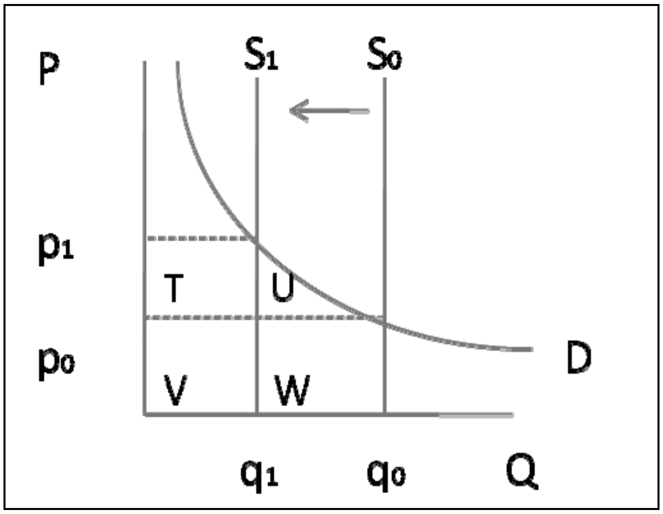


Figure 12. Illustration of Perfectly Inelastic Supply Assumption

Still another assumption is often made under a CCCBA. The price is assumed to not change as a result of the disease, in other words, the demand curve for livestock and livestock products is assumed to be perfectly elastic. This might be reasonable when the infected region slaughter is too small to make any impact on the aggregate supply so producers are price takers in the national market. In addition, it would have to be assumed that there is no influence from international trade. Figure 13 shows the impacts of a disease outbreak in the infected region under these assumptions. As in Figure 12, supply is reduced, but because the national supply and demand relationship is assumed to be unchanged price will remain fixed at p_1=p_0. Producers losses would be equal to area U, and there would be no chance of a gain from the outbreak.

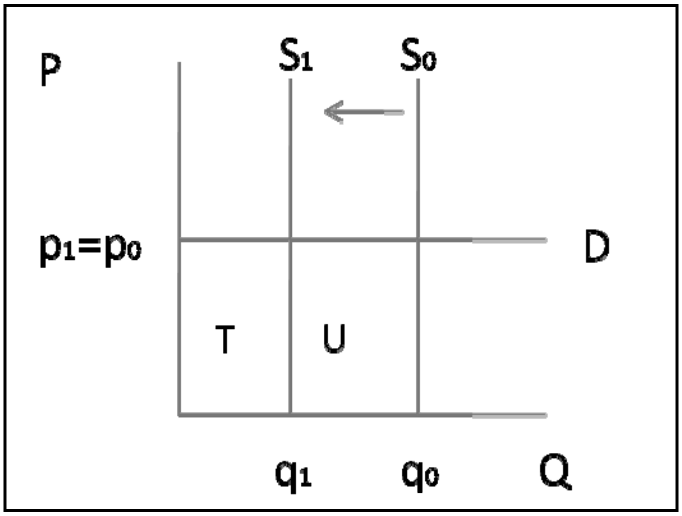


Figure 13. Illustration of Perfectly Inelastic Supply and Perfectly Elastic Demand Assumption

If these assumptions hold, then U should provide a reasonable estimate of the disease outbreak loss to the livestock industry. However, with an FMD outbreak the international trade restrictions would be expected to have an impact on world markets for livestock and livestock products. Even if producers in a particular region are price takers and no demand shift is expected from domestic consumers, trade losses can be expected at the national level as export levels for livestock and meat products go to zero.

Consider the short run supply assumption, where the infected region is a small contributor to aggregate supply and imports of livestock can still enter the country. The consequences of trade losses, even if the outbreak occurs in a small livestock producing area, in a meat market where the US is a net exporter (e.g. pork) are given by Figure 14. If the infected region (IR) is a small livestock producing region, then US aggregate supply will not shift significantly. (It will of course shift by some small amount if even one animal is lost, but practically we would expect any change in the US domestic market to be quite small from such a small supply shift). Export value (the grey box) goes to zero, so domestic price drops to the autarky level, domestic quantity demanded increases to the autarky level, and domestic quantity supplied reduces to the autarky level. US consumers would gain from the lower domestic prices and larger domestic quantity supplied. US producers would lose from the lower prices and loss of quantity exported. In the infected region, where supply is reduced due to the stamp out policy, the new US price is put into place. Producers experience a loss of area U+W from animal slaughter, but also would experience a loss of area T due to the price drop. This analysis is of course dependent on the assumptions of the relative size of the supply shift and the export market, as will be discussed in more detail below.

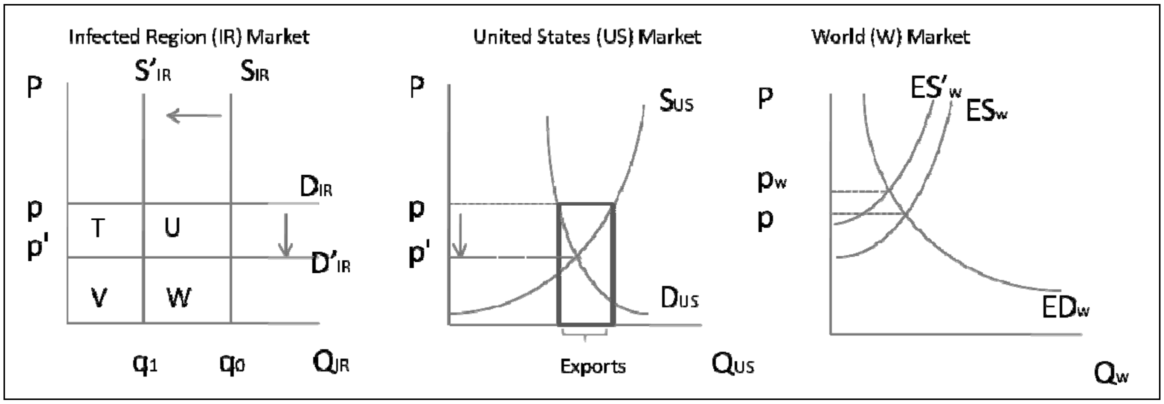


Figure 14. Illustration of International Trade Impacts

In FMD outbreaks occurring in livestock producing countries heavily involved in export markets, the trade impacts alone would make the assumption of domestic price remaining unchanged difficult to justify. FMD outbreaks occurring in Taiwan (Yang et al.), the UK (Thompson et al.) and South American (Rich and Winter-Nelson) countries have been explored empirically, all indicate that trade losses combined with supply shifts to affect prices.

Furthermore, comparing policies based on calculating the area U in Figure 13 doesn't take into account impacts in substitute (e.g. poultry) markets or feed markets. CCCBA is appropriate for local level, short-run analysis in the context of animal disease that does not affect national aggregate supply and would not have large trade impacts or demand impact. Studies that have used CCCBA in the context of FMD are: Disney et al.; Randolph et al.; Bates, Carpenter and Thurmond.

3.2.2.2. Input-Output (I-O)

Like CCCBA, I-O analysis is dependent on budgets and pre-specified multipliers plus Leontief production functions. Unlike CCCBA, impacts on other sectors (e.g. employment) can be estimated. Impact Analysis for Planning (IMPLAN) is a commonly used program based on I-O modeling. In an I-O model, sectors are placed in broad categories called accounts and impacts to the sector are estimated after the animal disease shock. The multipliers in the model measure the total change throughout the economy from a one unit change in the livestock sector. I-O provides a description of a local economy and a predictive model to estimate impacts of animal disease shocks to that economy (Harris and Doeksen). A weakness of I-O models, that it shares with CCCBA and social accounting models is that they do not allow for price changes, input substitution or dynamic changes in the sector over time (Rich, Miller and Winter-Nelson). Figure 15 provides an overview of how I-O models work. Studies using I-O type of analysis are: Garner and Lack; Ekboir; and Mahul and Durand.

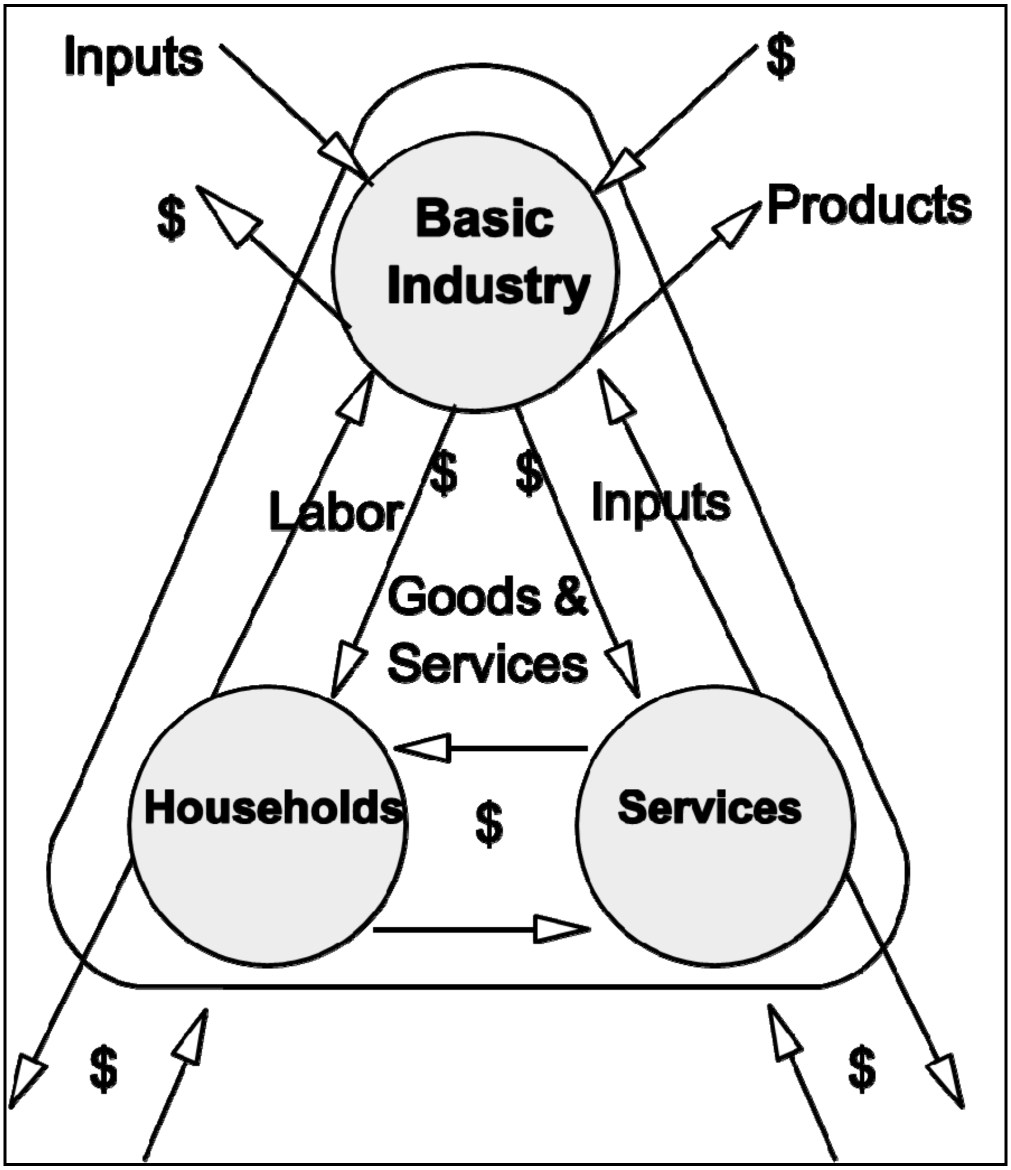


Figure 15. Conceptual Flow Chart for Input-Output Modeling (Harris and Doeksen)

Ekboir simulated the impact of an FMD outbreak in California to estimate economic impacts, analyze current response policies, evaluate alternative strategies for dealing with the disease, and establish the value of monitoring services versus their costs. He finds that, under timely identification of the disease and prompt emergency response, the value of public animal health monitoring is high. Also, the state was unprepared at the time to take the prescribed measures to eradicate the disease. The man-power cost of the stamping-out policy and the large levels of vaccine that would be required to do ring vaccination prove to be very costly. Their study provides an estimate of almost $5 billion in cleaning and disposal alone with a total outbreak cost of up to $13.5 billion (Ekboir).

3.2.2.3. Partial Equilibrium

Partial Equilibrium (PE) analysis can be used effectively in local, regional and national level analysis. PE analysis has the advantage of more closely modeling market movements by utilizing econometrically derived parameters; as a result PE analysis, while more complex and costly to build than CCCBA, can also give a greater depth and scope of detail on an event that has ripple effects throughout the economy given the data and manpower necessary to build one. PE analysis assesses the direct and secondary effects of an animal disease outbreak because it includes not only initial prices and quantities, but also own price elasticities and sometimes cross price elasticities. This type of analysis has become more common as the threat of foreign animal disease became reality in countries around the world in the early to mid 2000s. Studies that have used a partial equilibrium approach include: Paarlberg, Lee and Seitzinger; Mangen and Burrell; Rich and Winter-Nelson; Schoenbaum and Disney; Paarlberg et al.; and Pendell et al.

PE uses a set of supply/demand relationships that recognizes interdependencies between markets in the US. This means several aspects of the disease outbreak can be considered in a single modeling framework, while still making underlying assumptions reflecting actual market relationships. In particular, the vertical relationships between meat markets and livestock markets can be modeled explicitly; trade implications can be considered; the importance of relative supply and demand shift magnitudes on changes in consumer and producer surplus can be considered; impacts on infected region producers and non-infected region producers can be differentiated; impacts in substitute markets can be derived; and impacts in horizontally linked markets (e.g. feed corn) can be assessed. A few of these will be graphically examined here.

First consider the vertical relationships between meat markets and livestock markets. Consider the impact of FMD on cattle and fed beef markets shown in Figure 16. Recall from essay 1 that the US is a net exporter of fed beef (high value beef) and a net importer of live cattle to feed out. By using partial equilibrium analysis, national level fed beef supply and trade impacts can be combined with regional level cattle supply, packer demand and trade impacts to get the change in price in fed beef and live animals, changes in producer surplus and changes in consumer surplus.

First examine the bottom two panels that indicate the US live cattle market and the North American live cattle market, where the North American live cattle market is the excess demand of the US and the combined excess supply of Canada and Mexico for live cattle. Here supply has been shown as being very nearly perfectly inelastic to simplify the short run analysis. This figure indicates that the shift in short run supply in the infected region cattle market ($S_{C\text{-}US}$ to $S'_{C\text{-}US}$), reduces the aggregate national short run supply of live cattle; however, this changes the excess demand in the North American live cattle market and as a consequence the reduction in supply is at least partially offset by an increase in imports of cattle for feeding. Thus the reduction in the supply of fed beef in the US meat market (top left panel) is smaller than would originally be expected. Initially this would increase price of live cattle, the exports of meat and the price of meat; however, exports go to zero due to trade restrictions. This pushes the price of meat down to level p". Meat consumers stand to gain from lower prices and higher quantities, but meat producers would most likely lose given the loss of exports and subsequent lower prices.

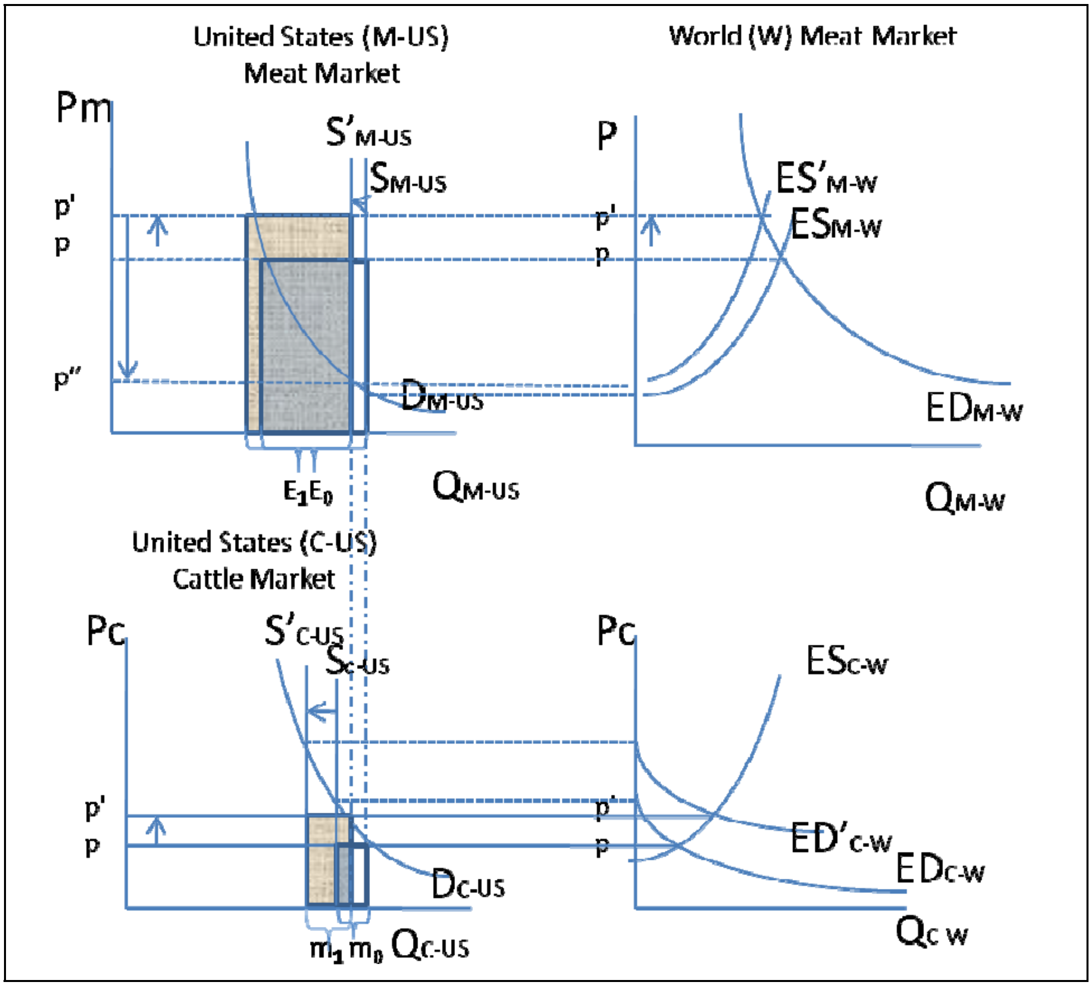


Figure 16. Interdependencies between Meat and Live Animal Markets

The livestock producers in the entire country could gain or lose depending on the relative size of the loss from value of production lose and the gain in surplus from the price increase. Producer impacts can be further broken down into those for the infected region and those for non-infected regions as shown in Figure 17. The demand in the two regions have been shown as being very nearly perfectly elastic (regions are price takers) to simplify the graphical analysis, which may not be the case particularly when the region where the FMD infection takes place is a major livestock commodity producer.

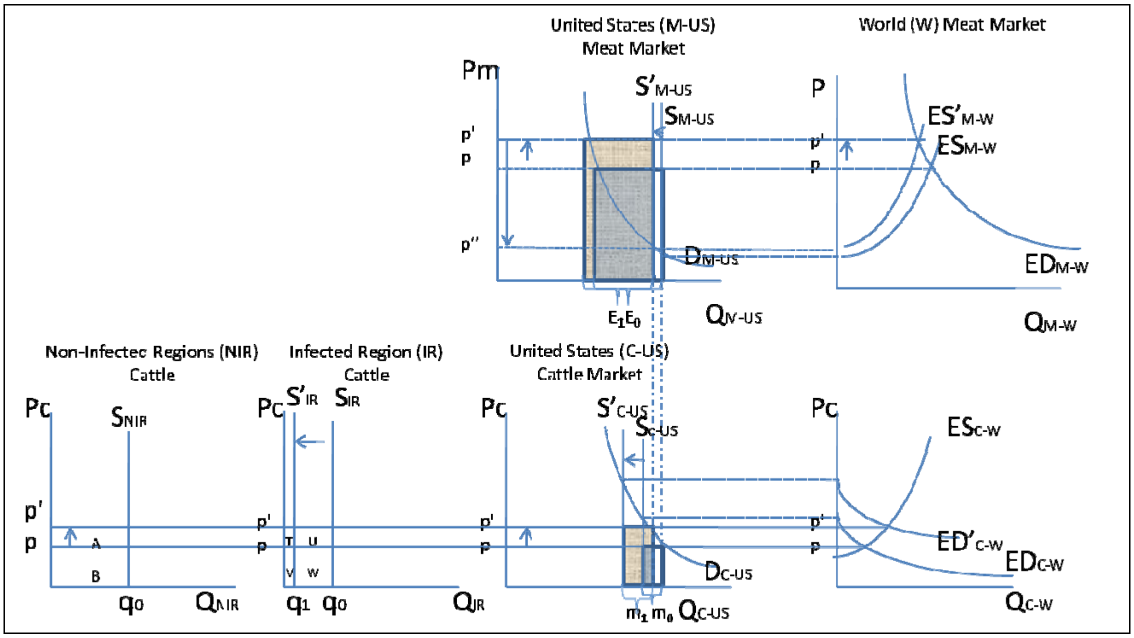


Figure 17. Breakdown of Regional Producer Changes

In the infected region, the gain or loss to producers would depend on the relative size of the value loss related to the supply shift (U+W) and the gain from the price increase (T+U). Given the size of slaughter levels related to the stamp out policy in FMD outbreaks occurring in other countries, it is not unexpected that the area of W would be larger than the area T. This implies producers in the infected region can expect a loss in surplus from the outbreak. Producers in non-infected regions do not have the supply shift, but would get the increase in surplus related to the price increase (area A). As a result, producers in non-infected regions stand to gain from the outbreak. This is a result that has not been explored empirically in integrated analyses, although it has been recognized as a possibility theoretically (Paarlberg, Lee and Seitzinger). This may not be true of pork markets in the US given an FMD outbreak because of the importance of the pork export market; hog producers in the infected and non-infected regions may be harmed from an FMD outbreak.

Other parts of the agricultural sector are impacted beyond the fed beef market (or other affected livestock market). A reduction in slaughter cattle inventories implies a shift in feed grain markets (i.e. corn) that will have impacts on the price of corn for feed as shown in Figure 18. Another consideration would be the domestic demand shift for domestic meat and livestock. This is not explored in this essay, but has the potential to cause a decrease in the price of meat and livestock if the demand shift is greater than the supply shift.

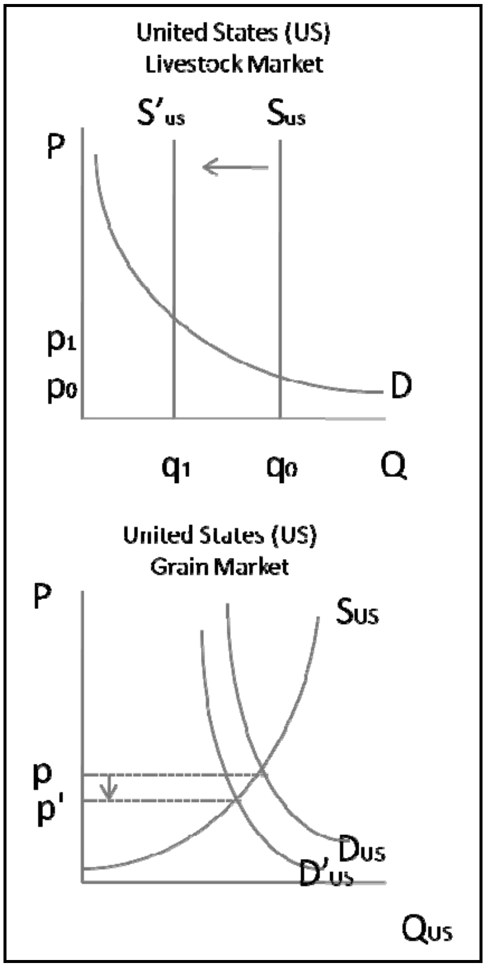


Figure 18. Reduced Demand for Corn for Livestock Feeding

Examining PE studies that have estimated FMD impacts in the US, the studies by Paarlberg, Lee and Seitzinger and Schoenbaum and Disney are discussed more extensively. Paarlberg, Lee and Seitzinger estimate the impact of a more widespread FMD outbreak in the U.S. similar to what was seen in the U.K. in 2001. The model maximized the value of national output subject to resource constraints and minimized the cost of resources subject to competitive pricing. Firms are assumed to be price takers in input markets and perfectly competitive in final goods markets for beef, pork, poultry, lamb, milk, eggs, rice and soybean oil. The model looked at depopulation of infected animals as well as expected bans on exportation of livestock, red meat and dairy products and reduced demand due to consumer fears in domestic markets for these products. Own and cross price elasticities, revenue shares, input costs and substitution elasticities were obtained from prior studies. They estimated a loss of $14 million in U.S. farm income (Paarlberg, Lee and Seitzinger).

Schoenbaum and Disney took a more hypothetical approach by choosing alternative computer generated animal populations to identify a U.S. policy effective over different regions. The model is a cost minimization model where cost is the sum of government expenditures for disease control, producer surplus and consumer surplus changes. Markets are live cattle, hogs and sheep, dairy, beef, and pork. It includes export market losses. They found there was not a universally best strategy, but suggest that ring vaccination around contagious areas is least costly due to the shorter duration and subsequently smaller numbers of animals slaughtered if done early. If animals were both vaccinated and later slaughtered due to the disease, it is clearly more costly. Their cost estimates range from $234 million to $2.4 billion (Schoenbaum and Disney).

3.2.2.4. Computable General Equilibrium (CGE)

These models combine aspects of all of the models discussed above into a computable representation of a complete economy. An advantage of CGE models is that they have the potential to give the most complete information possible on the economic impacts of an FMD outbreak. However, their complexity and the large data requirements are a disadvantage compared to partial equilibrium analysis. Two models have attempted to develop this kind of analysis for foot-and-mouth disease: Perry et al. for South Africa and Blake, Sinclair and Sugiyarto for the U.K.

3.2.3. Risk and Uncertainty

The consequences of an animal disease outbreak are quite large, but the probability of an outbreak happening are virtually unknown for diseases that have not occurred in the US for a very long time. The risk vectors to disease spread from other countries exist, but the tipping point at which an outbreak would happen is unknown. Furthermore, the extent of the outbreak if/when it does happen is unknown. Thus risk and uncertainty should also be examined.

Consider the two most recent instances of Avian Influenza in the US. Neither the outbreak in Texas nor the outbreak in Maryland received much attention; particularly when compared to the media storm surrounding the AI outbreaks in Asia. Epidemic models should capture the uncertainty and risk associated with the disease spread; however, economic models must deal with the uncertainty related to consumer reaction, international market reaction, and market response. Misinformation about an outbreak of FMD could cause significant mispricing in futures markets due to herding behavior, momentum trading and spillover effects. These issues will be explored in Section 6. An area that has received virtually no attention is how risk attitude of policy makers at all levels will impact which control strategies are preferable in the face of an outbreak, which are explored in Section 5.

3.2.4. Integrated Modeling

Current combined epidemic/economic models are generally multidisciplinary efforts between epidemiologists and economists. The epidemic study focuses on the spread of the disease. For example, if a simulated outbreak occurs in a feedlot, the study will return a number of animals in each state (e.g. number dead) and numbers of animal receiving any sort of mitigation treatment. Usually these involve scenarios depicting the use of multiple disease control strategies that can in turn be used as the scenarios for the economic model. The economic model can give a variety of output, depending on which of the model types listed above is used. At a minimum, the economic model gives the value of lost animals, the direct cost of treatment and response, the value of lost production revenue, and the foregone income from shutdown. After the economic analysis results have been examined, the scenarios can be revised if necessary and the study refined.

Thorough, in-depth studies that include the costs of animal disease and evaluate both vulnerability and the complete economic consequences of control strategies are needed to support planning. This section has given an overview of the economic impacts where of an animal disease attack and the approach to appraisal thereof. We also discuss multiple areas that have received little attention.

Thorough analysis requires collaboration, drawing on expertise from the industry plus a science group including those with knowledge in epidemiology, biology, and economics. This level of collaboration is difficult, but indispensible in dealing with the needed issues. Also key to a quality economic assessment is the integration of models and the identification of the right economic impact categories for the disease and region of interest.

3.3. General Framework

In general, the development of a combined economic/epidemic model requires three steps, with an optional fourth step:

1. Define Scenarios
2. Make appropriate adjustments in epidemic model to reflect economic questions
3. Make necessary conversions for the epidemic model output to become the economic model input and make appropriate adjustments in the economic model

4. Provide a feedback loop from the economic model to better inform the epidemic model and or modify the control strategies

Each of these steps will be described in greater detail below.

3.3.1. Defining Scenarios

The first step before starting an integrated economic/epidemic study is to determine the focus and scope of the region to be depicted plus the nature of the disease outbreak and possible control strategies. This includes whether the disease is episodic or endemic, the geographic spread assumptions, what control strategies and control strategy levels may reasonably be employed, and assumptions related to the impact on demand and international trade. These decisions form the assumptions behind the alternative scenarios run and may at least in part determine what kind of epidemic and economic model structure is most appropriate. In general there is always a “base” scenario that runs the integrated simulation model once for no disease incursion. This makes assessment of alternative scenarios more meaningful in that there is a frame of reference from which to compare.

3.3.2. Epidemic Modeling

The second stage in doing integrated disease modeling is to estimate the animal loss, degraded performance and extent of the control effect caused by the disease using principles of epidemiology. This is typically done using an epidemic model. Such models are usually specific to a particular disease and/or region and rely on estimates of parameters for the disease in question. These parameters are typically based on laboratory and field research determining:

- Susceptible Species
- Environmental Factors Affecting Death or Spread and Animal Reactions
- Animal Reaction Rate Distributions (Death, Impaired, Altered Fecundity, etc)
- Spread Rate Distributions
- Effectiveness of Control Strategies

Epidemic models that are "state transition" models examine how an animal will move through a series of states. These states are given different names depending on the model, but are all essentially the same four conditions.

The first state, usually termed "susceptible", identifies the population that could get the disease. For example, foot-and-mouth disease (FMD) can be contracted by any type of cloven hoofed animal. The total number of cloven hoofed animals in a particular area, therefore, makes up the susceptible population.

The second state goes by many terms ("latent", "sub-clinically infectious", "incubating" are used in the models discussed here), but is usually the state in which the susceptible animal has contracted the disease but has not yet shown any clinical signs. For many diseases animals in this state can still "shed" the disease, meaning other susceptible animals can contract it. Day one of the disease episode is assumed to be the day the first animal enters this state.

The third state is the "infectious" or "clinically infectious" period in which the signs of the disease become apparent. It is usually at this stage that the disease is diagnosed and response begins, but random testing may reveal the disease during the second stage.

The fourth stage, "recovered/removed", captures both the biological state of the disease and the results of disease response activities. Recovered implies animals have either developed antibodies to the disease during the period they were sick and are now immune from the disease but could be impaired or have some differential performance characteristic, or it could also capture the impact of vaccination in conferring immunity on animals. Removed implies that animals have died, either due to the disease itself or because they were slaughtered for disease control purposes.

This study will utilize the integration of two such foreign animal epidemic models have assessed FMD—AusSpread (Ward et al., 2009) and the DADS model (Bates, Thurmond and Carpenter). These models have been integrated with FASOM to assess economic impacts in studies completed under the National Center for Foreign Animal and Zoonotic Disease Defense (FAZDD). They are discussed in detail below.

3.3.2.1. AusSpread

The AusSpread model was originally developed by the Australian Department of Fisheries and Wildlife (Garner and Lack), but was later re-specified for the High Plains of Texas (Ward et al., 2009). AusSpread is a stochastic, state transition model whose states are referred to as susceptible-latent-infected- recovered/removed (SLIR). The model is spatially driven, operating within a geographic information system (GIS) framework. The model uses initial data on region distributions of livestock species including the location and size of feedlots, dairies, large and small beef operations, swine, small ruminants (sheep and goats) and backyard herds. Intensive survey work was done to estimate these herds predicted contact structure in order to most accurately model the spread of FMD within the High Plains region (Ward et al.,2007). The AusSpread model uses direct and indirect contact pathways to model disease spread. In addition to modeling contacts between herds the model also incorporates disease spread due to sale barns, order buyers and windborne spread from large feedlots and swine facilities (Ward et al., 2007).

3.3.2.2. The Davis Animal Disease Simulation Model

The Davis Animal Disease Simulation (DADS) Model was developed to simulate FMD spread and has been specified to represent conditions in the concentrated dairy producing region of the Central Valley of California by Bates, Thurmond and Carpenter. The DADS model is a spatial, stochastic epidemic model designed to simulate intra-herd and inter-herd transmission of foot-and-mouth disease (FMD). Like AusSpread, the DADS model is a state transition model, which tracks herds as they go through disease states susceptible, sub-clinically infected, clinically infected, recovered/removed (SIR). It uses Monte-Carlo simulations to identify the transition of FMD to naive herds starting with a randomly selected index herd, then tracks the progression of the disease after control strategies have been implemented. Livestock premises in the model include beef, dairy, swine, goats, and sheep as well as sale yards. The model utilizes species-specific transition periods, GIS locations of herds, and probability distributions on direct and indirect contacts among herds.

3.3.3. Economic Modeling

The third stage is the bridging of the epidemic and economic models and the disease related adjustments in the economic model. There are many factors that may determine which kind of economic model is appropriate. This would be decided in the first stage when the focus and scope of the integrated effort is determined. If the focus is geographically small, examining local region impacts only for example, then an economic model like an input/output (I/O) model might be appropriate as prices probably do not change. If the interest is solely on the cost of one particular control strategy compared to another in a small infection area, then a cost calculating cost-benefit analysis (CCCBA) might be appropriate. If however, the desire is to capture to the impacts of the disease to the fullest extent possible, then a partial equilibrium or a computable general equilibrium model should be utilized.

In this particular examination, a model that maintains a great amount of flexibility is chosen. The Agricultural Sector Model (ASM) portion of the Forestry and Agricultural Sector Optimization Model (FASOM) has the capability to examine all three level of focus because it has imbedded within a large partial equilibrium model both the capability to do a CBA or an I/O analysis.

3.3.3.1. FASOM

The Forestry and Agricultural Sector Optimization Model (FASOM), is a highly flexible mathematical programming model of the forest and agricultural sectors of the United States. For detailed mathematical description of the model see "FASOMGHG Conceptual Structure and Specification: Documentation" by Adams et al. This model uses a price-endogenous, spatial equilibrium market structure that simulates the allocation of land over time to competing activities in both sectors as well as the resultant consequences for the commodity markets supplied by this land. The model is intertemporal, meaning it can be run dynamically (multiple periods up to 100 years) or statically (single year). The model seeks to maximize the net present value of consumer and producer surplus or the net returns from the forest and agricultural sector activities. The model is designed to allocate resources such that a Pareto Optimal allocation is achieved. This structure allows for the simulation of prices, production, land usage, consumption, and other economic indicators under the animal disease scenario depicted in the epidemic data (Adams et al.). The ASM portion of FASOM focuses solely on the allocation of land among agricultural activities—cropland and grassland—rather than forestry activities. Since no forces are at work in an animal disease outbreak that might change the short term allocation of land into forestry, the focus can remain on the ASM portion of the model.

3.3.3.1.1. Overview of the ASM Structure

The Agricultural Sector Model contains budgets for beef, dairy, hogs, sheep, broilers, turkeys, egg layers and horses although the last category is treated in a very cursory fashion. Within the beef and hog operations a number of intermediate budgets are represented to separate out important stages of production.

- Beef: Beef animals generate fed and non fed beef with intermediate outputs of heifer and steer calves, heifer and steer yearlings and cull cows. We model production at the cow-calf, stocker and feedlot stages plus an infusion of calves and cull cows from the dairy herd. Specifically we represent cow/calf operations, steer and heifer calves in stocker operations, steer and heifer yearlings in stocker operations, beef yearlings in feedlots, and beef calves in feedlots.
- Dairy: Dairy animals generate milk and calves with intermediate outputs of cull cows.

- Hogs: Hogs generate fed hogs with intermediate outputs of feeder pigs and cull sows. We model production at the (1) farrowing, (2) finishing and (3) farrow to finish stages.
- Sheep: Sheep generate wool, lamb and cull ewes.
- Turkeys: Turkeys generate turkeys.
- Broilers: Broilers generate broilers.
- Egg Production: Hens generate eggs. A single laying hen on average produces 257 eggs or just over 21 dozen per year.
- Horses and Mules: Horses and mules produce horses and mules.

Livestock budgets in ASM generally depict several major categories of items, which might include:

- production of meat, wool, or milk in pounds produced per year per animal
- intermediate animals moved to other sectors in cwt – net of usage of animals for replacements
- use of intermediate animals moved from other sectors (negative sign in table) in cwt
- use of feed in cwt
- use of pasture in acres
- use of grazing in animal unit months (aum)
- use of other inputs in $
- other costs in $
- greenhouse gas emissions in metric tons

In implementing an animal disease, the focus will be on reducing the production of outputs and increasing other costs. This will imitate a “disease shock” on the region of interest. Budgets in ASM are normalized to a one animal basis. This means epidemic data in terms of head slaughtered, vaccination, or restricted must also be normalized. Intuitively, the impact of the disease is spread evenly across an entire region such that the average productivity per animal in the region is reduced and the average cost of production per animal is increased. To see how an animal disease shock is imposed in the overall conceptual structure, refer to Figure 19. Because of the supply and demand relationships in the model, an animal disease shock impact assessment can occur both upstream and downstream of the actual livestock production budgets.

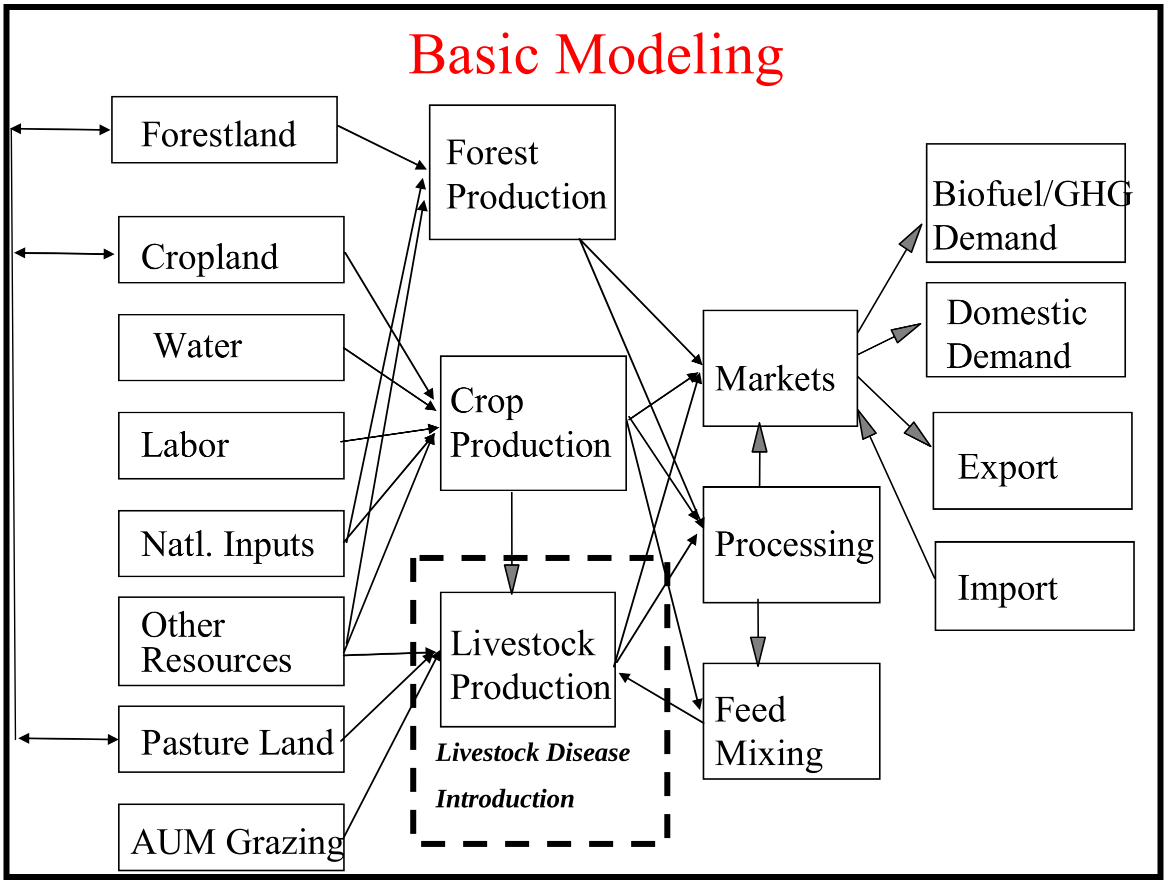


Figure 19. Basic FASOM Modeling Structure and Disease Shock Imposition (adapted from Adams et al.)

3.3.3.1.2. Geographic Representation

ASM is built on a county level, results are reported on either a sub-regional basis or are aggregated to a regional basis. The full ASM runs over 11 regions and 66 sub-regions.

The 66 sub-regions consist of one sub-region for each continental US state except for further breakdowns in California, Illinois, Indiana, Iowa, Ohio, Oregon, Oklahoma, Texas and Washington. These states have sub-state production regions based on differences in production conditions.

In addition to the trade of goods within the US regions and sub-regions, FASOM also allows trade flow with 37 international regions listed below. Figure 20 gives a map of these regions. Within the model, animal products the US imports are eggs, wool, non-fed beef, fed beef, pork, secondary dairy products (i.e. butter, cheese, dry milk), and some live cattle. The US exports of animal products are eggs, fed beef, wool, pork, secondary dairy products, chicken and turkey.

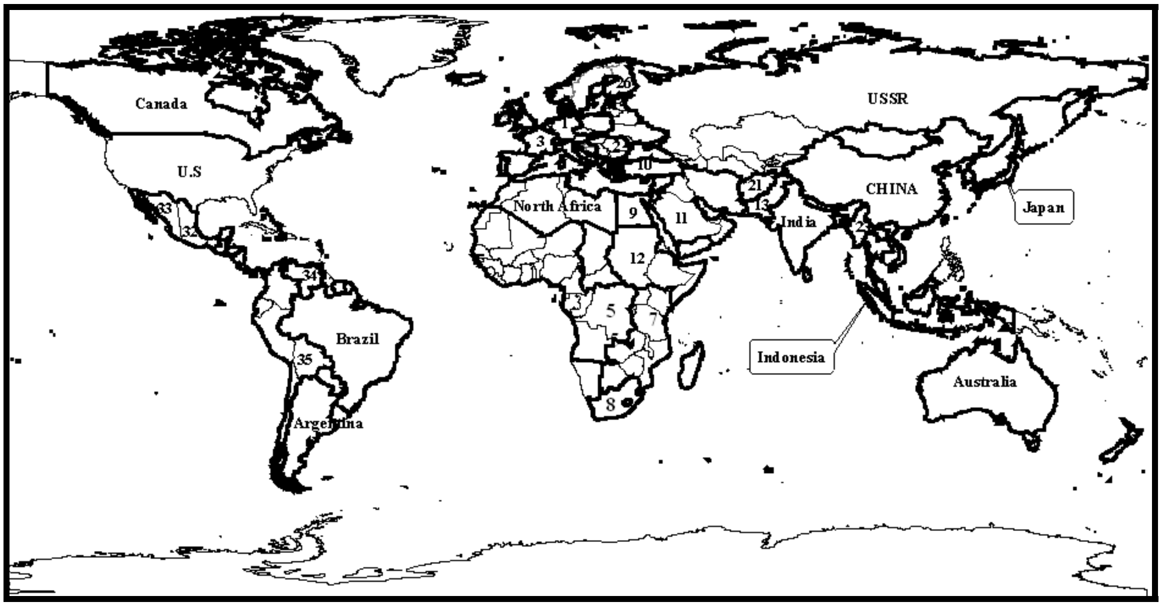


Figure 20. International Market Regions in ASM

Outputs and inputs are also moved both through time and across space. This means a steer calf produced under cow/calf budgeting assumptions in Florida can later become a stocker calf in a stocker calf budget in Kansas. Alternatively, corn raised using a crop budget in Iowa can later be fed in a cattle finishing operation in Texas.

Land allocations for livestock operations are assigned based on the biological carrying capacity of land in a particular region. Each animal in a cow/calf or grazing operation requires a certain amount of animal months of grazing from pasture land according to the budgets within FASOM specific to a particular sub-region. Similarly, feedlots are assigned a specific amount of land to operate. ASM can shift land from pasture land to crop land, indicating a movement from animal production to crop production or vice versa.

3.3.3.1.3. Modeling the Market

The market structure in FASOM includes a mixture of explicit and implicit demand and supply curves in a five-year period that are solved such that the affected agricultural markets are in equilibrium (Adams et al.). In the case of animal disease, land cannot shift to reach equilibrium but as supplies change in response to the slaughter price will shift. From Adams et al. these supply and demand curves include:

- regional product supply,
- national raw product demand,
- regional or national processed commodity demand,
- regional or national supply of processed commodities,
- regional or national (depending on commodity) export demand
- regional or national (depending on commodity) import supply,
- regional feed supply and demand,
- regional direct livestock demand,
- international transport perfectly elastic supply and

- country-specific excess demand and supply of rice, sorghum, corn, soybeans and the 5 types of wheat

3.3.3.1.4. Using FASOM to Model Animal Disease

FASOM has several benefits in this type of analysis. First, it provides a great deal of detail in the effects of a disease outbreak. In animal disease modeling there is an immediate death loss, but there is also a reduction in the animals entering the meat chain in later periods due to the need to replace breeding stock. For example, in beef cattle, heifers that would have been fed out are instead diverted to replacement breeding stock. This more fully captures, not just the one shot death loss of the disease, but also the long term recovery of the industry from the disease.

The regional structure also allows more detail since a disease shock can be confined (quarantined) to a single region or sub-region and system resilience can be reflected with readjustments in the locus of production. Also inputs like feed are diverted to alternative beneficial uses. The FASOM model also captures the change in welfare from an animal disease because it calculates a dollar loss of value added net income and a cost of commodity prices rising. The trade impacts can also be estimated within FASOM.

3.4. Modeling Combined Economic/Epidemic Studies

Imposing a shock like an animal disease requires both the use of an epidemic model that specifies animal mortality, infected animals, extent of treatment activities and an economic model that captures the broader impacts of the disease beyond death animals. This type of analysis has been performed both with an AusSpread-ASM integration and a DADS model-ASM integration. This section provides a broad overview of the assumptions and general structure of these models for imposing an animal disease (FMD) in the US. The following section will discuss the programming details.

3.4.1. Integrating Epidemic Model Results into ASM

In this dissertation, two models—AusSpread and the DADS model—were used to examine the consequences of FMD. Since the basic results of both models are so similar, so is the general structure of the integration scheme. Thus this section will first present the interface simultaneously for both models, covering a discussion of the data drawn from the epidemic models, adjustments required in the ASM model and finally the kind of output that can be achieved.

3.4.1.1. Determining the Problem Parameters

There are several assumptions that must be made before integrating an epidemic model into ASM. First, is the disease assumed to be episodic or endemic? Episodic disease is a single outbreak, which is subsequently eradicated through disease management strategies over a relatively short period of time. If a disease becomes endemic it will periodically resurface in a region either because it could not be eradicated upon entry in that region or because it continues to spread from other regions/countries. West Nile Virus is an example of a zoonotic disease that has become endemic in the United States.

In order to assess a single episode of animal disease, ASM—which is an intermediate run equilibrium model—is essentially turned into a short run disequilibrium model by restricting the model from moving land and herds used in affected livestock production to other uses and, in the case of herds, places. This means the ASM model must be manually locked down spatially at the production level. Without this limitation the model would move the locus of cattle production to other regions and transfer land in the infected area from beef production to alternative efficient uses plus adjust feed production. However, for animals moving from birthing to growing operations the model should still be able to divert animals moving from non-infected to infected regions. Similarly inputs, such as feed, can be diverted from infected regions where pre-disease input levels are no longer needed as a result of slaughter. If the disease is modeled as endemic, such a re-structuring of the impacted industries would be appropriate.

Second to be considered are the kind of disease management alternatives that are realistic in the context being considered. Some of the more dangerous diseases to U.S. agriculture have not occurred here in decades. So care must be taken in getting parameters that will make the simulation models as accurate a portrayal of reality as possible. Also, there are certain disease response alternatives that will be appealing from an epidemiology standpoint but may be quite costly. Thus, the costing assumptions in the economic model must be comprehensive, gathered carefully and current.

Finally, what will the secondary impacts of the disease management alternatives be? This is a question that cannot be answered in the epidemic model; instead, the economic model must seek to examine issue like lost trade, welfare slaughter, processor vulnerability and livestock inputs supplier vulnerability. The remainder of this essay is dedicated to going through the ASM structure, and then describing each step in integrating epidemic models.

3.4.1.2. Data Requirements from Epidemic Models to Drive Economic Models

In order to incorporate results from an epidemic model into the parameters describing the sector in the ASM model, data need to be matched up as an input to the economic model. This includes first defining a standardized set of inputs to the economic model. In general the sets required in the integrated ASM model to run an FMD disease outbreak are as follows:

Altrun: The names of the set of alternative scenarios that are being considered. This will be each unique identifier for each scenario name if the model is being run on average epidemic results, or it could be a unique identifier for each iteration within each scenario if the full distribution of economic losses is desired.

Iter: The numbers of stochastic replications run in the epidemic model. This must be at least 1 if the averages from the stochastic epidemic model are being run through the economic model, but may go up to the maximum number of iterations run in the stochastic epidemic model. For the two epidemic models considered here the standard number of iterations was 100.

Id: A unique identifier for every premises in the affected region. This will vary by region and perhaps epidemic model.

Type: For each premises in the region, the type of that premises should be indicated so the appropriate budgets can be adjusted. At a minimum these should indicate operation type on a premises (beef grazing, beef feeding, dairy, sheep or swine operation). Ideally, more detail would be provided as will be discussed later on.

All_stock: The total number of animals on each premises.

Status: The herd status at the end of the run for each unique premises id. This will generally be limited to the statuses corresponding to the states of the epidemic model: susceptible, infected, dead and vaccinated. Adult animals that contract FMD rarely die from the disease, but the current U.S. response policy is to "stamp out" all of the infected and dangerous contact animals combined with vaccinate-to-die if vaccination is used. So the status of each premises should be categorized as either susceptible or dead at the end of the outbreak. This is because all sub-clinically infectious, infectious and immune animals are slaughtered.

In addition, if alternative runs will include movement restrictions of herds then costs related to these movement restrictions can be calculated. Since FMD is so contagious, current US policy indicates quarantine zones will be used to contain the disease and vaccinations may be considered as a means to contain the disease. The data requirements from the epidemic model to estimate these movement restriction costs are as follows:

Restricted: This is an indicator variable used to identify herds in the quarantine zone (0 = not restricted, 1 = restricted). This variable may need to be conditioned on later so that only restricted premises that were not slaughtered for infection or vaccination are in a separate group. This allows an estimate of the animals that would need to be maintained while the movement restriction is in place, but will still be alive at the end of that period.

When_res: The number of days that the herd is under quarantine.

Days_left_res: the number of days that the herd will remain under quarantine at the end of the epidemic. Some models do not have this number, rather a standardized assumption can be made. For example, a 90 day period in which no new cases are identified may be the standard policy before movement restrictions are lifted.

Animals under movement restrictions will also be subject to additional surveillance to check for signs of FMD. There will be increased costs associated with the labor and materials necessary to perform these surveillance visits, so the following data would be required to calculate these increased costs:

Surv: An indicator variable used to identify herds that will be under surveillance

N_visits: The number of times the herd is visited before surveillance ceases. This may be two visits in which no signs of FMD are observed, or may be weekly for the entirety of the outbreak. This is an assumption of the modeler or defined by policy generally.

A control strategy that is the center of some controversy is the use of vaccine. For scenarios involving vaccination an additional piece of data is required:

Vacc: Indicator variable for herds that are vaccinated (0=no vacc, 1=vacc). If a vaccinate to live strategy has been employed, these animals will only be subject to the increased cost of the vaccination process and potentially a decline in the value of the animal after the movement restriction ban has been lifted. If a vaccinate to die strategy has been employed these animals must be added to the death loss from the disease. If vaccination is used, under current US policy those animals must also be slaughtered.

3.4.1.3. Incorporating Data from the Epidemic Models into ASM

Data from both the AusSpread model and the DADS model are reported in terms of animal populations receiving particular treatments. The next step in integrating the two models is to convert that data into a format used to adjust the budgets in the ASM model. This is a simple conversion to percentage impacts. For example, for the animals slaughtered:

$$\%Dead_{i,t} = \sum_p Dead_{i,t,p} \Big/ \sum_p All\_Stock_{i,t,p}$$

So for the sum over all premises indicated by ids (p) where the status is “dead” is divided by the sum of all stock in all statuses for premises’ ids. This calculation would be performed for each stochastic replication (i) and each type of herd (t). Thus the data is transformed from individual premises impacts to regional impacts where for each type of herd (e.g. cow/calf or dairy) the percentage of that particular herd type population in the diseased region that is susceptible, dead, vaccinated, or quarantined are calculated for each iteration. This allows the regional budgets in ASM to be adjusted as discussed earlier.

3.4.1.4. Adjustments Performed in the ASM Model

Herd types in ASM impacted by FMD are beef cattle (cow/calf, stocker and feeder), dairy cattle, sheep, and hogs (farrow to finish, feeder pig production and pig finishing). Scenarios considered varied between the High Plains study and the California study, but in both cases alternative disease mitigation strategies were considered and compared. The High Plains study looked at 64 scenarios covering

- Four infection index herd types (a large feedlot, a backgrounder feedlot, a large beef grazing operation and a backyard operation)
- Sixteen different combinations of disease mitigation strategies

  - early versus late detection
  - adequate versus inadequate vaccine
  - ring and targeted vaccination
  - regular versus enhanced surveillance

The California study looked at 15 scenarios for a dairy index herd covering

- Three different vaccination option (no vaccination, 10 kilometer ring vaccination and 20 kilometer ring vaccination) and
- Five different detection periods (7 day delay, 10 day delay, 14 day delay, 21 day delay and 22 day delay).

Both models made adjustments in ASM as discussed below.

For each budget two adjustments were made. The first is a decrease in the regional output of impacted animal products. For example, in California dairy budgets both the number of dairy calves being produced and the amount of milk being produced is reduced to reflect the extensive slaughter associated with disease control. The second adjustment in the budget is an increase in the other costs of producing livestock in that region. These increased costs reflect the costs of disease management and carcass disposal. Costs will be discussed in greater detail later in this paper.

3.4.1.4.1. Beef Cattle Budgets

The number of adults in the beef herd was adjusted to reflect reactions due to the death of directly infected and indirect contacts as a part of the "stamp out" policy as well as the slaughter of infected animals. This necessitated changes in cow calf production, stocker operations and feedlot operations as illustrated in Figure 21. The general budget adjustment is given in the equation below.

$$LB\_Cattle_{\mathrm{Re}g,Type,Animal} = LB\_Cattle_{\mathrm{Re}g,Type,Animal} * (1 - Perc\_Change)$$

Where *LB_Cattle* is the pounds of calves produced by a single cow

Reg: the region of infection

Type: the type of budget being adjusted

Animal: the output of the budget being adjusted

Perc_Change: the percentage of disease loss in the infection region

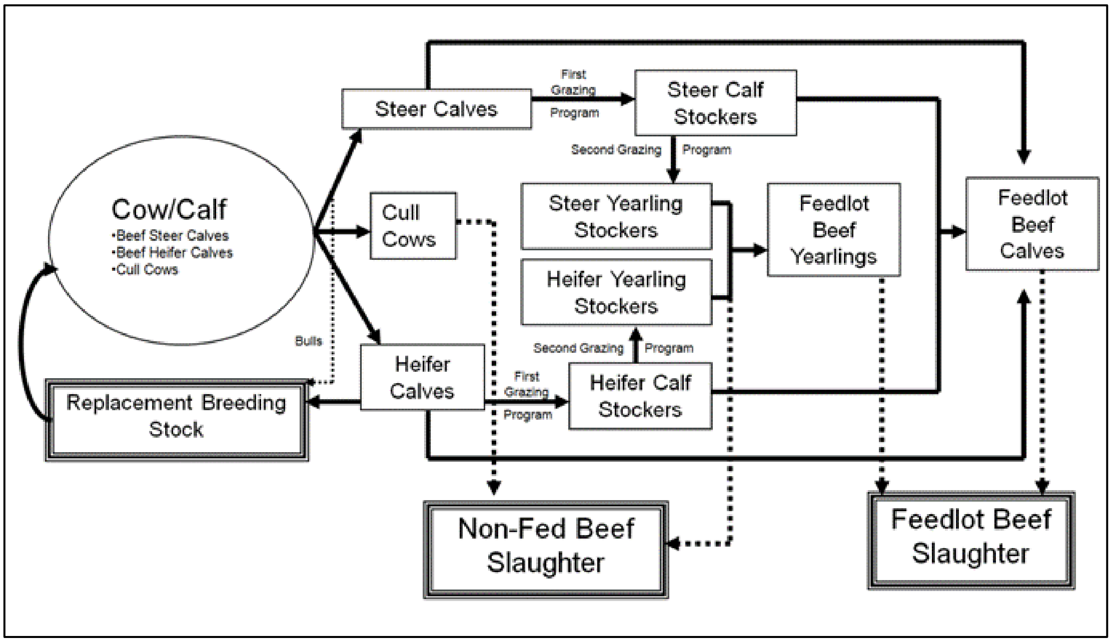


Figure 21. ASM Beef Cattle Flow Chart

3.4.1.4.2. Cow/Calf

The cow/calf budget is the first step in the production process that includes multiple levels of budgets; therefore, by making adjustments in the cow/calf budget effects flow through the entire model. The calves coming out of the cow/calf budget are reduced by the proportion of death loss. Heifer calves must be diverted as replacement animals for the cows that are infected and slaughtered. Herds routinely retain replacement animals from the calves; ordinarily the portion of heifer calves not retained are sent to fed-beef, but under a disease outbreak additional demand for replacements would divert some or all these animals to replenish breeding stock levels. The replacement rate must be explicitly specified in the model.

FMD studies were assumed to be episodic, so the size of the cow/calf herd in all locations was held fixed to reflect the short term impact of the outbreak without long-term adjustment. Table 3 provides a national average budget outline for cow/calf production. In particular, the steer and heifer calves and the other costs must be adjusted.

Table 3. National Average ASM Cow/Calf Budget

Baseline specification	National Average	Units / Description
base.Hay	-0.782	US tons of hay used in production
base.CullBeefCo	0.664	100 lbs of cull been cow on the hoof
base.SteerCalve	2.022	100 lbs of steer calves
base.HeifCalve	1.251	100 lbs of heifer calves
base.CowGrain0	0.771	100 lbs grain blend for cow/calf operation
base.CowHiPro0	0.574	100 lbs protein blend for cow/calf operation
base.Pasture	4.908	Acres of pasture land
base.AUMS	0.754	Animal unit months
base.Labor	8.317	Hours
base.SaltMiner	4.891	Dollar cost of salt and minerals
base.CottonSeed	2.222	Lbs of cottonseed
base.othercosts	201.778	Dollars
base.Profit	188.441	Dollar difference between revenues and costs
base.Methane_EntericFerment	0.045	Metric tons methane from enteric fermentation
base.Methane_Manure	0.002	Metric tons methane from manure management
base.NitrousOxide_Manure	.00023	Metric tons nitrous oxide from manure management
base.VolatileSolidsinManure	4.260	Metric tons of volatile solids from manure management
base.Head	1.000	Budget is for one animal

3.4.1.4.3. Stocker Operations

The imposition of FMD at the cow/calf level decreases the number of steers and heifers that flow into the first and second grazing programs of the stocker operation because of the stamp out policy and also because of quarantine restrictions on animals allowed to move around in the infected area. Stocked calves can move across regions that are unaffected, but they cannot move into or out of the infection region. The yield of stocked calves and stocked yearlings subsequently declines. The disease also causes direct death loss in the stocker operations. Table 4 gives the national average budget for a steer stocker operation; other budgets exist for heifer stockers, steer yearling stockers and heifer yearling stockers.

Table 4. National Average Steer Stocker Budget

Baseline Specification	National Average	Units / Description
base.Hay	-0.022	US tons of hay used in stocker operation
base.SteerCalve	-4.241	100 lbs steer calf input into stocker op
base.StockedSCalf	5.843	100 lbs of steer calves after first stocker phase ready to feed
base.StockPro0	0.362	100 lbs protein blend for stocker cattle
base.Pasture	0.789	Acres of pasture land
base.AUMS	0.631	Animal unit months
base.Labor	1.578	Hours
base.SaltMiner	0.419	Dollar cost of salt and minerals
base.WheatPastu	9.496	Dollar rental rate of green wheat pasture
base.othercosts	60.728	Dollars
base.Profit	67.577	Dollar difference between revenues and costs
base.Methane_EntericFerment	0.045	Metric tons methane from enteric fermentation
base.Methane_Manure	0.002	Metric tons methane from manure management
base.NitrousOxide_Manure	2.300000E-4	Metric tons nitrous oxide from manure management
base.VolatileSolidsinManure	0.795	Metric tons of volatile solids from manure management
base.Head	1.000	Budget is for one animal

3.4.1.4.4. Feedlot Operations

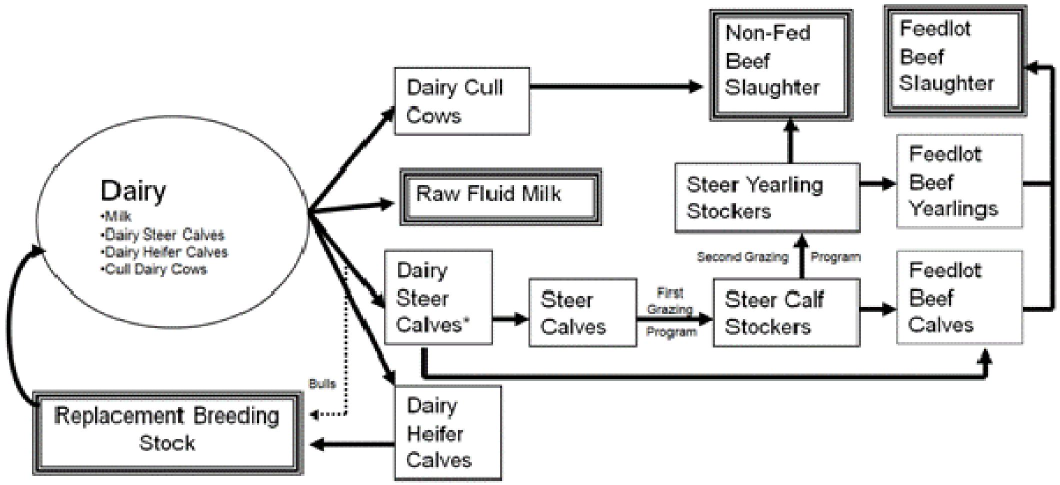
Like stocker operations, feedlots were not held spatially fixed except in the affected region. The amount of fed beef declined due to the reduced number of steers and heifers coming out of the stocker operations and direct from cow/calf operators. In addition to the reduced number of cattle available for feeding, there was a direct death loss of animals in the feedlot. The budgets related to feedlot operations are more complex in that multiple types of feedlot operations exist. However, the feedlot beef calf budget, which also has alternatives for direct feed out and dairy calf feed out not shown, is given in Table 5. A similar budget exists for yearlings in feedlots.

Table 5. National Average Feedlot Calf Budget

Feedlot Beef Calves Baseline Specification	National Average	Units / Description
base.Silage	-0.815	US tons of silage used in feedlot
base.Hay	-0.446	US tons of hay used in feedlot
base.FeedlotBeefSlaughter	11.968	100 lbs fed beef on the hoof
base.StockedCalf	-5.888	100 lbs of calves after first stocker phase ready to feed
base.biomanure	0.714	US tons manure available for bioprocesses
base.CatGrain0	38.991	100 lbs grain blend for finishing cattle
base.HighProtCa	3.233	100 lbs protein blend for finishing cattle
base.Pasture	0.006	Acres of pasture land
base.Labor	3.328	Hours
base.othercosts	89.487	Dollars
base.Profit	-27.280	Dollar difference between revenues and costs
base.Methane_EntericFerment	0.045	Metric tons methane from enteric fermentation
base.Methane_Manure	0.002	Metric tons methane from manure management
base.NitrousOxide_Manure	2.300000 E-4	Metric tons nitrous oxide from manure management
base.ManageManureFrac	0.106	Portion of manure managed in a manure management system
base.VolatileSolidsinManure	0.875	Metric tons of volatile solids from manure management
base.LiquidVSManureVolume	0.880	Liquid volatile solids from manure management
base.HeadinLiquidSystems	1.006	Head involved in liquid management systems
base.Head	1.000	Budget is for one animal

3.4.1.4.5. Dairy Cattle Budgets

Changes in dairy budgets as the result of an FMD outbreak are similar to those in the beef herd. Like the cow/calf herd, the number of cows in the dairy herd was spatially fixed preventing the model from shifting production to non infected areas. Figure 22 provides an overview of the dairy cattle budget flow.



*Dairy Steer Calves merge in with the Steer Calves in the Beef Cattle Flow

Figure 22. ASM Dairy Cattle Flow

The dairy herd experienced a rise in the number of deaths and subsequent reduction in milk produced. Like the cow/calf operation the off farm yield of dairy calves declined due to death loss and replacement needs. The number of dairy steer calves entering the fed and non-fed beef markets declined due to death, so the amount of fed and non fed beef declines in the impacted region. The impact of the reduced yield of heifer calves resulted in a decline in the number of available replacements and a reduction in the amount of fluid milk available for sale.

Table 6 gives the baseline technology specification of the national average dairy budget. Notice the budget produces milk, cull dairy cows and dairy calves, which must be reduced as well as an "other cost" line item which must be increased. Similar budgets increase for alternative technologies, namely the use of Bovine Somatotropin (BST), a 20% increase in productivity as a result of improved genetics and a 20% reduction in the dairy herd size.

Table 6. National Average Dairy Budget

Baseline Specification	National Average	Units / Description
base.Silage	-6.600	US tons for dairy production
base.Hay	-5.060	US tons for dairy production
base.Milk	193.906	100 lbs of raw milk
base.CullDairyCows	1.657	100 lbs of cull dairy calves
base.DairyCalves	2.057	100 lbs of dairy calves
base.biomanure	4.940	US tons manure available for bioprocesses
base.SoybeanMeal	0.860	US tons soybean meal
base.DairyCon0	108.529	100 lbs grain blend for dairy cattle
base.Pasture	1.750	Acres of pasture land
base.Labor	31.587	Hours
base.othercosts	1272.391	Dollars
base.Profit	1435.851	Dollar difference between revenues and costs
base.Methane_EntericFerment	0.138	Metric tons methane from enteric fermentation
base.Methane_Manure	0.077	Metric tons methane from manure management
base.NitrousOxide_Manure	0.001	Metric tons nitrous oxide from manure management
base.ManageManureFrac	0.039	Portion of manure managed in a manure management system
base.VolatileSolidsinManure	6.698	Metric tons of volatile solids from manure management
base.LiquidVSManureVolume	6.707	Liquid volatile solids from manure management
base.HeadinLiquidSystems	1.000	Head involved in liquid management systems
base.Head	1.000	Budget is for one animal

3.4.1.4.6. The Sheep Budget

Sheep production is represented as a single stage process, so the budget has to be reduced by the amount of sheep killed under the stamp out policy. The number of sheep operations in the infected region was held fixed to reflect the short term impact of the outbreak without long-term adjustment. Due to the slaughter in the sheep herds, the amount of lamb available to sale declines as well as the amount of wool that will enter the market. Figure 23 provides a flow of the single stage budget and Table 7 provides the national average budget for sheep production.

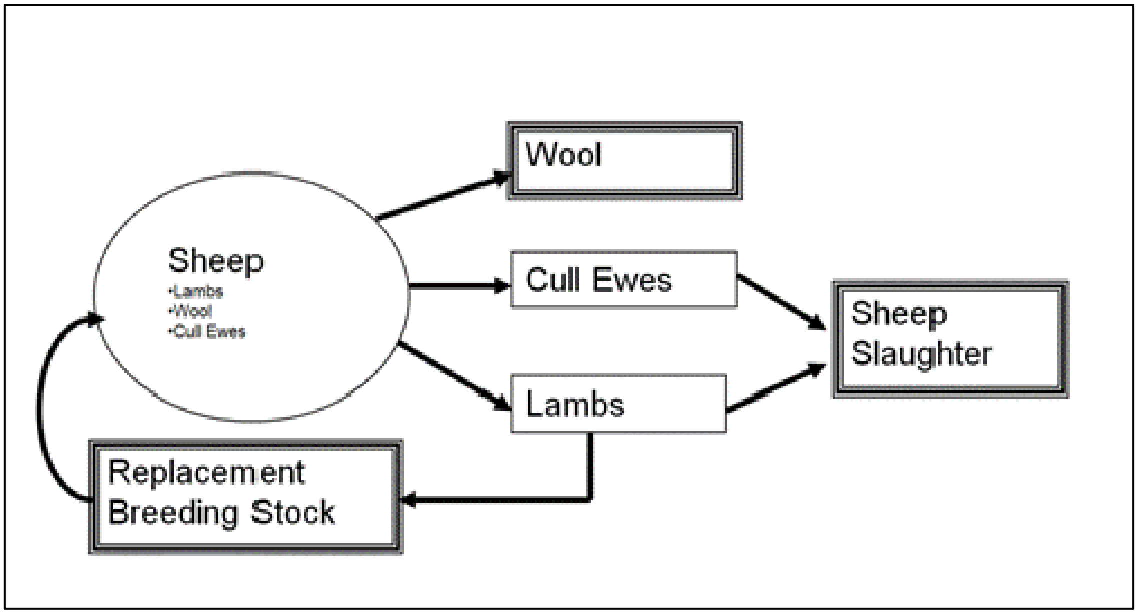


Figure 23. ASM Sheep Budget Flow

Table 7. National ASM Sheep Budget

Baseline Specification	National Average	Units / Description
base.LambSlaugh	1.541	100 lbs live wt of slaughter lambs
base.CullEwes	0.663	100 lbs live wt of cull ewes
base.Wool	31.124	Lbs raw wool
base.SheepGrn0	1.349	100 lbs grain blend feed for sheep
base.SheepPro0	1.238	100 lbs protein blend feed for sheep
base.Pasture	2.215	Acres of pasture land
base.AUMS	2.714	Animal unit months
base.Labor	4.792	Hours
base.SaltMiner	6.688	Dollar cost of salt and minerals
base.othercosts	47.485	Dollars
base.Profit	62.694	Dollar difference between revenues and costs
base.Methane_EntericFerment	0.012	Metric tons methane from enteric fermentation
base.Methane_Manure	0.001	Metric tons methane from manure management
base.NitrousOxide_Manure	.000007	Metric tons nitrous oxide from manure management
base.VolatileSolidsinManure	0.257	Metric tons of volatile solids from manure management
base.Head	1.000	Budget is for one animal

3.4.1.4.7. Farrow to Finish and Feeder Pig Production Budgets

There were two ways to address the swine production budgets in ASM when specific types of swine operations are not specified in the epidemic data. The first way was to adjust at the end using the slaughter hog budget. The second way, and the one used, is to adjust at the beginning in the budgets dealing with farrowing. The simple flow of hog information through the ASM model is presented in Figure 24.

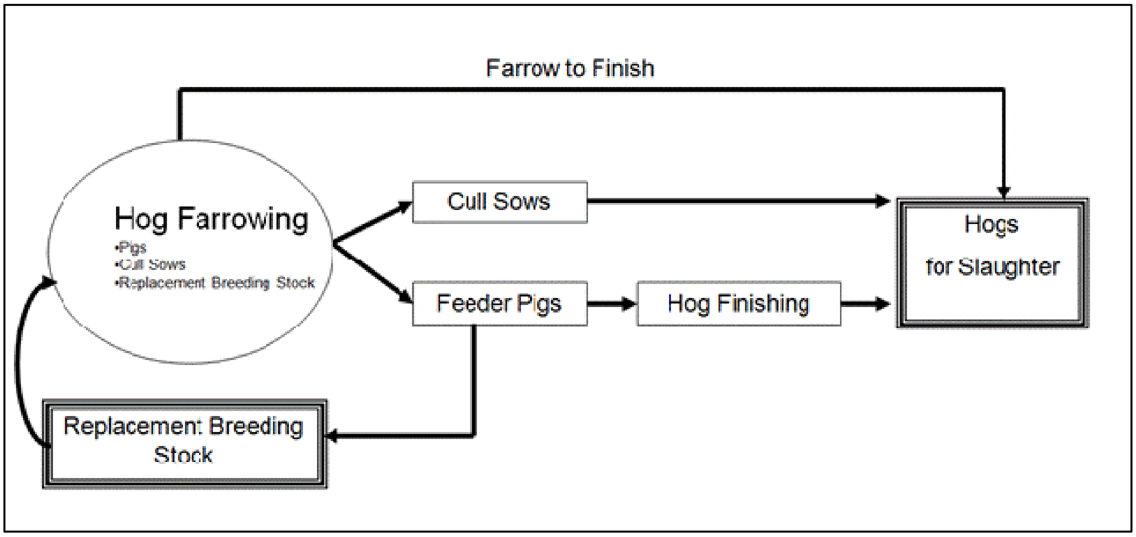


Figure 24. ASM Hog Flow Chart

There are two farrowing operation budgets. Farrow to finish are those operations that take a pig from birth to slaughter. These types of operations are in the minority in modern slaughter pig production. The second type of budget is feeder pig production, which takes the animal from birth to weaning. From there the feeder pig moves into a feeding operation followed by slaughter. These two front end budgets are spatially locked down in the same way and for the same reasons as the cow/calf budget. Pig finishing is not spatially locked down. In this particular case, hog production losses are taken out of the feeder pig production budget, which is provided in Table 8.

Table 8. National Average Feeder Pig Budget in ASM

Baseline Specification	National Average	Units / Description
base.FeederPig	8.798	100 lbs live weight of feeder pigs
base.CullSow	2.289	100 lbs live weight of cull sows
base.biomanure	1.966	US tons manure available for bioprocesses
base.FPGGrain0	47.655	100 lbs grain blend for feeder pigs
base.FPGProSwn0	11.043	100 lbs protein blend for feeder pigs
base.Labor	46.327	Hours
base.FeedMix	23.314	Dollar cost of feed blending
base.othercosts	359.592	Dollars
base.Profit	373.218	Dollar difference between revenues and costs
base.Methane_EntericFerment	0.001	Metric tons methane from enteric fermentation
base.Methane_Manure	0.010	Metric tons methane from manure management
base.NitrousOxide_Manure	0.00002	Metric tons nitrous oxide from manure management
base.VolatileSolidsinManure	2.987	Metric tons of volatile solids from manure management
base.LiquidVSManureVolume	2.989	Liquid volatile solids from manure management
base.HeadinLiquidSystems	1.001	Head involved in liquid management systems
base.Head	1.000	Budget is for one animal

3.4.1.5. Output from the Economic Model

The ASM Model has several benefits in terms of examining multiple areas impacted by the disease shock. The impact categories discussed below are by no means all that can be examined, but they are the areas that have been used most intensively for this animal disease analysis.

Change in Welfare: Welfare change is a measure of economic gain/loss that is more encompassing than loss measures like GDP or disease mitigation cost (Paarlberg, Lee and Mathews) and useful in determining the impact of policy changes and disease shocks (Rich, Miller and Winter-Nelson). ASM shows changes in total national agricultural welfare from the baseline of no disease and breaks those changes down by domestic agriculture producers, consumers and processors. In addition it examines changes in welfare for foreign producers, consumers and processors. The focus here will be on changes in total US welfare from agriculture.

Regional and Sub-Regional Agricultural Producers Surplus: Only examining the total US agricultural producers welfare changes may mask the fact that some regions' producers will be hit harder than other regions. In fact, some regions producers who are not directly infected could potentially gain from the outbreak. To examine these dynamics producers surplus is best examined on a regional and sub-regional basis.

National Price Changes for Major Raw Commodities in $/Unit: These percentage changes in the price from the no disease base are a key benefit to using the ASM model. They include not just the commodities impacted directly like beef, pork and milk but also the price changes in complement and substitute products. This more fully captures the dynamics of who gains and who loses from the disease outbreak.

Input/Output Analysis: Using multipliers provided by the Food and Agricultural Policy Research Institute (FAPRI) model, a simple input/output analysis is performed in the impacted region. In particular employment effects are examined.

Up to this point, this essay has attempted to provide intuition and justification for integrated economic/epidemic modeling approach taken. If a more detailed explanation of the programming related to an integrated model is desired, see the Appendix of this dissertation. Since the two models are very similar, only the DADS-ASM integrated model is presented.

3.5. Additional Economic Modules

In addition to the work done in ASM, the output of the economic model can be used in additional economic analyses. In particular, analyses could be done on risk aversion by decision makers in ranking alternative control strategies as shown in the context of the AusSpread-ASM integration and the DADS-ASM integration the examination of trade impacts over multiple years into the future, or the balance of pre-event investment to event disease control costs. Ideally, there would be a feedback from the economic model to the epidemic model. The economic model results would refine epidemic model assumptions on control strategy parameters. This is an area that could be pursued in the future.

3.6. Summary

This essay has outlined the key assumptions underlying economic model choice and has given an overview of how the linked model has been developed. Of the three most often used economic models—CCCBA, I-O, and PE—the choice will depend on the disease characteristics, epidemic model (e.g. size of region, spread rate assumptions etc.) and international market restrictions policies. The disease characteristics and epidemic model will determine the size of the supply shift and the size of the demand shift. Also, the assumed size of the outbreak, the region in which it is assumed to occur, and the focus on short run versus long run economic impacts determines whether the assumption of perfectly inelastic supply or perfectly elastic demand is appropriate. International trade restrictions that can be expected from the outbreak will also influence the type of model used, particularly when the market being impacted has a large presence in the international market (e.g. US pork).

The integrated model developed here assesses impacts in vertically and horizontally linked markets, consumers and producers, and domestic and international markets within a single framework. This is a unique contribution among partial equilibrium integrated models since most have done some portion of this but have not modeled the entire agricultural sector. Rather they have modeled the livestock sector and select related sectors to answer specific questions of interest.

4. ESSAY 3: A CASE STUDY IN LINKING FMD EPIDEMIC MODELS WITH THE ASM MODEL—THE DADS-ASM INTEGRATION APPLICATION IN THE CENTRAL VALLEY CALIFORNIA DAIRY REGION

4.1. Introduction

Essay 3 carries out a strategy assessment using the methodology developed in essay 2. California is the number one dairy producing state in the U.S. with 1.87 million head of cows producing $6.5 billion worth of milk and other dairy products in 2007 (USDA-NASS, 2008). Foot and mouth disease (FMD) is a large potential threat to the health and economic productivity of this industry. Herein a joint epidemic-economic study examining the consequences of an FMD outbreak in this industry was carried out to examine the effect of a number of management alternatives. The focus of this study was the Central Valley in Northern California. The exact index infection point of the outbreak will be chosen at random to avoid security sensitivities.

4.2. Background on California Livestock Agriculture

According to the 2007 Census of Agriculture, California was ranked as having the highest total value of agricultural products sold in the US at $33 billion. The majority of this comes from crops, nursery and greenhouse products; however, the production of livestock, poultry and their associated products was a $10.9 billion industry (NASS-USDA, 2008). California is ranked second only to Texas in terms of livestock value.

In California milk and other dairy products from cows are the highest value livestock commodity group at $6.9 billion in value of sales; this represents 22% of the nation's milk supply. This is followed by cattle and calves ($2.5 billion), and poultry and eggs ($1.5 billion) (USDA-NASS, 2009). Swine, sheep, goats and other animals make up a relatively small portion of the state's value of livestock. In terms of numbers of animals, poultry were the largest animal category, but cattle and calves represented 5.5 billion animals (USDA-NASS, 2009).

California is ranked first in dairy production in the US followed by Wisconsin, New York, Idaho and Pennsylvania (Dapper et al.). It is hypothesized that these other regions could potentially gain from a major animal disease outbreak in California due to slashed milk supplies and consequently increased milk prices. In 2008, total annual milk production in California surpassed 40 billion pounds (Francesconi et al.). This was a record breaking year, and dairy cooperatives and other processing plants initiated base caps for producers. There are 34 milk producing counties in the state, but almost 70% is produced in Tulare, Merced, Stanislaus, Kings and Kern counties (Dapper et al.). This area is the focus of the study presented here, particularly Tulare county.

The utilization of milk has been primarily for butter and nonfat dry milk powder (34% of production) and cheese production (43% of production) where the primary cheeses produced are Mozzarella, Cheddar and Jack (Dapper et al.). The leading counties in dairy manufacturing capacity are Merced, Tulare, Madera, Humboldt and Yolo accounting for a total of 86% of manufacturing capacity among them (Dapper et al.). There were 117 plants in California in 2008 (Dapper et al.), creating the potential for a bottleneck for remaining facilities if a large number of these facilities are under movement restrictions. If the manufacturing facility is located in the county infected by disease, it will also be under movement restrictions halting the movement of products outside the movement restriction zone. Furthermore, there is a question as yet unanswered of whether manufacturing facilities would allow milk from premises under surveillance for the disease from entering their operation without stringent testing and cleaning of trucks.

4.3. Study Design

4.3.1. Scenarios

The hypothetical FMD outbreak was initiated in a dairy herd by contact with a feral hog, and subsequently spread through California's population of domesticated livestock. The epidemic was simulated using the DADS model. Resulting data on the losses from the epidemic were run through the ASM component of the FASOM model to gain perspective on the economic consequences of the disease, including both the direct disease mitigation costs and other economic consequences. Specific disease mitigation issues considered here were:

- Rapidity of detection of an outbreak. Specifically initial detection of the outbreak will be simulated with it occurring 7, 10, 14, 21 or 22 days after the initial infection.
- The use of vaccination versus not using vaccination, plus 10 and 20 km vaccination around the infected premises (IP).
- The hourly cost of delay in detection. Specifically what is the cost to the US for every additional hour of delay between 21 and 22 day detection.
- The effects of disease management on welfare slaughter and milk "dumping".

Table 9 provides the exact scenarios considered, the results of which are reported throughout this report. The DADS model was used to simulate each scenario 100 times to characterize a distribution of potential outcomes for the detection and vaccination scenarios. In ASM, economic impacts were assessed assuming 100 independent, random trials. Then risk aversion of decision makers in the model was considered and strategies evaluated in relation to their risk preference. The model was also modified to allow greater consideration of welfare slaughter and national trade alternatives.

Table 9. Epidemic Model Scenario Definitions

Scenario Name	Vaccination	Delay
Base (No disease outbreak)	NA	NA
NoVacc_7Day	None	7
NoVacc_10Day	None	10
NoVacc_14Day	None	14
NoVacc_21Day	None	21
NoVacc_22Day	None	22
10Km_7Day	10 km ring around IP	7
10Km_10Day	10 km ring around IP	10
10Km_14Day	10 km ring around IP	14
10Km_21Day	10 km ring around IP	21
10Km_22Day	10 km ring around IP	22
20Km_7Day	20 km ring around IP	7
20Km_10Day	20 km ring around IP	10
20Km_14Day	20 km ring around IP	14
20Km_21Day	20 km ring around IP	21
20Km_21Day	20 km ring around IP	22

4.4. Economic Impact Categorizations

Economic impacts can be divided into two categories: direct and secondary. Most studies examining livestock disease have focused on direct impacts of the disease. Due to the highly integrated nature of the modern economy, consequences of agricultural contamination at any given point along the supply chain could be manifested in other sectors of the economy as well. For example in the recent foot FMD outbreak in the UK, the largest category of losses came from tourism. Such losses are termed secondary losses.

The losses that should be examined in any given epidemic-economic study will vary depending on the type of disease, species of animals impacted and the importance of those species to the economy, as well as regional and international animal disease policies.

4.4.1. Direct Losses

Direct losses accumulate to the livestock sector as a direct consequence of an animal disease attack. This category of losses has received the most attention because they are typically easily quantified, particularly for the supply side. Direct losses are also of interest in establishing the cost of a particular response policy from a governing agency viewpoint.

4.4.1.1. Lost Animals and Changes in Animal Value

The most obvious direct loss results from animals or herds that are removed from the supply chain due to the disease. This may arise from massive preventative slaughter, as in the case of FMD, or death due to the disease itself, such as with BSE. It also captures increased culling and abortion in young animals for production operations, as would be the case with Rift Valley Fever.

The value of animals lost can be calculated using a schedule of market values based on pre-disease market conditions. This is often the method used in studies for calculating indemnity payments to producers from preventative slaughter. There are two issues with using this method. First, it does not recognize the role of livestock as a capital asset (Thompson et al.). In particular for purebred animal producers, the value of an animal represents an investment in genetic improvements that may not be accounted for in a per pound cash market value as it would for a commercial animal. Second, producers who have animals not infected but expecting to absorb the full revenue loss from a negative price change may be tempted to claim their herd has been in direct contact with infected herds in order to collect a higher price per unit. It is suspected that the payout schedule was set too high in the 2001 FMD outbreak, leading to slaughter levels greater than necessary for disease control (Anderson, 2002).

Welfare slaughter is an issue that has not received much attention in the literature, but has proven to be a real issue in historical animal disease outbreaks that include quarantine zones and strict movement restrictions. These policies may prevent feed grains and pre-made feeds from being shipped into the restricted regions plus movement of animals to feeding or other operations. For enterprises employing confined feeding or those raising young animals previous to feeding, the amount of feed on hand and facilities to keep animals would likely not be sufficient beyond normal movement times may be insufficient to allow the animals to be kept. This leads to additional slaughter, and consequently higher indemnity payment levels to producers. As discussed in previous sections, producers expecting lower prices for animals post-outbreak may volunteer animals for welfare slaughter to prevent additional price change losses. Welfare slaughter will be discussed in more detail in Section 4.7.1.1.

4.4.1.2. Costs of Disease Management

The direct costs of disease management account for the resources required for response to the disease outbreak including the cost of vaccination, slaughter, disposal, cleaning, disinfecting and administrative costs. This would include cost for labor, equipment, and materials (Schoenbaum and Disney). The market price changes also will impact the losses producers face. Prices could change as a result of the supply shift caused by slaughter of live animals, the destruction of milk, meat and meat products ordinarily destined for the market and the time lag for operations to return to full production. Some studies have assumed prices do not change at the national level, but this would only be the case in a very small disease outbreak that does not change the aggregate national supply or affect demand.

Another cost producers absorb is the loss in quality from withholding market-ready animals from slaughter. The additional time to slaughter causes carcasses to be too large or not be at the optimal level of conditioning to achieve one of the premium grades, which leads to carcass discounts. For some diseases, in order to ship meat products out of the region where the infection occurs, carcasses must either be processed into cooked meat products to kill the disease causing agent or be put in non-human consumption products such as pet food.

Carcass disposal becomes a serious issue in a disease outbreak resulting in large scale animal mortality or large scale slaughter. Factors such as environmental regulations and public health impacts will also determine the disposal method hierarchy established (Scudamore et al.) in addition to the cost per unit for disposal and the time required to dispose of all carcasses. The type of control strategy employed can also affect the carcass disposal method chosen since it will, hopefully, reduce the number of dead animals (Jin, Huang and McCarl).

4.4.1.3. Trade Losses

Animal disease often has significant impacts on international trade. Outbreaks in the last decade have increased the volatility in international meat markets through their effects on consumer preferences, trade patterns, and reduced aggregate supply (Morgan and Prakash). Upon confirmation of an animal disease outbreak, restrictions are often placed on where livestock and meat products can be exported as well as what products are shipped. The extent of these damages will vary by disease and country, but in general countries experiencing an animal disease outbreak will experience immediate restricted international trade due to domestic supply changes and world demand shifts until the infected country is shown to be disease free for a pre-determined amount of time. Domestic market impacts may be partially offset by imports (Thompson et al.).

If the disease is not carried in the meat, localized cuts in production will reduce the livestock and meat products available for export. In addition, movement restrictions in the country will prevent normal supplies from reaching the market and export restriction shift meat normally shipped overseas to domestic supply (Thompson et al.).

If the disease is carried in the meat, it either must be cooked to destroy the organism or it must be removed from the meat supply chain. Upon confirmation of BSE in the US in 2003, more than 50 countries either completely stopped beef exports from the US or severely restricted them resulting in beef exports at only 20% of the previous year's levels (Hu and Jin).

Even in the case of diseases that can be transferred to humans through the meat, markets have historically been found to recover within two years; however, the nation that experienced the outbreak may take longer to recover their share of the world market (Morgan and Prakash). At particular risk are developing countries.

4.4.2. Secondary Losses

Secondary losses are less easily quantified, but ignoring them in a study can lead to severe under-estimation of the total cost of the outbreak. These studies are often done separately from the integrated epidemic-economic model analysis; however, they should ideally be included in the integrated model as much as possible. In some cases, such as environmental costs, the estimation may have to be done separately.

4.4.2.1. Related Industries

Disease outbreaks can have effects that extend well beyond the meat production chain (Pritchett, Thilmany and Johnson). While industries directly in the meat production chain will typically experience the greater loss and have consequently been the focus of disease outbreak economics literature, little work has been done to ascertain the impact on service industries linked to the meat industry. Figure 25, adapted from Pritchett, Thilmany and Johnson provides a general idea of how interrelated these markets are. A good example is the feed industry. In countries with large concentrated animal feeding operations, such as the US, a significant source of demand for feed grains is represented by livestock demand. Disease outbreaks leading to large scale animal mortality will reduce the domestic demand for feed grains. In addition, movement restrictions in the quarantine zone will restrict not only the transport of livestock but the transport of feed grain supply trucks/unit trains coming into or out of the region. These disruptions and demand shifts will be reflected in the price of feed grains. Other industries that would be impacted by a disease outbreak are transportation, veterinary service and supply industries, and rendering services (Pritchett, Thilmany and Johnson).

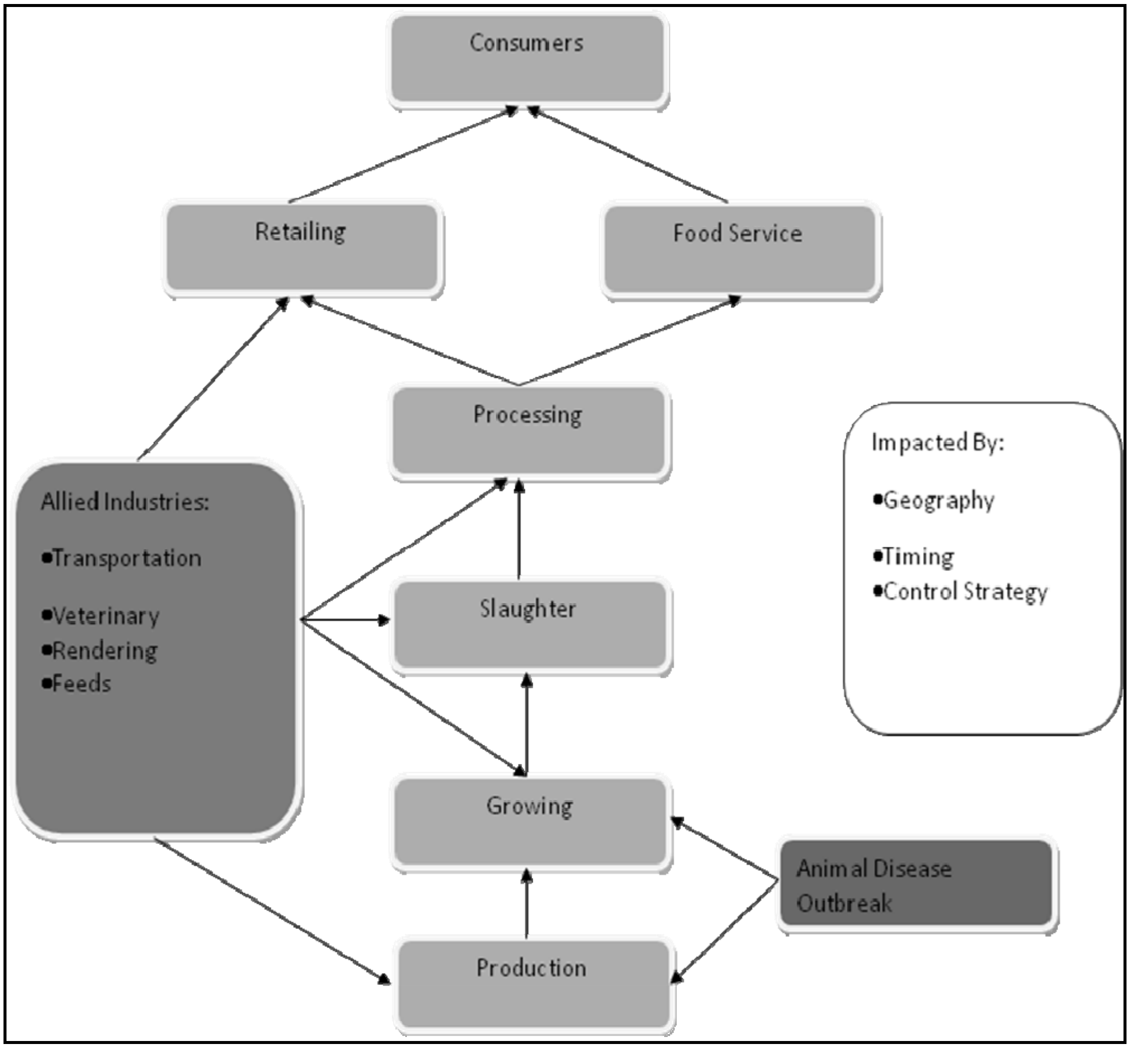


Figure 25. Interrelationship of Livestock Sector (Pritchett, Thilmany and Johnson)

4.4.2.2. Local Economies

Disease outbreaks will have the greatest monetary impact on the area where the outbreak occurs. Local producers whose premises are depopulated must wait to rebuild their operation, removing the money that would have been spent on feed, supplies, and livestock related services at local businesses. Movement restrictions divert commercial and tourist traffic coming through the region, removing income to local businesses like gas stations, hotels and restaurants. Businesses may choose to shut down or livestock operations may opt not to repopulate, decreasing the number of jobs available to local residents. Alternatively, the process of controlling the disease may provide some increased local employment but this would be short term only.

In the 2001, UK FMD outbreak 44% of the confirmed cases occurred in the county of Cumbria (Bennett et al.). Farmers and businesses in the county were surveyed after the outbreak to ascertain their losses. Although 63% of farmers in the county said they would continue farming, only 46% planned to build back up to their previous level of operation. There was an estimated direct employment loss of 600 full-time jobs and an indirect employment loss of 900 jobs (Bennett et al.).

In the entire north east region of the UK, 52% of businesses reported negative impacts but these impacts were spread across various sectors (Phillipson et al.). Relatively low impacts were felt by construction, education, health care, and personal services and moderately impacted firms were retail, transportation, business services and manufacturing. Some of these moderately impacted business were able to adapt, for example a livestock hauler took other types of overland transport until the livestock sector was able to recover. Severely impacted sectors were hospitality, outdoor recreation, farm service providers and farming (Phillipson et al.).

Depending on the area of the country impacted by the animal disease and the size of the outbreak, tourism/hospitality can represent a serious source of secondary losses. Returning to the Cumbria county survey, after the 2001 UK FMD outbreak the loss in gross tourism revenues in that county were expected to be around £400 million. Reports predicted the recovery of the county economy would largely depend on the long term recovery of the tourism industry (Bennett et al.). On a national level, tourism was the largest source of losses related to the FMD outbreak at £2.7 to £3.2 billion (Thompson et al.).

The macro-level data from the UK did not show the level of impact that was initially expected considering the impact on UK agriculture. Lessons learned from this outbreak provide valuable information for increasing the resiliency of the US economy to a similar outbreak. First, timing is everything. The two years prior to the outbreak were strong years for the economy, allowing firms to build up a buffer against a bad year (Phillipson et al.). Similarly, households were in a position to absorb some of the impact. Second, the economic impacts from the outbreak may be spread over multiple years in a 'lag effect' of the outbreak (Rich and Winter-Nelson). This gives firms and households time to make adjustments, softening its immediate impact in the overall economy to a gradual decline and gradual recovery.

Continuity of business, or the ability of small firms to cope with the impacts, is an issue that is identified as an important issue, but little has been done to quantify it. The most straight forward way of examining this issue is to examine impacts at the household level since small firms and households are closely interdependent (Phillipson et al.). Coping during a crisis, such as an animal disease, occurs in phases where earlier phases are characterized by protection of future earning capability and later phases are characterized by downsizing and the sale of core assets. Vulnerability then is defined by high exposure of risk factors and low levels of assets that can be used to keep the firm in the black (James and Ellis).

4.4.2.3. Environmental Impacts

There are two primary environmental impacts related to animal disease outbreaks: water and air quality. Ground water can be negatively impacted by disease carcasses being buried in areas where materials can leach from decomposing carcasses. Preventing this could restrict the amount of on-farm burial in the event of an animal disease outbreak, leading to additional spread risks by moving animals to suitable sites or delays in disposal by alternative methods. Water quality is also impacted by runoff from cleaning depopulated premises and from dumping infected milk as a result of movement restrictions. In a study of the 2001 FMD outbreak in the Netherlands, the illegal discharge of milk into sewage systems, rivers and smaller waterways lead to a high to very high probably of spreading the disease to other cattle operations within 6-50 km of the dump site (Schijven, Rijs, and de Roda Husman).

Air quality can be impacted when animal pyre burning or curtain burning of carcasses is employed. Curtain burning is preferred since it reduces the emissions into the air, but it is not always feasible since it requires more time and resources than pyre burning (Scudamore et al.). Studies in the UK, where pyre burning was used extensively at one point in the outbreak, have examined the levels of dangerous compounds in livestock, dairy products and eggs produced nearby. Slight increases in concentrations of dangerous compounds were found in lamb, chicken and eggs, but these were not samples destined for the food chains. Milk tests indicated dangerous compound concentrations were within acceptable ranges. Overall, the study concludes there is no evidence that the pyres were responsible for contaminating food produced in that region (Rose et al.).

Human health has been another concern related to air quality. Pyre burning releases considerable amounts of ash and pollutants into the atmosphere that can be breathed in by carcass disposal workers and local residents. A study in Cumbria county in the UK found that levels of respiratory irritants, although elevated above normal levels from the pyres, did not exceed air quality standards or exceeded them by very little. Furthermore, the pollutants were unlikely to cause damage to all but the most sensitive (e.g. asthmatics and those with weak lungs) individuals (Lowles et al.).

4.4.2.4. Meat Demand

Consumer demand response comes from two sources in an animal disease outbreak. The first is the easier of the two to quantify, the adjustment in consumption patterns from price changes. Historically, consumers have experienced a small net loss in overall welfare although this is partially offset by lower domestic prices (Thompson et al.). The second impact is substitution in consumption patterns as a result of changes in consumer confidence. How much of an impact reaches consumers depends on several factors such as industry organization, consumer demographics, and information release policies.

4.4.3. Cost Assumptions Specific to this Study

The DADS model simulations done herein, outbreaks were restricted to California since the premises locations and other model parameterizations that DADS uses are most accurately estimated for this state. The index herd in the scenario was a large dairy (>2000 animals) selected at random from among all large dairies in CA. On the date of initial infection, it was assumed one cow was in the 1st day of her latent disease state in the index herd and the disease spread from there using random draws from disease spread parameter distributions.

Vaccination was limited to dairy herds and dairy calf/heifer operations within a 10 km ring around the diagnosed infected premises (IP) and was not constrained by a specific number of doses. This is reasonable for two reasons. First, the outbreak simulation was being constrained to a specific region of the country. Realistically, we assume vaccine availability would be 250K doses in 4 days, 500K a week later and then 1 million doses a week thereafter. Since the outbreak is being limited to California, vaccination will likely only occur for 1-2 weeks. Second, this kind of unconstrained information will be useful in guiding policies on what kind of vaccine availability should be in place.

Other assumptions are: (1) slaughter of all herds in which at least one animal has been diagnosed as infected; (2) restricted movement for 10 days in the infected area that is placed in a 10 km radius around the IP; (3) restricted movement for 10 days in the surveillance area that is placed in a 20 km radius around the IP; and (4) a 3-day statewide ban on animal movement.

The direct cost incurred as a result of an FMD outbreak has two components. The first component is the disease management cost, which is the number of animals affected times the cost per head of disease management. This included the cost to test animals that are slaughtered and animals that are restricted, veterinary charges to visit infected premises and to check restricted premises, and vaccination cost for those animals within the ring vaccination area. Cost of disease management is added to the second element, which is the cost of carcass disposal. It is assumed that all infected animals are slaughtered. The cost of carcass disposal included: the cost of appraising the herd for slaughter, cost of euthanasia, cost of cleanup and disinfection of premises, and cost of carcass disposal. The costs are based on a schedule that varies by the size of the herd. Costs are as follows:

- The cost of appraisal for slaughter for small (<100 head), medium (100-500) and large (>500) herds was assumed to be $300, $400 and $500 per herd, respectively.
- Euthanasia costs were assumed to be $5.00 per head, regardless of herd type.
- The cost of disposal of a culled animal was assumed to be $11 per head in small (<100 head) and medium (100-500) herds, and $12 per head in large herds.
- The cost of cleaning and disinfection for small (<100), medium (100-500) and large (>500) herds was assumed to be $5,000, $7,000 and $10,000 per herd, respectively.
- A dose of vaccine was assumed to cost $5.50 per head. The cost of vaccine is likely more complicated than this given the cost of contracting to produce the required number of doses, even if they are not used in the outbreak, and increasing vaccine production; however, this cost assumption was based on previously published work by Ward et al. (2007).
- Fixed costs were assumed for vaccination: $300, $500 and $800 for small (<100 head), medium (100-500) and large (>500) herds.
- Fixed surveillance costs were assumed to be $150, $200 and $400 for small (<100 head), medium (100-500) and large (>500) herds.
- It was assumed that suspect herds were visited twice a week during a 30-day period for regular surveillance strategies, and 4 times a week for enhanced

surveillance strategies. The cost of these visits were assumed to be \$50, \$75 and \$100 for small (<100 head), medium (100-500) and large (>500) herds.

- The cost per trip (one way) into or out of the movement restriction zone will require truck cleaning in the amount of \$130 per trip.
- The feed cost for dairy blend feed ration for lactating cows is \$310 per ton delivered. This does not include the cost of roughage, which will likely be stored on farm. The number of deliveries required per day is 3 for large dairies, 1 for medium dairies and 0.5 for small dairies. Using a medium representative dairy operation in California, it is estimated that dairy producers will only have to bring in only a portion of feed from the outside; using on-farm production to account for the rest. This is a cost per animal of \$4.97 per cow per day out of the total cost per cow per day of feed of \$7.23. Feed costs typically are about half of the cost cwt of milk, so this number is not unreasonable given recent farm milk prices.

Animal price assumptions are presented in Table 10. These assumptions are used to calculate indemnity payments. The meat demand assumption made here is that international demand for US meat will go to zero as well as international demand for non-pasteurized dairy products. Domestic meat and dairy demand is not assumed to shift as a result of the FMD outbreak. Finally, the trade assumption is that regionalization is not utilized and as a result there is a total lockdown of all livestock, meat and non-pasteurized dairy products.

Table 10. Market Price Assumptions

	Animal Type	Average Weight	Average Market Price per Head
Steers:	Stocker	600 lb class	654.00
	Feeder	800 lb class	685.60
	Fed	1000 lb class	857.00
	Fed	1200 lb class	1028.40
	Fed	1400 lb class	1199.80
Heifers:	Stocker	600 lb class	644.00
	Feeder	800 lb class	678.60
	Fed	1000 lb class	850.00
	Fed	1200 lb class	1021.40
	Fed	1400 lb class	1192.80
Milk Cow	Replacement Heifer		1280
Cull Cow	Dry Cow		400
Sheep	Cull Ewe	160 lb	46.40
	Replacement Ewe	80 lb	83.20
	Ram	230 lb	66.70
	Whether	90 lb	93.60
	Male Feeder Lamb	60 lb	62.40
	Female Feeder Lamb	50 lb	52.00
Hogs	cull sows	215 lb	60.63
	rep gilt	180 lb	79.56
	boars	225 lb	99.45
	feeder	140 lb	61.88

4.4.4. Herd Demographics

The breakdown of herd types is given in Table 11 from the DADS model. These groupings are aggregated in ASM as: (1) Cow/Calf (2) Sheep (3) Dairy (4) Feeder Pig Production and (5) Hog Farrow to Finish. Goats are captured in the sheep category, dairy calf operations are listed as small feedlots, and backyard and saleyard are folded into the beef cattle categories. Table 12 provides their inventories and the total inventory of animals in the region of interest.

Table 11. Herd Definitions from DADS Model

Herd Type	Definition
Large Beef	More than 250 head beef cattle
Small Beef	1 to 250 head beef cattle
Large Dairy	More than 2000 head dairy cattle
Medium Dairy	1001 to 1999 head dairy cattle
Small Dairy	1 to 1000 head dairy cattle
Large Dairy Calf	More than 250 head dairy calves
Small Dairy Calf	1 to 250 head dairy calves
Large Swine	More than 2000 head hogs
Small Swine	Less than 2000 head hogs
Goat	All size goat operations
Sheep	All size sheep operations
Backyard	Less than 10 head on premises
Saleyards	Mixed stock sale yard facilities

Table 12. Inventories of Animals in Susceptible Region When Moved to ASM

Operation Type	Inventory (head)
Cow/Calf	911,805
Sheep	388,920
Dairy	1,382,305
Swine	45,594
TOTAL	2,728,624

In the DADS model, herd status is defined as susceptible, sub-clinically infectious, clinically infectious, immune or dead. At the end of the outbreak period (day 120), it is assumed that all infectious herds have been slaughtered or are destined to be slaughtered. Thus the "status" variable is defined as either susceptible (status = 0) or dead (status = 3) when it enters the economic part of the model. Susceptible implies that the herd is composed of animals that could be infected with FMD and the herd lives in the Central Valley region, but at day 120 the herd had not become infected with the disease. Dead implies that the herd was slaughtered for disease control purposes.

4.5. *Epidemic Model Results*

Basic statistics for the epidemic model data across each scenario's 100 random trials were calculated, including mean, standard deviation, coefficient of variation, median, min, max, and 25% and 75% probability intervals. The proportion of animals slaughtered or restricted out of the total population represented by the approximately 22,000 livestock premises in California that is modeled in the DADS model is also presented.

4.5.1. <u>Animals Slaughtered for Disease Control</u>

Summary statistics for the number of head slaughtered is presented in Table 13. For a graphical representation, Figure 26. Spread of Disease Control Slaughter Distribution shows across the different scenarios that slaughter will increase as the delay to detection increases but the maximum of the number slaughtered distribution is reduced by the use of vaccination. These results will motivate examination of delays in detection and slaughter later in the economic results overview.

Table 13. Summary Statistics for Disease Control Slaughter[3]

	Min	25%	Median	75%	Max	Mean	StDev
NoVacc_7Day	5	5,020	8,730	14,618	39,504	10,625	7,622
NoVacc_10Day	3,000	14,949	30,443	42,675	88,944	30,378	18,566
NoVacc_14Day	14,369	42,185	62,558	86,389	48,675	66,886	29,615
NoVacc_21Day	74,207	175,273	213,693	249,692	364,539	211,138	62,791
NoVacc_22Day	72,580	202,269	260,370	305,071	419,274	252,761	77,045
10Km_7Day	650	4,968	7,798	15,397	50,205	11,062	8,697
10Km_10Day	2,340	14,748	26,042	37,595	113,998	28,735	18,958
10Km_14Day	14,095	46,440	67,784	86,712	141,755	67,698	28,058
10Km_21Day	69,278	169,581	210,315	255,654	348,933	213,891	66,192
10Km_22Day	72,730	221,787	256,861	303,541	454,588	260,291	70,882
20Km_7Day	170	5,013	10,605	15,618	43,172	11,898	8,106
20Km_10Day	3,175	19,151	28,771	40,131	90,992	30,573	17,650
20Km_14Day	2,000	51,670	72,163	91,266	173,107	73,280	29,860
20Km_21Day	74,631	148,962	201,092	245,888	366,220	199,984	66,773
20Km_22Day	83,201	203,149	253,127	296,203	392,806	248,659	69,573

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[3] Variables for summary statistics tables are defined in Table 9.

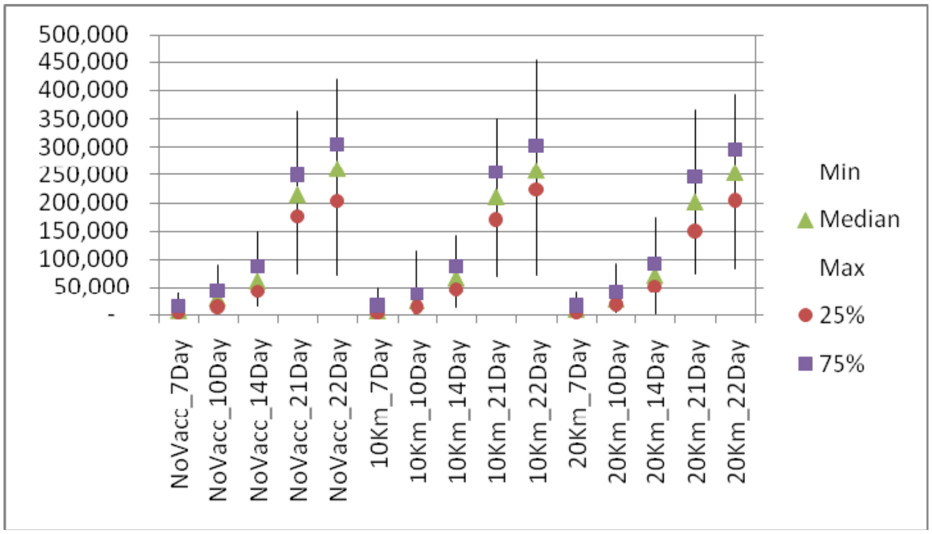

Figure 26. Spread of Disease Control Slaughter Distribution[4]

4.5.2. Herds Placed Under Movement Restrictions

Summary statistics for the number of herds quarantined is presented in Table 14. Figure 27 shows across the different scenarios the herds placed under movement restrictions will increase as the delay to detection increases but the maximum herds restricted of the herds quarantined distribution is decreased by vaccination.

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[4] For Figure 26 - Figure 28, the vertical line represents the spread from min to max, the square indicates the 75th percentile, the circle represents the 25th percentile and the triangle represents the median. The vertical axis is in number of head or herds as indicated in the text, and the horizontal axis is the scenario considered. Variables are defined in Table 9.

Table 14. Summary Statistics for Herds Quarantined

	Min	25%	Median	75%	Max	Mean	StDev
NoVacc_7Day	73	401	677	1,092	4,728	968	881
NoVacc_10Day	169	873	1490	2,192	5,294	1,756	1,155
NoVacc_14Day	793	2,051	2,683	4,444	7,994	3,287	1,658
NoVacc_21Day	1,873	4,028	5,240	7,304	10,032	5,486	2,124
NoVacc_22Day	1,765	4,625	6,211	7,470	11,109	6,126	2,212
10Km_7Day	68	451	767	1,112	3,435	926	677
10Km_10Day	246	1,005	1,588	2,603	6,069	1,963	1,310
10Km_14Day	783	2,014	2,783	3,799	6,842	3,005	1,307
10Km_21Day	931	4,043	5,491	6,950	8,848	5,321	2,090
10Km_22Day	2,020	4,927	6,114	7,603	10,574	6,187	1,795
20Km_7Day	43	383	823	1,308	4,575	1,049	898
20Km_10Day	219	998	1,606	2,785	5,778	2,019	1,376
20Km_14Day	68	1,991	2,794	3,891	7,387	3,064	1,453
20Km_21Day	1,433	3,853	5,381	6,556	9,186	5,215	1,929
20Km_22Day	1,807	4,574	5,770	7,248	10,305	5,804	1,907

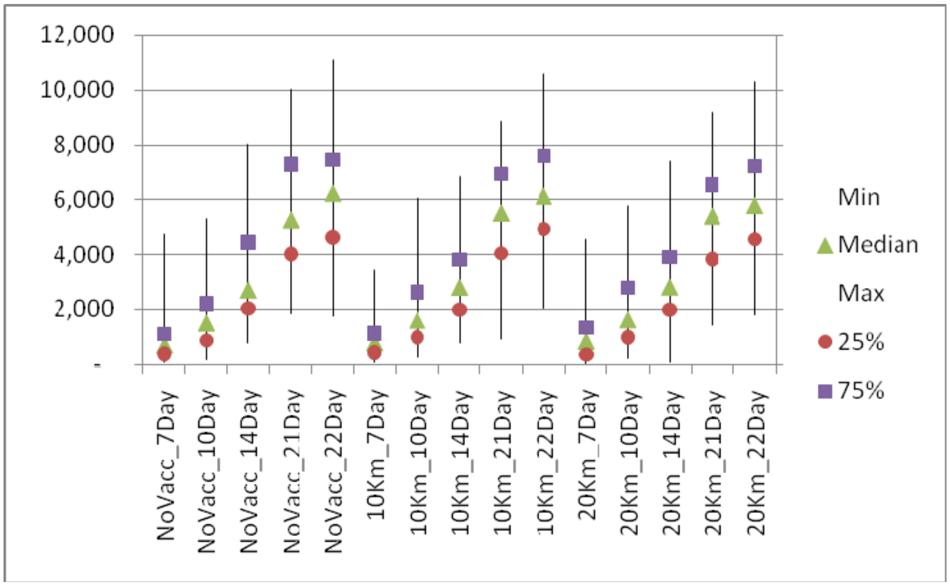

Figure 27. Spread of Herds Quarantined Distribution

4.5.3. Animals Slaughtered for Welfare Purposes

The movement restrictions put in place create the potential for welfare slaughter in the movement restriction zone because feed and critical services cannot be brought to the livestock in a cost effective manner without increasing the risk of greater disease spread. The summary statistics for the number of head that would be slaughtered for welfare purposes if feed could not be brought into the quarantine zone are presented in Table 15. As shown in Figure 28, vaccination could be an effective way to prevent excessive welfare slaughter under late detection. However, if the disease is caught early enough vaccination may not be necessary. This will be discussed in more detail in the economic results section.

Table 15. Summary Statistics for Head in Danger of Slaughter for Welfare Purposes

	Min	25%	Median	75%	Max	Mean	StDev
NoVacc_ 7Day	5,940	235,661	352,331	453,797	696,395	332,491	151,155
NoVacc_ 10Day	51,573	324,767	456,937	545,969	948,431	448,722	150,845
NoVacc_ 14Day	246,473	510,457	570,849	748,747	1,138,469	615,726	204,872
NoVacc_ 21Day	195,180	560,001	704,347	967,424	1,197,707	735,976	266,263
NoVacc_ 22Day	162,137	611,594	839,106	936,171	1,293,811	772,731	263,361
10Km_ 7Day	27,504	235,996	302,006	434,349	810,378	330,125	155,252
10Km_ 10Day	89,664	404,407	505,213	587,915	892,516	484,373	155,054
10Km_ 14Day	268,452	511,539	565,245	659,013	992,671	582,999	152,569
10Km_ 21Day	181,645	582,792	688,260	868,456	1,182,927	682,257	243,904
10Km_ 22Day	9,358	630,434	739,431	908,970	1,373,980	747,872	239,304
20Km_ 7Day	7,660	237,569	300,983	450,758	951,683	342,446	171,887
20Km_ 10Day	72,470	386,820	490,207	584,427	1,061,914	488,398	188,681
20Km_ 14Day	28,644	488,024	561,779	684,081	1,063,976	580,934	175,106
20Km_ 21Day	6,320	564,407	675,494	883,045	1,420,058	672,584	281,457
20Km_ 22Day	43,638	606,228	761,650	893,865	1,151,420	731,483	227,340

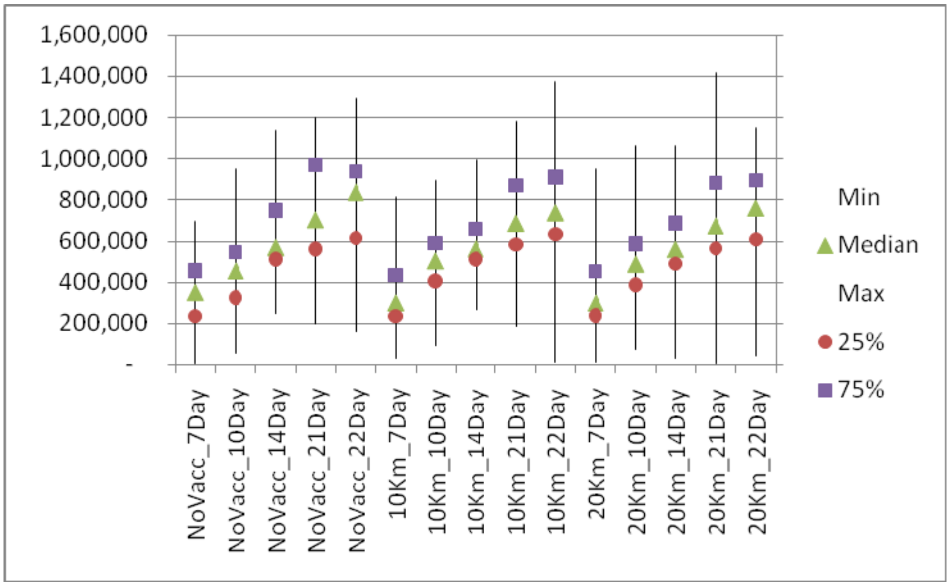

Figure 28. Spread of Head in Danger of Welfare Slaughter

4.6. Economic Model Results

The data above were used to adjust the sheep, cow/calf, dairy, farrow to finish, and feeder pig production budgets in ASM in the outbreak region, Northern California in this case. All animals infected were assumed to be slaughtered for disease control. Each of these groups will be addressed separately. For an overview of the thought process behind integrating animal disease into ASM see essay 2.

In this study the FMD outbreak was restricted to the Northern California region (Figure 29). However, since this region of California is a significant contributor to national supply of livestock products and since the US is a significant player in the world market, effects will be felt through the entire country and the rest of the world. The ASM model captures the change in economic welfare[5] or economic surplus from an animal disease

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[5] Economic welfare loss is the loss in the aggregate well-being of participants in a market based on alternative allocations of scarce resources. This is sometimes referred to as economic surplus. The second term will be used here to prevent confusion with the term welfare slaughter.

because it calculates a dollar loss of value added net income and a welfare cost of commodity prices rising. The trade impacts are also be estimated within ASM. The results presented below include the trade losses assuming the export of FMD affected, non-pasteurized products is closed for the entire country for the remainder of the year after the outbreak is brought under control.

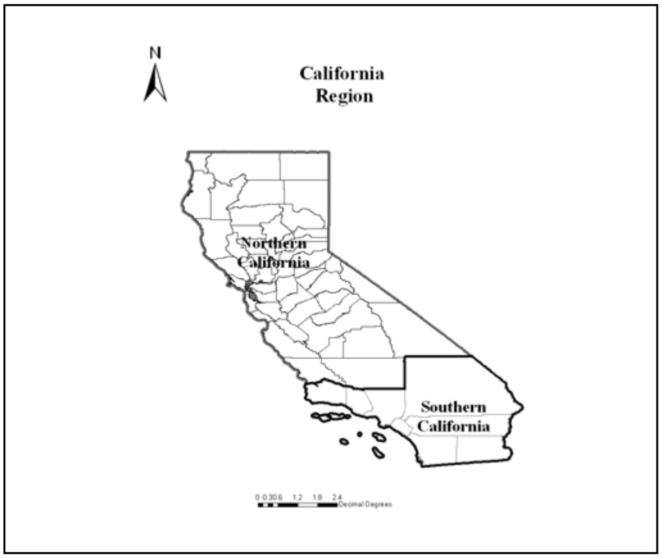

Figure 29. ASM Sub-Regional Breakdown of California

4.6.1. National Agricultural Economic Surplus Impacts Under Alternative Delays in Detection and Vaccination

Examining results first from a national level, the change in total agricultural economic surplus is examined resulting from the outbreak. These results include international trade impacts, but do not examine a policy of regionalization of production to limit trade impacts. Table 16, Table 17, and Table 18 provide summary statistics for each of the alternative scenarios where losses are measured in millions of year 2004 dollars. As detection of the disease is delayed, median losses increase. Furthermore, median loss under vaccination exceeds losses under no vaccination. This is due to the increased slaughter and costs accompanying a vaccination scenario.

Table 16. Summary Statistics for National Loss in Total Agricultural Surplus-No Vaccination (Millions of 2004$)

	NoVacc_7Day	NoVacc_10Day	NoVacc_14Day	NoVacc_21Day	NoVacc_22Day
Mean	-2,700.15	-7,234.44	-15,955.49	-52,773.11	-64,690.18
StDev	2,064.24	4,985.89	8,980.83	23,399.11	29,789.40
95 % LCI	-3,169.90	-8,369.06	-17,999.22	-58,097.94	-71,469.21
95 % UCI	-2,230.40	-6,099.83	-13,911.77	-47,448.29	-57,911.15
Min	-10,712.43	-22,841.37	-41,302.48	-103,456.86	-129,949.90
Median	-2,292.40	-7,105.06	-15,234.25	-55,433.41	-68,980.89
Max	34.05	34.05	34.05	29.87	-13.83
Skewness	-1.11	-0.62	-0.32	0.65	0.59
Kurtosis	1.61	0.25	-0.01	0.46	0.14

Table 17. Summary Statistics for National Loss in Total Agricultural Surplus -- 10 Km Ring Vaccination (Millions of 2004$)

	10Km_7Day	10Km_10Day	10Km_14Day	10Km_21Day	10Km_22Day
Mean	-3,956.72	-9,328.42	-19,724.10	-60,253.28	-74,859.55
StDev	3,055.83	6,255.07	9,568.56	26,957.88	31,680.93
95 % LCI	-4,652.12	-10,751.86	-21,901.57	-66,387.95	-82,069.03
95 % UCI	-3,261.31	-7,904.99	-17,546.62	-54,118.60	-67,650.08
Min	-15,322.41	-35,228.20	-44,211.64	-112,697.26	-149,809.74
Median	-3,128.46	-9,359.11	-19,460.55	-60,683.94	-76,907.02
Max	34.05	34.05	34.05	29.87	-15.28
Skewness	-1.24	-0.89	0.23	0.55	0.70
Kurtosis	2.19	2.05	0.16	0.35	1.13

Table 18. Summary Statistics for National Loss in Total Agricultural Surplus -- 20 Km Ring Vaccination (Millions of 2004$)

	20Km_7Day	20Km_10Day	20Km_14Day	20Km_21Day	20Km_22Day
Mean	-4,954.40	-10,546.03	-21,907.81	-50,091.27	-71,682.91
StDev	3,301.69	6,279.97	10,670.21	31,551.89	30,347.65
95 % LCI	-5,705.75	-11,975.14	-24,335.98	-57,271.38	-78,588.98
95 % UCI	-4,203.05	-9,116.93	-19,479.64	-42,911.16	-64,776.84
Min	-66.64	-59.55	-48.71	-62.99	-42.34
Median	-13,927.17	-26,563.21	-53,727.52	-121,195.84	-125,492.53
Max	-4,776.39	-10,880.95	-22,772.48	-55,622.56	-78,792.09
Skewness	34.05	34.05	34.05	29.87	-15.28
Kurtosis	-0.43	-0.19	0.18	0.31	0.92

A graphical representation can help understand the results. Examining the change from the no-disease baseline in millions of dollars, Figure 30 gives the results for no vaccination. The median national agricultural economic surplus loss is increasing as the delay in FMD detection increases as would be expected. The spread of the distribution of national agricultural surplus losses also increases, indicating a greater risk of large scale events.

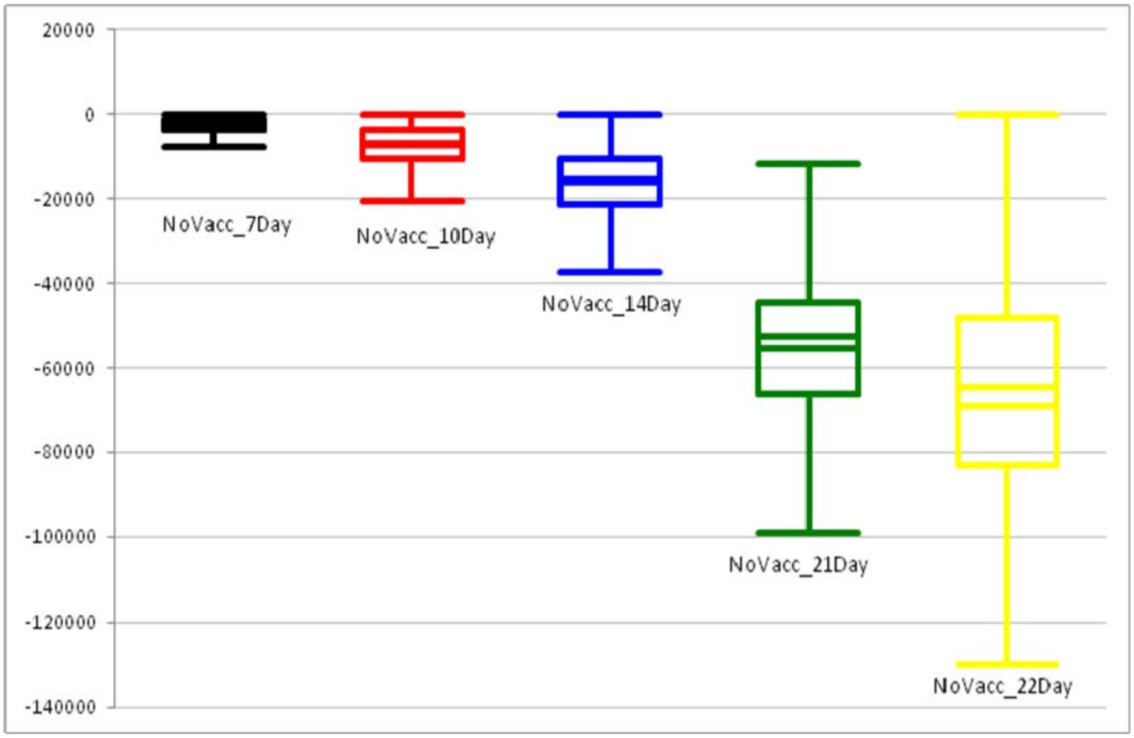

Figure 30. Box Plot of National Agricultural Surplus Loss Spread -- No Vaccination[6]

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[6] The box plot can be read as follows: The vertical axis is the change in national agricultural surplus in millions of dollars. The line closest to zero is the minimum loss in national agricultural surplus from the no-disease base in millions of dollars. The vertical line represents the spread between the minimum and maximum loss. The lowest horizontal line is the maximum loss in national agricultural surplus from the no-disease base in millions of dollars. The box represents the spread from the 25th to 75th percentile in national agricultural surplus losses. The two horizontal lines inside the box represent the mean and median loss value of the distribution of losses.

When vaccination is used as a way of controlling the spread of the disease, the same pattern is seen but with a greater success in reducing the spread of national agricultural surplus losses. Figure 31 shows results when 10 km ring vaccination is employed and Figure 32 shows results when 20 km ring vaccination is employed. Under the latest days to detection (21 and 22) the 10 kilometer ring vaccination is not as successful in reducing the spread of national agricultural surplus loss as the 20 kilometer ring vaccination. However, the mean and median national agricultural surplus loss is not reduced by vaccination. Based on these results, 20 kilometer ring vaccination would be a viable control strategy to minimize national agricultural surplus losses under late detection if decision makers wish to reduce the probability of an extreme outcome, but does not appear to provide any additional benefits under earlier detection scenarios or in reducing mean and median national agricultural surplus losses.

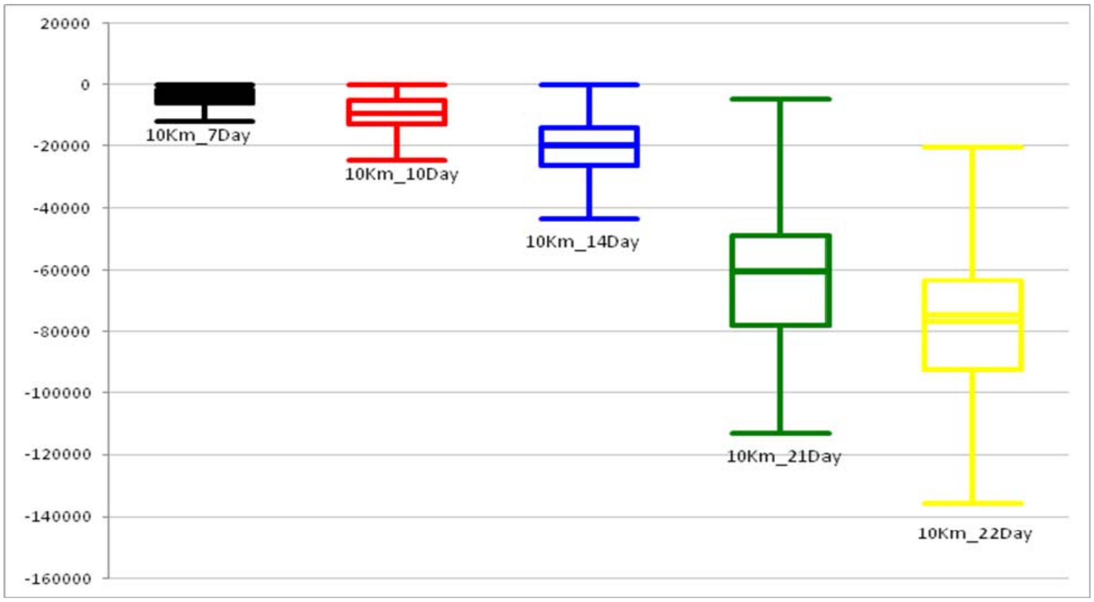

Figure 31. Box Plot of National Agricultural Surplus Loss Spread -- 10 Km Ring Vaccination

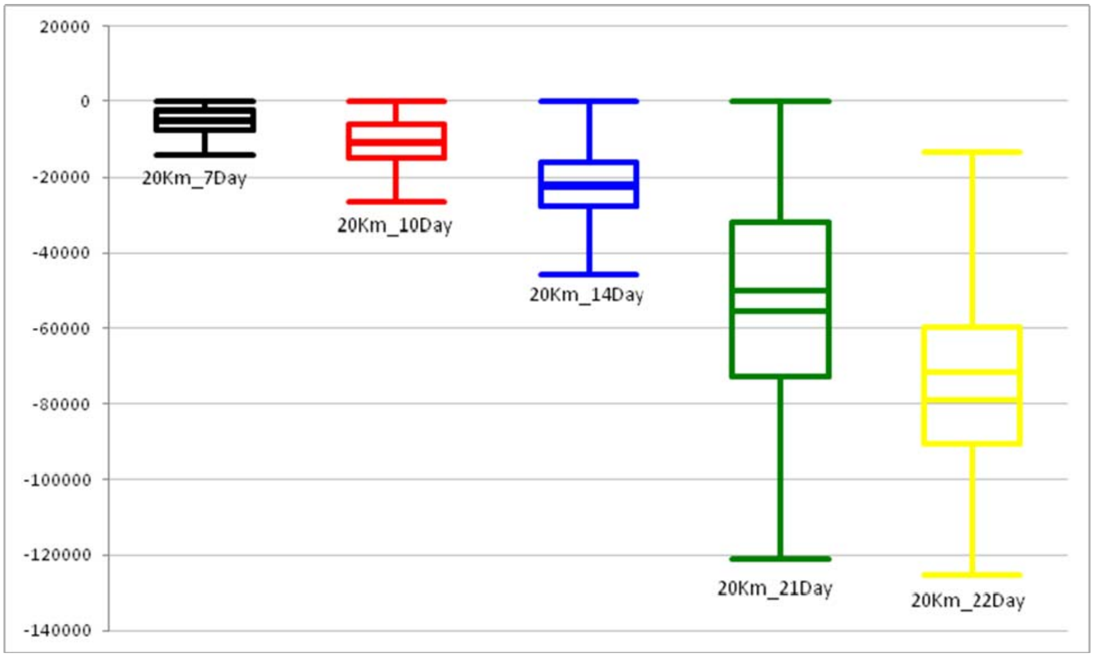

Figure 32. Box Plot of National Agricultural Surplus Loss Spread -- 20 Km Ring Vaccination

Clearly, the vaccination policy would be set without clear knowledge of how many days might expire before the disease is detected. Figure 33 shows the box plot of national agricultural surplus losses under alternative vaccination strategies across all delays in detection. While 10 km ring vaccination does not provide benefits outweighing the costs in terms of additional slaughter required (recall the "vaccinate to die" assumption) and additional costs of disease mitigation, it appears 20 km ring vaccination does provide sufficient benefits to reduce the spread of national agricultural surplus losses. Even 20 km ring vaccination does not appear to reduce the mean or median national surplus loss. Thus in this particular study, vaccination of dairy herds in a 20 km ring around infected premises is not a viable policy for slowing the spread of the disease and minimizing the mean or median national surplus losses from the disease. It may however, be a viable option for reducing the chance of an extreme disease outcome occurring.

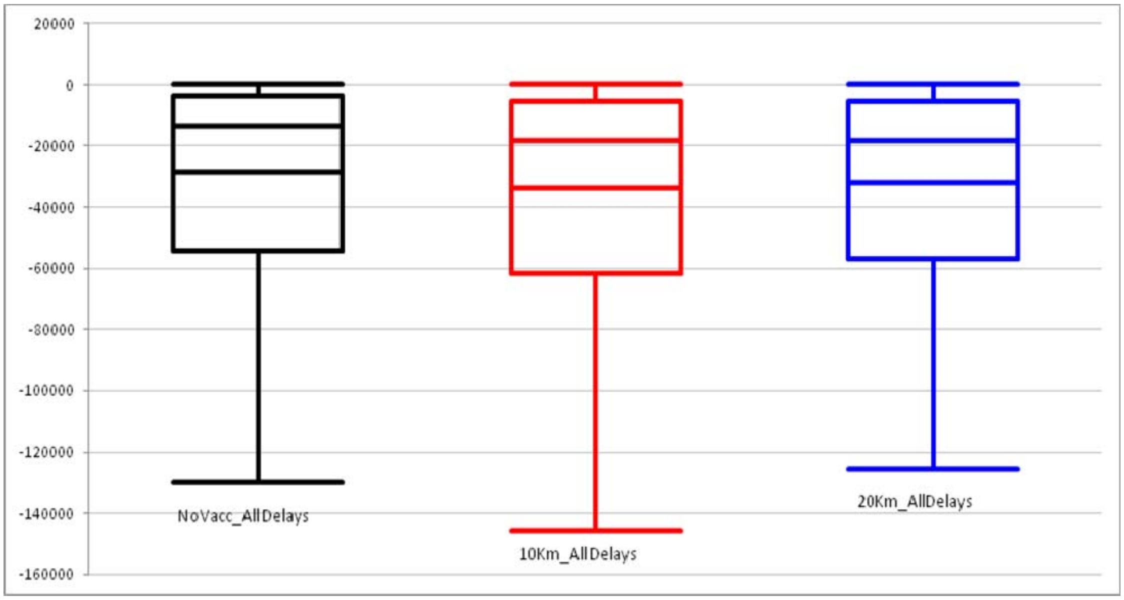

Figure 33. Box Plot of National Agricultural Surplus Loss Spread Under Alternative Vaccination

4.6.2. Risk Aversion Analysis

Under alternative delays in detection, earlier detection is always preferred to later detection across all risk neutral and risk averse individuals. This corresponds to prior studies that have consistently found early detection to be preferable to later detection as a way of reducing the duration of an FMD outbreak, the level of slaughter employed to eradicate the disease, and the national costs of controlling the disease.

Vaccination has both pros and cons. First under current "vaccinate to die" strategy more slaughter is employed and second vaccination is costly in terms of supplies and man-hours. However, the goal of vaccination is to slow the spread of the disease. Thus, it should be examined as a risk reduction technique. Stochastic Efficiency with Respect to a Function (SERF) is used here. The SERF method identifies where dominance between two alternatives switches (breakeven risk aversion coefficients) given bounds on the absolute risk aversion coefficient (ARAC). SERF allows for estimation of the utility-weighted risk premiums between alternatives to provide a cardinal measure for comparing the payoffs between risky alternatives (Hardaker et al.). Figure 34 presents the SERF diagram showing that the highest expected utility is obtained from 20 Km vaccination as the ARAC rises. For vaccination, as risk aversion rises vaccination becomes the preferred strategy. However, for risk neutral decision makers, choosing no vaccination may be a preferable strategy since vaccination does not reduce the mean or median national agricultural welfare loss.

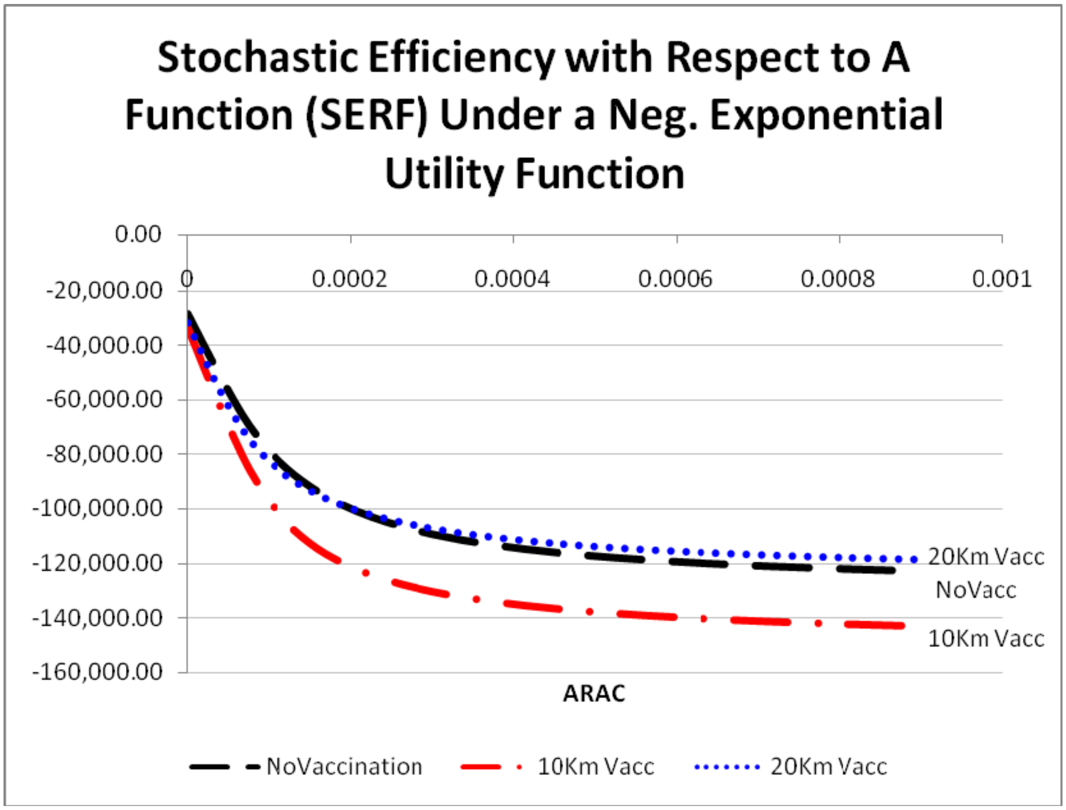

Figure 34. SERF Diagram Under Alternative Scenarios[7]

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[7] The three scenarios compared are no vaccination (NoVacc), 10 km ring vaccination (10Km Vacc) and 20 km ring vaccination (20Km Vacc) averaged across all delays in detection. The vertical axis represents the utility of loss under a negative exponential utility function. The horizontal axis represents the absolute risk aversion coefficient at which the corresponding level of loss occurs.

4.6.3. The Cost of an Additional Hour Delay in Detection

The 2001 UK FMD event was a late detection outbreak. Authorities reported detection occurred 21 days after the initial infection was found and although early detection has been shown to always be a good strategy for minimizing disease losses, just how much is gained per hour of faster delay has not been examined. Thus in this study, the increased cost per hour of delay between 21 and 22 days was examined.

The number of head slaughtered increased by almost 1,900 per hour delay and an additional 28 herds were placed under movement restrictions per hour delay. The median national economic surplus loss increased by $4.3 million per hour of delay between 21 and 22 days detection under no vaccination without trade losses, but including trade losses it increased by $370 million per hour of delay between 21 and 22 days detection under no vaccination.

As an extension of the risk aversion analysis, the cost of an additional hour delay under alternative vaccination strategies can be compared as shown in Figure 35. The average cost of an additional hour of delay increases with vaccination, but 20 km ring vaccination second order stochastic dominates both 10 km ring vaccination and no vaccination. Thus even in examining results by hourly national welfare loss under late detection, vaccination is an appealing strategy for reducing the risk of greater losses.

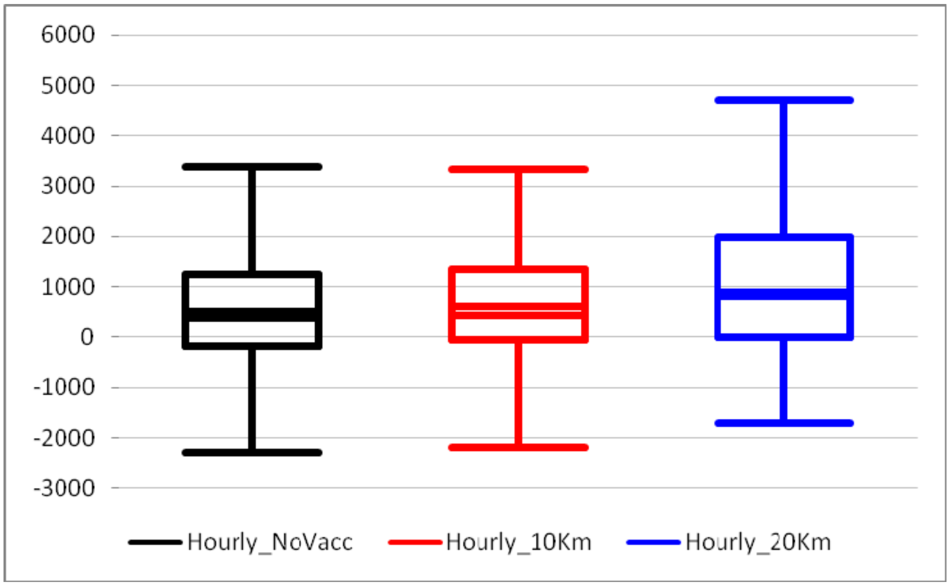

Figure 35. Box Plot of Cost per Hour of Delay between 21 and 22 Days

4.6.4. <u>Price Impacts</u>

Price impacts under this set of assumptions are driven by the reduction in supply associated with slaughter and trade restrictions. Results are broken out by live animal impacts, meat and livestock impacts excluding dairy, dairy price impacts and price impacts for feed grains.

4.6.4.1. Price Impacts for Live Animals

Recall that ASM is acting almost as a short run equilibrium model where price and quantity changes are a reflection of the animal disease shock but herd adjustments are not allowed. There are two sources of movement in live animal prices. The first is obviously the shift in supply resulting from massive slaughter of animals in California, dairy calves in particular. The second, forces driving quantity demanded and supplied in other regions such as a greater surplus of grain available for feeding and increased domestic meat prices due to international trade restrictions. These two forces will be moving against each other, and the direction of the price change expected will depend on the relative sizes of these shifting factors. Table 19 provides results across all vaccination levels for beef animals.

Other than dairy production operations, feeding operations for dairy calves and some beef calves make up the remainder of cattle production in California. The majority of cattle feeding occurs in lower Sacramento, San Joaquin and Imperial Valleys (CCA). Simulation results indicate a reduction in the number of yearlings and fed cattle in the region, but this is offset by an increase in the production of yearlings and fed cattle in other regions (particularly the Great Plains). The increase in production in other regions could be from lower feed prices encouraging expansions in feeding operations or increased imports to take advantage of higher domestic fed beef prices, which in turn pulls up prices on yearlings and slaughter cattle.

For cow/calf operations, a supply shift from California will not significantly change the aggregate national supply of beef animals. California had only 662,423 beef cows in their national inventory as of 2007 (USDA-NASS, 2008). National cow/calf quantity is not affected enough to shift aggregate supply of calves or stockers. However, demand for calves and stockers would change due to effects trickling down from changes in calf demand in feeding operations and supply changes in other regions, resulting in a lower price for calves.

Table 19. Mean Prices of Live Cattle Under Alternative Days of Detection[8]

Mean	Feedlot Beef Slaughter	Steer Calve	Heifer Calves	Stocked Calf	Stocked HCalf	Stocked SCalf	Dairy Calves	Stocked Yearling
Base	73.554	122.206	130.051	87.129	103.329	103.212	122.206	85.356
7Day	73.554	118.114	117.432	84.060	103.291	103.017	119.922	87.751
10Day	73.554	118.125	118.214	84.069	103.432	103.081	119.930	89.440
14Day	73.554	118.140	119.231	84.082	103.595	103.123	119.945	90.244
21Day	73.728	118.623	121.195	84.447	103.622	103.128	120.443	89.474
22Day	73.962	119.257	122.293	84.927	103.656	103.133	121.096	89.267

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[8] Variables are delays in detection averaged across all vaccination scenarios.

California is not a major producer of hogs and pigs, ranking 29th in the nation (USDA-NASS, 2009). However, international trade restrictions without the use of zoning implies that pork will also be a restricted commodity. The US is a major exporter of pork, so a block of pork exports means lower demand for hogs for slaughter and feeder pigs. Price changes in these commodities reflect these adjustments. California is ranked third in sheep and goat production, but with no trade impacts and relatively small quantity impacts in the region in question there is not enough market forces being brought to bear in order to shift lamb or mutton prices. Table 20 provides results across all vaccination levels for hogs and sheep.

Table 20. Mean Prices of Live Hogs and Sheep Under Alternative Days of Detection

Mean	HogsforSlaughter	FeederPig	CullSow	LambSlaugh	CullEwes
Base	66.681	122.009	38.906	47.457	22.545
7Day	66.5882	121.26801	38.8452	47.457	22.545
10Day	66.561	121.12786	38.8273	47.457	22.545
14Day	66.5546	121.09496	38.8231	47.457	22.545
21Day	66.5658	121.15661	38.8304	47.457	22.545
22Day	66.5674	121.16923	38.8315	47.457	22.545

Although poultry production is not affected by FMD directly, chicken and turkey serve as a substitute for beef and a complement for pork (Davis et al.). Thus demand effects will be moving in opposite directions as a result of an FMD outbreak. The direction of the price change will depend on which is larger. The change in the price of chicken and turkey will determine the changes in the price of broilers, turkeys and eggs. The next section provides an overview of these results. Table 21 provides the prices changes in eggs, broilers and turkeys.

Table 21. Mean Prices of Eggs and Live Poultry Under Alternative Days of Detection

Mean	Eggs	Broilers	Turkeys
Base	0.919	47.219	54.894
7Day	0.915	47.433	55.318
10Day	0.915	47.433	55.318
14Day	0.915	47.433	55.318
21Day	0.915	47.433	54.495
22Day	0.915	46.778	54.495

4.6.4.2. Price Impacts for Meat and Livestock Products Excluding Dairy

A key assumption that is worth stating again is that domestic meat consumption is not reduced due to "fear factors" about meat safety. Rather, price changes are driven by supply shifts in live animals and international trade impacts. Table 22 provides prices for beef, pork and poultry over all vaccination scenarios. For beef, changes in national supply were apparently small enough to not affect price in the earlier days to detection but does increase price under the latest detection scenarios. Pork price however, most likely due to the international trade impacts, is reduced. Chicken and turkey prices are increased under early detection scenarios; however, under 22 day detection chicken price decreases below the pre-disease base and under 21 and 22 day detection turkey price decreases below the pre-disease base. This may be reflective of the role of poultry as a substitute for beef. One other commodity price that could be mentioned here is the price of wool. As the number of sheep is reduced, the supply of wool available will decrease and consequently the price of wool is increased as shown in Table 23.

Table 22. Mean Prices of Beef, Pork and Poultry Under Alternative Days to Detection

Mean	FedBeef	Pork	Chicken	Turkey
Base	127.2	79.12500	61.069	75.208
7Day	127.2	79.00023	61.337	75.805
10Day	127.2	78.96373	61.337	75.805
14Day	127.2	78.95515	61.337	75.805
21Day	127.5	78.97017	61.337	74.644
22Day	127.8	78.97232	60.518	74.644

Table 23. Mean Price of Wool Under Alternative Days to Detection

Mean	WoolClean
Base	0.739
7Day	0.739
10Day	0.739
14Day	0.739
21Day	0.740
22Day	0.740

4.6.4.3. Price Impacts for Dairy Products

Perhaps one of the most important price impact categories to discuss under this particular set of scenarios is the impact on the prices of dairy products. Table 24 shows prices under the base and each delay in detection averaged across all vaccination strategies. The first column is the price per cwt of milk at the farm. The remaining columns are prices of processed milk products. Note that price impacts do not reflect international trade restrictions as long as products are pasteurized. The pasteurization process has been found to kill the FMD virus (Thurmond and Perez). Furthermore, there is little international trade in dairy products.

Most products see the price increase that would be expected from the reduction in supply associated with slaughter. Farm level milk prices increase on average across the nation, which will be reflected in the change in producer wellbeing in other major dairy production regions. Furthermore, whole and low fat milk, cream, evaporated condensed milk, butter, cheeses and ice cream all experience price increases. Only skim milk and non-fat dry milk have price decreases as a result of the outbreak.

Table 24. Mean Price of Dairy Products Under Alternative Days to Detection

Mean	Milk	Fluid Milk Whole	Fluid Milk Low Fat	Skim Milk	Cream	Evap CondM
Base	14.927	0.3350	0.3120	0.1330	0.690	0.349
7Day	15.049	0.3359	0.3121	0.1330	0.706	0.354
10Day	15.136	0.3363	0.3126	0.1329	0.717	0.357
14Day	15.362	0.3375	0.3131	0.1326	0.746	0.365
21Day	15.977	0.3404	0.3143	0.1316	0.823	0.387
22Day	16.144	0.3412	0.3148	0.1315	0.843	0.392
Mean	Non Fat Dry Milk	Butter	Amer Cheese	Other Cheese	Cottage Cheese	Ice Cream
Base	1.1470	1.4020	1.7600	2.0210	1.5950	1.8380
7Day	1.1444	1.4366	1.7720	2.0291	1.5974	1.8675
10Day	1.1423	1.4614	1.7808	2.0349	1.5994	1.8883
14Day	1.1368	1.5260	1.8035	2.0499	1.6046	1.9423
21Day	1.1224	1.7009	1.8650	2.0910	1.6189	2.0888
22Day	1.1206	1.7444	1.8818	2.1024	1.6227	2.1261

4.6.4.4. Price Impacts for Feed Grains

A final price impact category that usually receives little attention is feed grains. Feed grain price changes are the result of changes in demand for feed grains when livestock operations are subject to a disease outbreak. Slaughter in California means a reduction in the demand for feed grain in that region, which in turn results in additional supply for other regions. This is reflected in the decrease in feed grain prices shown in Table 25.

Table 25. Mean Price of Feed Grains Under Alternative Days to Detection

Mean	Corn for Beef Cattle	Corn for Dairy Cattle	Corn for Hogs	Corn for Poultry
Base	4.6160	4.40000	4.5770	4.44100
7Day	4.6087	4.39516	4.5727	4.43856
10Day	4.6083	4.39445	4.5723	4.43825
14Day	4.6080	4.39428	4.5722	4.43819
21Day	4.6076	4.39439	4.5723	4.43826
22Day	4.6075	4.39427	4.5722	4.43818

4.6.4.5. Summary of Price Changes

Intuitively, these price changes could reflect the following scenario. The supply of dairy products goes down as well as the supply of calves coming from California. Fed cattle numbers go up nationally, possibly supplemented by increased imports of live animals, fueled by the higher price of beef compounded with lower grain prices caused by a surplus of unused grain originally destined for cattle use. The supply decrease in domestic fed cattle and yearlings is more than offset by increased demand for fed cattle and yearlings. However, since imports are still allowed from Canada and Mexico, this demand effect does not appear to trickle down into grazing operations (stockers and calves), which just experience the supply shift resulting in lower prices of stockers and calves.

4.6.5. Regional Livestock Producer Surplus Impacts

Ranking scenarios based on losses to national economic wellbeing includes the sum of changes in consumer, producer and processor surplus. However, simply looking at national agricultural surplus may over or under estimate impacts to regional livestock producers who are expected to be the hardest hit by the outbreak. This section will break down livestock producer surplus impacts by ASM region, a map of which are shown in Figure 36.

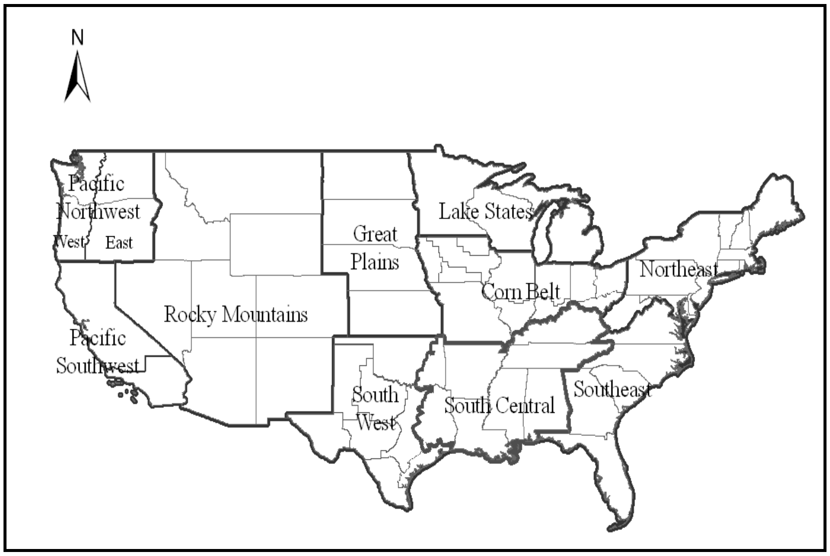

Figure 36. ASM Regions and Sub-regions

Based on what is known about production demographics in various parts of the country, the following analysis examines individual regions to determine those who gain and those who lose from the disease. Note, when the term "producer" is used in this section it means livestock producers not all agricultural producers including crop farmers.

4.6.5.1. Total US Livestock Producer Surplus Changes

When looking at the change in producer surplus in the nation as a whole, the median loss from a no disease base is $15.8 billion as shown in Table 26. Summary Statistics for Total Livestock Producers' Surplus Changes Relative to the Base. Comparing across delays in detection for all vaccination types, early detection still second order stochastic dominates late detection. This implies that producers should have an incentive to participate in earlier detection if it is clear the losses that could be sustained from later detection. Comparing across different vaccination strategies, a different ranking is discovered. Producers prefer that vaccination not be used during the outbreak, followed by 20 km ring vaccination. Only under the latest detection scenario, when risk aversion is increasing does 20 km ring vaccination become preferred to no vaccination. This is not unreasonable from a producer standpoint given the additional slaughter inherent in the use of vaccination. Examining the producer surplus loss in the nation as a whole may underestimate the producer impacts in the infected region, so the remainder of this section will examine the producer impacts region by region.

Table 26. Summary Statistics for Total Livestock Producers' Surplus Changes Relative to the Base Scenario[9]

	Mean	StDev	Min	Median	Max
Total_7Day	(3,590.50)	2901.029842	(14,521.48)	(2,879.86)	142.98
Total_10Day	(8,601.54)	5803.350086	(33,790.68)	(8,649.68)	142.98
Total_14Day	(18,350.00)	9635.195504	(51,795.76)	(18,583.05)	142.98
Total_21Day	(52,438.08)	26895.06769	(118,096.74)	(55,095.09)	143.18
Total_22Day	(68,298.85)	29995.8705	(146,141.28)	(72,506.45)	(81.73)

4.6.5.2. Pacific Southwest (PSW)

Starting with the region of outbreak it can reasonably be expected that producers' wellbeing in this region will fall more than in any other region. As expected the median change in national producer surplus from the no-disease base is $16.5 billion as shown in Table 27. This is the largest loss region in the simulated outbreak under all scenarios. Comparing this to the total US producer surplus change, not examining this region individually would underestimate the loss producers would face. Rankings of strategies remain the same. Early detection is always preferred to later detection and no vaccination is the preferred strategy unless detection occurs late and decision makers are more risk averse.

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[9] Variables are the total US economic surplus change averaged across alternative vaccination strategies for delays in detection.

Table 27. Summary Statistics for California (Pacific Southwest) Livestock Producers' Surplus Changes Relative to the Base Scenario

	Mean	StDev	Min	Median	Max
PSW_7Day	(3,860.17)	2965.57	(15,188.63)	(3,197.30)	(26.60)
PSW_10Day	(8,979.70)	5951.003	(34,888.22)	(8,980.65)	(26.60)
PSW_14Day	(19,025.03)	9927.107	(53,264.65)	(19,160.05)	(26.60)
PSW_21Day	(53,927.82)	27540.89	(120,504.57)	(56,798.49)	(24.33)
PSW_22Day	(69,855.60)	30620.06	(148,931.84)	(74,348.53)	(33.23)

4.6.5.3. Dairy Producing Regions

As stated earlier, California is the top dairy producing state in the US followed by Wisconsin (which resides in the Lake States region), New York, Pennsylvania (which are both in the Northeast region), and Idaho (which is in the Rocky Mountains region). Given the decrease in dairy coming from California as a result of the outbreak, there is a strong potential that producers in these regions could gain as a result of higher dairy prices. As shown in Table 28, under all delays in detection and vaccination strategies, the producers in the Lake States (LS) and Northeast (NE) regions gain from the outbreak. Producer surplus gains in the LS region ranged from a median $35 million under the earliest detection scenario to $372 million under the latest detection scenario, in which dairy prices are highest.

Results in the Rocky Mountain (RM) region were more mixed. Median producers surplus in the RM region falls under early detection at 7 days by $35 million; however, it should be noted that some of the cattle production in California is shipped to Idaho to be fed out. Starting with detection at 10 days though, simulations indicate producers begin to gain in median surplus. This gain ranges from $7.6 million at 10 days to $469 million at 22 days.

Table 28. Summary Statistics for Other Dairy Producing Regions Livestock Producers' Surplus Changes Relative to the Base Scenario[10]

	Mean	StDev	Min	Median	Max
LS_7Day	40.34	15.90662	5.45	35.92	103.06
LS_10Day	62.36	33.09408	5.45	57.96	208.16
LS_14Day	120.31	60.93538	5.45	108.34	281.77
LS_21Day	274.58	125.5223	0.92	315.02	435.73
LS_22Day	318.85	117.2334	0.25	372.59	544.38
NE_7Day	21.85	12.93702	(6.01)	18.00	72.74
NE_10Day	40.10	27.04435	(6.01)	37.00	159.50
NE_14Day	87.58	49.56092	(6.01)	77.16	218.98
NE_21Day	216.45	102.0455	(6.49)	249.03	347.06
NE_22Day	245.99	95.34417	(13.55)	288.97	429.32
RM_7Day	(35.07)	29.25864	(92.95)	(46.14)	91.33
RM_10Day	7.68	58.28563	(92.95)	4.69	258.78
RM_14Day	108.82	101.9264	(92.95)	100.51	372.48
RM_21Day	379.94	217.4802	(95.04)	443.59	692.07
RM_22Day	469.19	210.46	(95.06)	534.19	866.20

4.6.5.4. Other Livestock and Grain Production Regions

Regions that are major producers of cattle largely realized gains from the disease outbreak. This includes the Great Plains (GP) region that realized gains in median producer surplus ranging from $282 million under 14 day delay in detection to $320 million under 22 day detection--the region also had gains at 7, 10 and 21 days delay. This region houses a thriving cow/calf and cattle feeding industry as well as grain production. Producers in that region stand to benefit from lower grain prices for cattle and increased prices for fed cattle resulting from the outbreak. Results are shown in Table 29.

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[10] Here the Lake States region is abbreviated LS, the Northeastern region is abbreviated NE and the Rocky Mountain region is abbreviated RM.

Table 29. Summary Statistics for Great Plains Region Livestock Producers' Surplus Changes Relative to the Base Scenario

	Mean	StDev	Min	Median	Max
GP_7Day	300.47	12.37781	249.56	307.35	315.62
GP_10Day	289.19	16.72731	238.40	287.75	319.25
GP_14Day	282.78	18.05414	239.45	287.03	317.80
GP_21Day	300.59	36.94364	229.46	299.61	384.63
GP_22Day	316.65	40.06479	222.26	320.91	379.60

Producers in the Southwest (SW) region realize a small loss in producers surplus at 7 day delay in detection of $4 million, but realize gains under later detection ranging from $2 million at 10 day delay in detection to $64 million at 22 day delay in detection. Dairy producers in the region will gain from higher milk and dairy product prices and lower grain prices. Fed beef operations will gain from lower grain prices and higher fed beef prices resulting from the outbreak. Results are shown in Table 30.

Table 30. Summary Statistics for Southwest Region Livestock Producers' Surplus Changes Relative to the Base Scenario

	Mean	StDev	Min	Median	Max
SW_7Day	(4.05)	6.955987105	(14.81)	(4.02)	17.96
SW_10Day	2.41	9.423441148	(14.81)	1.96	32.81
SW_14Day	15.58	13.24821979	(14.81)	17.05	46.79
SW_21Day	49.58	30.18861476	(15.67)	53.26	109.51
SW_22Day	59.10	31.94402985	(21.85)	64.41	111.54

The Corn Belt (CB) is where the majority of the hog production in the US occurs. As such, this region experiences losses in median producer surplus ranging from $4.7 million at 22 days delay in detection to $28.5 million at 7 days delay in detection. These losses will most likely occur as a result of the trade restriction moving the price of hogs and pork down, although it may be partially offset by the decrease in the price paid for feed corn. Results are shown in Table 31.

Table 31. Summary Statistics for Corn Belt Region Livestock Producers' Surplus Changes Relative to the Base Scenario

	Mean	StDev	Min	Median	Max
CB_7Day	(8.17)	31.10313	(33.31)	(28.54)	41.25
CB_10Day	(10.39)	29.34425	(33.31)	(27.55)	45.58
CB_14Day	(7.46)	29.14301	(33.31)	(21.11)	50.85
CB_21Day	4.09	31.47634	(34.84)	(6.99)	66.18
CB_22Day	7.98	31.26028	(35.14)	(4.74)	69.03

Producers in the South Central region of the US lose in median surplus under these simulated outbreaks except for under a 21 day delay in detection. This may be due to the mixed production in that region, with losses resulting from cow/calf production impacts. Results are shown in Table 32.

Table 32. Summary Statistics for South Central Region Livestock Producers' Surplus Changes Relative to the Base Scenario

	Mean	StDev	Min	Median	Max
SC_7Day	(47.17)	6.947994686	(58.98)	(49.80)	(16.39)
SC_10Day	(37.21)	12.53958739	(58.98)	(36.79)	14.53
SC_14Day	(15.97)	20.68908048	(58.98)	(14.97)	33.64
SC_21Day	35.23	47.36841891	(64.66)	44.25	115.77
SC_22Day	(72.62)	49.13154456	(196.10)	(70.66)	14.33

The Southeast region covering Florida, Georgia, North and South Carolina and Virginia will have producers gaining in median wellbeing by a small amount under each scenario except for the 7 day delay in detection as shown in Table 33. These results, like the South Central region may be mixed due to the mix of livestock producer types in the region. Florida, in particular is a large cattle production state but North Carolina is a large hog production state. Thus the impact on this region will vary depending on the size of the outbreak. At only a 7 day delay in detection, the trade impact to hog production appears to be outweighing the impact to cattle and poultry producers.

Table 33. Summary Statistics for Southeast Region Livestock Producers' Surplus Changes Relative to the Base Scenario

	Mean	StDev	Min	Median	Max
SE_7Day	0.54	16.93687	(27.51)	(1.31)	53.82
SE_10Day	10.66	21.32897	(27.51)	5.00	83.00
SE_14Day	38.85	32.21059	(27.51)	39.66	116.72
SE_21Day	100.96	66.44067	(46.55)	120.58	217.94
SE_22Day	59.14	64.31642	(115.29)	82.61	171.37

4.6.6. Trade Impact Analysis

Results from an animal disease outbreak must include trade impacts to truly measure the extent of the outbreak impacts. Trade impacts are a demand side shift that is fairly certain since it is a proven policy when countries have a case of FMD within the borders. The extent and duration are uncertain though. Although the results presented here are including trade impacts, this may actually be a "worst case scenario" of the trade impacts. The likelihood of having a lockdown of all non-pasteurized livestock products for a full year even though the disease is contained within a few months is somewhat unlikely.

First, there is the possibility of zoning the disease to a particular region. In this study, zoning might mean that because the disease is contained in California only California exports arising from California would be restricted. This certainly would reduce impacts related to pork since California is such a small producers of this commodity, which makes up a large expected trade impact. Even if zoning were not utilized, some trade may be resumed before the end of the year where this assumes the remainder of the year trade restrictions will be in place.

Second, trade analysis was not taken out into future years since trade restrictions remain in place at some level 2-5 years into the future. This only looks at year 0, the year of the outbreak. In particular, for the use of vaccination trade will be restricted longer since the US would have a "FMD Free with Vaccination" status for several years. This may warrant allowing the ASM model to find a dynamic equilibrium since longer term trade restrictions may alter the livestock industry in the US. The future years of the restrictions would need to be considered to truly assess the disease outbreak with full trade impacts. The limitations described in this section could be explored in a separate extension of the study.

4.7. Movement Restriction Implications in the Central Valley

Response zones typically mean that within that zone, the movement of animals, equipment, feedstuffs, and people is severely restricted. The restrictions on movement vary by the type of quarantine area. An FMD outbreak initiating on a dairy in Tulare, Fresno, and King counties in California could have significant direct implications for dairy producers, but would also cause additional costs in moving necessary goods and equipment into and out of the quarantine area. This section will examine the additional costs producers will incur as a result of the movement restrictions put in place by quarantine zone measures. In particular, the impacts on milk movements out of the area and the ability of feed trucks to get into the area will be examined since these are key services producers need to ensure continuity of business for premises that are restricted but not subject to depopulation for disease control reasons. It is likely that feed will be able to get in and milk will be able to get out, but at an increased cost. Therefore three sets of total disease mitigation costs will be discussed: those under complete movement lockdown, milk "dumping", and business as usual with an increased cost of allowing these activities to continue in a secure way during the outbreak. By identifying how disease impacts go up without these increased costs, it allows policy decision makers to determine what is reasonable in the movement restrictions from an economic perspective.

4.7.1. Ex Ante Preparations for Animal Disease Outbreaks

An FMD outbreak in the Central Valley region would have substantial consequences, not only in direct disease mitigation costs but also in secondary and tertiary costs. Besides the stamping out of the infected, dangerous contact and suspected premises, carriers of the disease would have to be addressed. Feedstuffs on infected premises (hay, silage, grains) could be destroyed to prevent further spread of the virus (Bates, Carpenter and Thurmond). Milk would have to either be discarded on premises or taken out at considerable cost due to additional testing of the milk and disinfection of the truck. Other fomites that would require restriction, destruction or cleaning include: barns, feed bunks, on-farm equipment, roads, and manure treatment and disposal. Human carriers, like truck drivers and artificial insemination (AI) technicians, would have to be restricted and their vehicles and equipment disinfected at an increased cost.

4.7.1.1. Welfare Slaughter

In the 2001 U.K. FMD outbreak, 2.5 million animals were slaughtered for welfare reasons; this was the largest slaughter category in the outbreak. Welfare slaughter occurs when movement restrictions prevents the farmer/rancher's ability to bring feed to the animals, to sell a slaughter weight animal at market, or to sustain very young, susceptible animals. Most dairy farms in California will have some amount of silage and hay on premises during the majority of the year making the timing of the disease important. However, some things like corn and concentrates would be purchased through the year. Some experts and livestock industry professionals feel that, in a U.S. outbreak, feed will be made available to farmers/ranchers at an increased cost. The increased cost would cover the disinfection of trucks moving into and out of the restricted area.

4.7.1.2. Milk Dumping

Testing can be difficult due to diminished milk yield of infected cows and the increased chance of a false negative due to dilution of infected milk with uninfected milk

(Thurmond and Perez). Thurmond and Perez found that the use of a PCR assay in bulk milk would provide sensitive, early detection for FMD but at an increased cost. Milk production of infected animals is decreased, but still consumable if pasteurized. However, the value of the milk must be weighed against the additional cost of disinfection and testing. It may be more reasonable for the government to pay for the milk and dump it on premises, rather than ship it out of the response zone.

4.7.1.3. Alternative Movement Restriction Policies

In this preliminary analysis of the offset between the increased costs of allowing movement and the strict lockdown of a quarantine zone, the distribution of costs of disease mitigation will be compared across three policies. These policies are:

- "Lockdown": Complete movement restrictions on fomites such as feed trucks, AI technicians, and milk tankers.
- "Dumping Only": Milk is not allowed to exit the quarantine zone due to fears about false negatives for the PCR tests. Thus the milk is dumped within the quarantine zone. However, through additional costs of cleaning and disinfecting, feed trucks and AI technicians can move into and out of the quarantine zone.
- "Business As Usual": Both milk tankers and feed trucks can move into and out of the restricted zones, but at an increased cost of cleaning and disinfecting.

The purpose of examining these three policies specifically is to consider those policies that may be realistic in the California region. “Lockdown” may be the ideal from a disease management standpoint, but not practical. “Dumping Only” would be the situation in which a higher risk activity is restricted, but feed is still brought in despite the risk in an attempt to allow faster recovery of the region. Finally, “Business as Usual” is the situation producers may prefer since it would mean bringing feed in and taking milk out albeit at a higher cost for cleaning and disinfection.

4.7.2. Cost Categories

Table 34 provides a brief description of the different components of costs that were calculated in this analysis. These components are combined to get the total cost of disease mitigation under total lockdown, milk dumping only and business as usual but at an increased cost for cleaning and disinfection. Each of these cost categories and its calculation will be discussed in more detail below.

Table 34. Cost Category Descriptions

COST CATEGORIES	
dumping_indemnity	payment for milk dumped
disease_indemnity	payment for animals slaughtered for disease control
welfare_indemnity	payment for animals slaughtered for welfare reasons
welfare_foregoneincome	forgone income for premises depop for welfare reasons
disease_foregoneincome	foregone income for premises depop for disease control reasons
disease_costsslaughter	the cost to slaughter animals for disease reasons including herd appraisal-euthanasia-disposal
welfare_costsslaughter	the cost to slaughter animals for welfare reasons
costcleaning_slaughter	cost of cleaning premises after depopulation
costcleaning_fdtrucking	cost of cleaning feed trucks
costcleaning_mktrucking	cost of cleaning milk trucks
costsurv_herds	cost of testing and surveillance on herds
costsurv_milk	cost of testing on milk
costvacc	cost of vaccination
additionalfeedcost	cost of bringing feed into the region
TOTAL COSTS	
total_dumpingonly	total cost which includes bringing feed in but not getting milk out
total_lockdown	total cost if feed cannot be brought in and milk cannot be taken out
total_bau	total cost if feed can be brought in and milk taken out
welfarefd	total cost of welfare slaughter were feed can be brought in and milk taken out
welfarenf	total cost of welfare slaughter were feed cannot be brought in or milk taken out
costdiseasemgmt	cost per animal of foregoneincome-truck cleaning-surveillance-vaccination
costcarcassdisposal	cost per animal of cleaning and slaughter which includes appraisal-euthanasia-disposal

4.7.3. Cost Calculations

This section examines the algebra used to calculate the cost categories above in detail. Cost calculations are based on those presented in a working paper by Jin et al. with adjustments and additional cost categories appropriate for this study.

4.7.3.1. Indemnity Payments

Indemnity payments are those payments made by the government to producers who lose assets because of disease control. In California this will include those animals slaughtered due to disease control, but it would also reasonably include milk that had to be dumped and payments for animals that had to be slaughtered because feed could not be brought into the region.

4.7.3.1.1. Dumping Indemnity

The total value of indemnity payments made for dumped because it cannot be taken out of the quarantine zone is calculated as:

$$\text{dumping\_indemnity} =$$

$$\sum_{id} \sum_{herd} \sum_{type} N_{id} * HerdType_{id,herd} * (1 - State_{id,status}) * Milk * MilkValue * Q_{id}$$

where: *N* is the head of animals in a particular (*id)*

HerdType is 0 if the herd id (*id*) is not a small, medium or large dairy

State is an indicator variable that is 0 if the herd (*id)* is susceptible (*status=0)*. Diseased herds would be slaughtered, so it is assumed there is no reason to milk those animals.

Milk the cwt of milk produced per cow per day

MilkValue is the market value of a cwt of raw fluid milk to producers

Q is the number of days that particular premises (*id*) has been quarantined during the outbreak.

4.7.3.1.2. Disease Indemnity

The total value of indemnity payments made for animals slaughtered for disease control purposes is calculated as:

$$\text{disease\_indemnity} =$$

$$\sum_{id}\sum_{herd}\sum_{type}\sum_{status} N_{id} * HerdType_{id,herd} * State_{id,status} * Composition_{herd,type} * MV_{type}$$

where: *N* is the number of animals in a particular herd id (*id)*

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

Composition is a matrix used for the breakdown of a herd (*herd*) into animal types (*type)*

MV is the market value of a particular type of animal (*type)* as shown in Table 10. Market Price Assumptions .

4.7.3.1.3. Welfare Indemnity

The total value of indemnity payments made for animals slaughtered for welfare control purposes is calculated as:

$$\text{welfare\_indemnity} =$$

$$\sum_{id}\sum_{herd}\sum_{type}\sum_{status} N_{id}W_{id}HerdType_{id,herd}(1 - State_{id,status})Composition_{herd,type}MV_{type}$$

where: *N* is the number of animals at a particular premises (*id)*

W is an indicator of whether that particular premises (*id)* is in danger of welfare slaughter, meaning it has been quarantined for more than a particular number of days associated with an assumption of the feed on hand.

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined. Herd types that are grazing operations are eliminated from the pool of welfare slaughter eligible animals.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead). This prevents double counting with herds that will be slaughtered for disease control purposes.

Composition is a matrix used for the breakdown of a herd (*herd*) into animal types (*type)*

MV is the market value of a particular type of animal (*type)* as shown in Table 10. Market Price Assumptions .

4.7.3.2. Forgone Income

By using the market value of animals slaughtered at the time the outbreak occurs, the current value of the herd is captured but not the future value until that premises is repopulated. There is a wait period from the time of depopulation until the premises is deemed safe to be repopulated; in this study that period is assumed to be 60 days. Forgone income captures the daily revenue lost during those 60 days. This allows disease control totals to capture both the indemnity payment the government makes to operators and the loss in the future stream of revenues incurred directly by operators.

4.7.3.2.1. Disease Forgone Income

The first of the two forgone income calculations focuses on just those premises depopulated for disease control purposes.

$$\mathrm{disease\_forgoneIncome} =$$

$$\sum_{id}\sum_{herd}\sum_{type}\sum_{status} N_{id} HerdType_{id,herd} State_{id,status} Composition_{herd,type} DI_{type} Time$$

where: *N* is the number of animals at a particular premises (*id)*

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

Composition is a matrix used for the breakdown of a herd (*herd*) into animal types (*type)*

DI is the daily income of a particular type of herd (herd*)*. The daily income estimation used in Ward et al. (2007) was used here.

Time is the number of days between depopulation and repopulation. This was assumed to be 60 days.

4.7.3.2.2. Welfare Forgone Income

The second forgone income calculation focuses on those premises in danger of welfare slaughter.

$$\mathrm{welfare\_forgoneIncome} =$$

$$\sum_{id}\sum_{herd}\sum_{type}\sum_{status} N_{id} W_{id} HerdType_{id,herd} (1 - State_{id,status}) Composition_{herd,type} DI_{type} T$$

where: *N* is the number of animals at a particular premises (*id)*

W is an indicator of whether that particular premises (*id)* is in danger of welfare slaughter, meaning it has been quarantined for more than a particular number of days associated with an assumption of the feed on hand.

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined. Herd types that are grazing operations are eliminated from the pool of welfare slaughter eligible animals.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead). This prevents double counting with herds that will be slaughtered for disease control purposes.

Composition is a matrix used for the breakdown of a herd (*herd*) into animal types (*type)*

DI is the daily income of a particular type of herd (herd*)*. The daily income estimation used in Ward et al. (2007) was used here.

T is the number of days between depopulation and repopulation. This was assumed to be 60 days.

4.7.3.3. Slaughter Cost

The cost of slaughter is made up of several elements, each related to the depopulation of a herd. This includes the cost of appraising a herd for slaughter, the cost of euthanasia, and the cost of carcass disposal. The cost of appraisal is a schedule of fixed cost per herd varying with the three herd size levels. The cost of euthanasia has two components, a fixed component and a variable component. The fixed component is for the labor required per herd and the variable component is the cost per animal for supplies. The cost of carcass disposal is a per animal cost. These cost levels were obtained from Ward et al. (2007). Since the fixed component is based on a schedule varying by a herd size categorization (small, medium and large), fixed cost here was divided by the average number of animals in each herd size categorization so that each herd level cost was transformed to a per animal cost but still varying based on the herd size categorization.

4.7.3.3.1. Disease Slaughter Cost

The cost of slaughter and disposal of herds slaughtered for disease control purposes:

$$disease\_costslaugter =$$

$$\sum_{id}\sum_{herd}\sum_{status} N_{id} HerdType_{id,herd} State_{id,status} \left(CApp_{herd} + \left(CEU_{herd} + EU\right) + CDisp\right)$$

where *N* is the number of animals at a particular premises (*id)*

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

CApp is the cost of herd appraisal per animal for a particular herd size (*herd*)

CEU is the cost of euthansia per animal for a particular herd size (*herd)*

EU is a variable cost per animal of euthanasia regardless of herd size

CDisp is the cost per animal of carcass disposal regardless of herd size

4.7.3.3.2. Welfare Slaughter Cost

The cost of slaughter and disposal of herds slaughtered for welfare purposes:

$$\mathrm{welfare\_costslaughter} =$$

$$\sum_{id}\sum_{herd}\sum_{status} N_{id}W_{id}HerdType_{id,herd}(1 - State_{id,status})(CApp_{herd} + EU + CDisp)$$

Where *N* is the number of animals at a particular premises (*id)*

W is an indicator of whether that particular premises (*id)* is in danger of welfare slaughter, meaning it has been quarantined for more than a particular number of days associated with an assumption of the feed on hand.

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined. Herd types that are grazing operations are eliminated from the pool of welfare slaughter eligible animals.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead). This prevents double counting with herds that will be slaughtered for disease control purposes.

CApp is the cost of herd appraisal per animal for a particular herd size (*herd*)

EU is a variable cost per animal of euthanasia regardless of herd size

CDisp is the cost per animal of carcass disposal regardless of herd size

4.7.3.4. Cleaning Cost

The FMD virus is extremely hardy and in ideal conditions it can stay alive on a premises that has been depopulated, creating a risk of a secondary outbreak. Thus premises, people and equipment coming in contact with the disease must be cleaned and disinfected to prevent such a secondary outbreak. This cost of cleaning is a schedule of fixed cost varying by herd size.

4.7.3.4.1. Disease Premises Cleaning Cost

There is no additional cost of cleaning associated with premises depopulated for welfare slaughter reasons since the virus was not present there. The cost of cleaning and disinfecting diseased premises before repopulation is as follows.

$$\mathrm{costcleaning\_slaughter} = \sum_{id}\sum_{herd}\sum_{status} N_{id} HerdType_{id,herd} State_{id,status}\, CC_{herd}$$

Where *N* is the number of animals at a particular premises (*id)*

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

CC is the cost per animal of cleaning and disinfecting the premises varying by herd size category (*herd*). The cost estimates used by Ward et al. (2007) were used here.

4.7.3.4.2. Cost of Cleaning Feed Trucks

Any vehicle moving into or out of the restricted zone would need to be cleaned and disinfected to prevent further disease spread and secondary infection. If feed trucks are allowed to bring feed grains into the zone, they must be cleaned at each trip. The cost of cleaning feed trucks is as follows:

$$\mathrm{costcleaning\_fdtrucking} = \sum_{id}\sum_{herd}\sum_{status} W_{id} HerdType_{id,herd} (1 - State_{id,status}) (Q_{id} - FDays) FeedReq_{herd} CCT$$

Where *W* is still an indicator of whether that particular premises (*id)* is in danger of welfare slaughter, meaning it has been quarantined for more than a particular number of days associated with an assumption of the feed on hand. Only in this case those herds in danger of welfare slaughter would have feed brought in at additional cost rather than slaughter animals.

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined. Herd types that are grazing operations are eliminated from the pool of herds requiring feed during the outbreak.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

Q is the number of days that particular premises (*id*) has been quarantined during the outbreak

FDays is the number of days the herd can go without having a feed delivery--or the number of days feed on hand. This was assumed to be 5 days on average across different premises types, although dairy operations may be able to stretch on farm grain supplies further and calf raisers may not be able to go that long.

FeedReq is the number of feed trips required per day to supply that herd varying by the size of the herd (*herd)*. These numbers were calculated based on the daily feed consumption in pounds per animal, the average number of animals in a particular herd size category and the assumption that a feed truck will haul a maximum of 23 tons per trip.

CCT is the cost of cleaning a truck per trip. This is based on an interview with a feed truck washing facility. It is assumed that existing permanent facilities along major transportation routes are used to wash trucks since cost information for portable facilities were not available.

4.7.3.4.3. Cost of Cleaning Milk Tankers

Milk tankers picking up milk from farms inside the movement restriction zone would also need to be cleaned more stringently than normal. The cost of cleaning milk tankers is as follows:

$$\text{costcleaning\_mktrucking} =$$

$$\sum_{id}\sum_{herd}\sum_{status} DH_{id}HerdType_{id,herd}(1 - State_{id,status})\,Q_{id}MPickup_{herd}CCT$$

Where *DH* is the number of premises (*id)* that are small, medium or large dairy herds

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

Q is the number of days that particular premises (*id*) has been quarantined during the outbreak

MPickup is the number of tankers per day visiting a particular premises. This number is calculated based on the daily milk production of a particular herd size category and the size of a standard milk tanker. This is assumed to be 3 trips for large dairies (>2,000 head), 2 trips per day for medium dairies, and 1 trip per day for small dairies. This is not necessarily a trip that fills the tanker, rather a single tanker may visit multiple premises. The washing would need to occur at each trip though rather than each full tanker.

CCFT is the cost of cleaning a truck per trip. This is based on an interview with a feed truck washing facility. It is assumed that existing permanent facilities along major transportation routes are used to wash trucks since cost information for portable facilities were not available.

4.7.3.5. Surveillance

Surveillance of herds inside a movement restricted zone is performed to assure that all infected and dangerous contact herds are found and eradicated. This includes a visit by a veterinarian and testing. Milk is also tested as an FMD carrier as it leaves the zone.

4.7.3.5.1. Herds

Although the DADS model does not have a parameter for the number of surveillance visits made on a particular premises, it is assumed that at least two visits to a restricted herd occur. The first is an initial assessment, which is performed on every herd quarantined. The second a follow up visit to assure herds not deemed infected on the first visit and consequently slaughtered are still FMD free. At each visit there is a fixed cost per animal varying by herd size category for the veterinarian visit and a fixed cost per animal varying by herd size category of testing and equipment.

$$
\begin{aligned}
\mathbf{costsurv\_herds} = {} & \sum_{id}\sum_{herd} HQ_{id} * HerdType_{id,herd} * CS_{herd} \\
& + \sum_{id}\sum_{herd}\sum_{status} HQ_{id} * HerdType_{id,herd} * (1 - State_{id,status}) * CS_{herd}
\end{aligned}
$$

Where *HQ* is an indicator for whether a particular premises (*id)* has been restricted

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

CS is the cost per animal of premises of a single surveillance visit varying by herd size category (*herd*). The cost estimates used by Ward et al. (2007) were used here.

4.7.3.5.2. Milk

Testing must also be done on milk to assure each tanker is untainted before entering processing facilities. Although the pasteurization process has been shown to kill the FMD virus (Thurmond and Perez) it is unlikely that facilities untainted by the virus would risk its introduction onto their equipment. This is calculated as follows:

$$\mathrm{costsurv\_milk} =$$

$$\sum_{id}\sum_{herd}\sum_{status} DH_{id}HerdType_{id,herd}(1 - State_{id,status})\,Q_{id}MPickup_{herd}CSM$$

Where *DH* is the number of premises (*id)* that are small, medium or large dairy herds

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

Q is the number of days that particular premises (*id*) has been quarantined during the outbreak

MPickup is the number of tankers per day visiting particular premises. This number is calculated based on the daily milk production of a particular herd size category and the size of a standard milk tanker. This is assumed to be 3 trips for large dairies (>2,000 head), 2 trips per day for medium dairies, and 1 trip per day for small dairies. This is not necessarily a trip that fills the tanker; rather a single tanker may visit multiple premises. The washing would need to occur at each trip though rather than each full tanker.

CSM is the cost of testing a truck per trip. This is based on an interview with the Texas testing facility for a PCR assay test and is assumed to be $10.

4.7.3.6. Vaccination

Since vaccination is a disease control alternative being considered here

$$costvacc = \sum_{id} \sum_{herd} \sum_{status} N_{id} HerdType_{id,herd} HV_{id} (Vacc_{herd} + VaccD)$$

where *N* is the number of animals at a particular premises (*id)*

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined.

HV is an indicator that is 1 if the herd *(id)* has been selected for vaccination and 0 otherwise

Vacc is the cost of herd vaccination per animal for a particular herd size (*herd*)

VaccD is the cost per dose of vaccine regardless of herd size

4.7.3.7. Additional Feed Cost

The final individual cost category is the cost of the additional feed being brought into the region.

$$additionalfeedcost =$$

$$\sum_{id} \sum_{herd} \sum_{status} W_{id} HerdType_{id,herd} (1 - State_{id,status}) (Q_{id} - FDays) QCPA$$

Where *W* is still an indicator of whether that particular premises (*id)* is in danger of welfare slaughter, meaning it has been quarantined for more than a particular number of days associated with an assumption of the feed on hand. Only in this case those herds in danger of welfare slaughter would have feed brought in at additional cost rather than slaughter animals.

HerdType is 0 if the herd id (*id*) is not the same as the type of herd (*herd)* being examined. Herd types that are grazing operations are eliminated from the pool of herds requiring feed during the outbreak.

State is an indicator variable that is 0 if the herd (*id)* at the end of the outbreak is in the susceptible state (*status)* and 1 if the herd has entered the disease cycle (sub-clinically infectious, infectious, immune or dead).

Q is the number of days that particular premises (*id*) has been quarantined during the outbreak

FDays is the number of days the herd can go without having a feed delivery--or the number of days feed on hand. This was assumed to be 5 days on average across different premises types, although dairy operations may be able to stretch on farm grain supplies further and calf raisers may not be able to go that long.

QCPA is the cost per day per animal of feed being brought in. This is based on a cost quote of $310 per ton for delivered feed including labor and fees.

4.7.3.8. Total Costs

The total cost of disease mitigation from different quarantine zone policies on the movement of feed and milk in California are calculated as follows.

4.7.3.8.1. Dumping Only

total_dumpingonly =

dumping_indemnity + disease_indemnity + disease_foregoneincome + additionalfeedcost + disease_costsslaughter + costcleaning_slaughter + costcleaning_fdtrucking + costsurv_herds + costvacc

4.7.3.8.2. Lockdown

total_lockdown =

dumping_indemnity + disease_indemnity + welfare_indemnity + disease_foregoneincome + welfare_costslaughter + disease_costsslaughter + costcleaning_slaughter + costsurv_herds + costvacc

4.7.3.8.3. Business As Usual

total_bau=

disease_indemnity + disease_foregoneincome + disease_costsslaughter + costcleaning_slaughter + costcleaning_fdtrucking + costcleaning_mktrucking + additionalfeedcost + costsurv_herds + costsurv_milk + costvacc

4.7.3.8.4. Welfare Cost Only When Feed is Brought In

It may be interesting to note the cost of avoiding welfare slaughter in the region. In this case it would be the additional cost of cleaning and disinfecting the feed trucks required to bring feed in and the cost of the feed itself.

Welfarefd = costcleaning_fdtrucking + additionalfeedcost

4.7.3.8.5. Welfare Cost Only When No Feed is Brought In

The welfare cost when feed is brought in can be compared against the welfare cost when no feed is brought in. Such would be the case if all additional risk of disease spread is avoided, but it should be evaluated as whether the benefits in terms of lessening disease spread is weighed against the associated additional slaughter necessary for welfare reasons.

Welfarenf = welfare_indemnity + welfare_foregoneincome + welfare_costsslaughter

4.7.3.9. ASM Cost Per Animal

In the ASM budget adjustment, the cost for each operation should be increased by the cost of disease management and the cost of carcass disposal. However, total costs must be distributed across the region, so they are divided by the inventory in that region to get a per animal normalization. Given the confidence that feed will be able to be brought in, business as usual assumptions are made. The exception to the total business as usual cost calculation is that indemnity payments are not included since these are transfer payments.

Costdiseasemgmt = (disease_foregoneincome + costcleaning_fdtrucking + additionalfeedcost + costcleaning_mktrucking + costsurv_milk + costsurv_herds + costvacc) / totalinventory

Costcarcassdisposal = (disease_costsslaughter + costcleaning_slaughter) / totalinventory

4.7.4. Results

Total results are presented and compared against each other followed by conclusions as well as the implications for producers and policy makers in California.

4.7.4.1. Business as Usual

Under business as usual (BAU) feed can be brought in and milk taken out. First, comparing across days to detection regardless of vaccination strategy in Table 35, the cost of controlling the disease clearly increases as detection is delayed. Looking at Figure 37. Cost Spread Under Business as Usual for Alternative Delays in Detection the spread in the distribution of costs increases as well. This reiterates the value of earlier detection. In fact, between 21 and 22 days the increase in cost under BAU would increase by $522 million per hour.

The BAU movement restriction zone policy was used in running the ASM results. Looking at the last two rows of Table 35, the cost per animal in that region of controlling the disease also increases with the delay in detection ranging from $330 per head to $2,343 per head in disease management and from $558 to $18,093 per head in carcass disposal cost. The total cost per animal with a 7 day delay in detection is $888. If detection is delayed from 7 to 10 days the cost of disease management almost doubles (an increase of $1,526), and it more than doubles for an increase in delay from 10 to 14 days (an increase of $3,808). A drastic increase occurs between 14 and 21 days delay (an increase of $10,092) and a slightly smaller but still large increase between 21 and 22 days delay (an increase of $4,129). The point being, with such large increases in cost of disease control with greater delays in detection ex post, there is motivation to examine ex ante investments that would give a higher probability of early detection of the disease even if they are somewhat costly per animal.

Table 35. Cost of Disease Control Under Business as Usual for Alternative Delays in Detection[11]

BAU (Million $)	7 day Median	10 day Median	14 day Median	21day Median	22 day Median
disease_indemnity	$3.5	$10.8	$26.1	$81.9	$103.6
disease_foregoneincome	$2.4	$6.3	$14.7	$44.4	$60.8
disease_costsslaughter	$1,521.1	$4,780.0	$11,242.0	$34,816.7	$42,991.1
costcleaning_slaughter	$1.8	$63.9	$418.9	$4,553.1	$6,795.6
costcleaning_fdtrucking	$0.0015	$0.0029	$0.0050	$0.0091	$0.0105
costcleaning_mktrucking	$147.6	$205.5	$247.5	$334.1	$381.6
costsurv_herds	$34.6	$73.5	$128.8	$250.0	$278.6
costsurv_milk	$0.1790	$0.3713	$0.6314	$1.2	$1.3
cost_vacc	$1,043.4	$2,116.4	$3,049.4	$5,982.7	$6,912.0
additionalfeedcost	$135.9	$218.6	$297.9	$307.8	$344.2
total_bau	$2,600.8	$6,845.8	$12,315.6	$43,511.3	$56,052.9
($ per head)					
costdiseasemgmt	$330	$643	$1,765	$1,799	$2,343
costcarcassdisposal	$558	$1,771	$4,450	$14,508	$18,093

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[11] Business as Usual (BAU) involves allowing feed to come into the movement restriction zone and milk to leave the movement restriction zone, but at a higher cost of cleaning and disinfecting people and equipment.

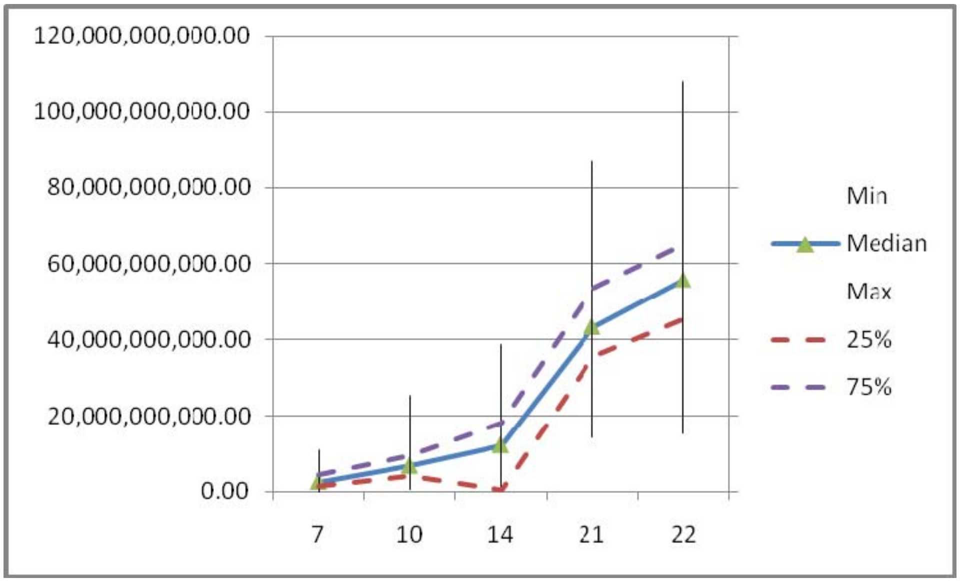

Figure 37. Cost Spread Under Business as Usual for Alternative Delays in Detection[12]

The results under alternative vaccination regardless of the delay in detection are not as straight forward, as shown in Table 36. No vaccination results in lower median costs of control compared to vaccination, but whether 20 km ring vaccination or 10 km ring vaccination results in lower costs varies by cost category. Looking at the spread of the distribution on total control cost shown in Figure 38, no vaccination minimizes the median cost of disease control. The median cost of control is very close between the two vaccination strategies with 10 km ring vaccination having a slightly lower median cost. However, in examining the 75th percentile and the maximum, 20 km ring vaccination clearly has an advantage in reducing these highly undesirable tail in the control cost distribution. Risk analysis reveals a preference for 20 km ring vaccination as a means of reducing the risk of extreme outbreaks.

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[12] For Figures 38 - 42, the vertical line is the spread from the minimum value to the maximum value, the top dashed line is the 75th percentile, the bottom dashed line is the 25th percentile and the solid line with the triangles is the median value. The vertical axis is the cost of disease mitigation in dollars and the horizontal axis is the number of days delay in detection.

Table 36. Cost of Disease Control Under Business as Usual for Alternative Vaccination

BAU	No Vaccination Median	10 Km Vacc Median	20 Km Vacc Median
disease_indemnity	$25,818,334	$27,522,171	$27,046,753
disease_foregoneincome	$14,074,812	$14,364,441	$15,497,555
disease_costsslaughter	$10,841,631,280	$11,670,285,666	$11,818,576,473
costcleaning_slaughter	$413,082,791	$477,143,983	$464,488,458
costcleaning_fdtrucking	$5,135	$4,879	$4,717
costcleaning_mktrucking	$239,596,321	$242,373,099	$232,456,033
costsurv_herds	$124,511,173	$128,959,656	$135,493,365
costsurv_milk	$621,330	$601,700	$602,140
cost_vacc	N/A	$2,856,037,580	$3,384,640,248
additionalfeedcost	$244,750,930	$249,205,144	$245,654,029
total_bau	$12,121,339,089	$16,225,569,000	$16,676,277,737
costdiseasemgmt	$239	$1,288	$1,500
costcarcassdisposal	$4,121	$4,569	$4,435

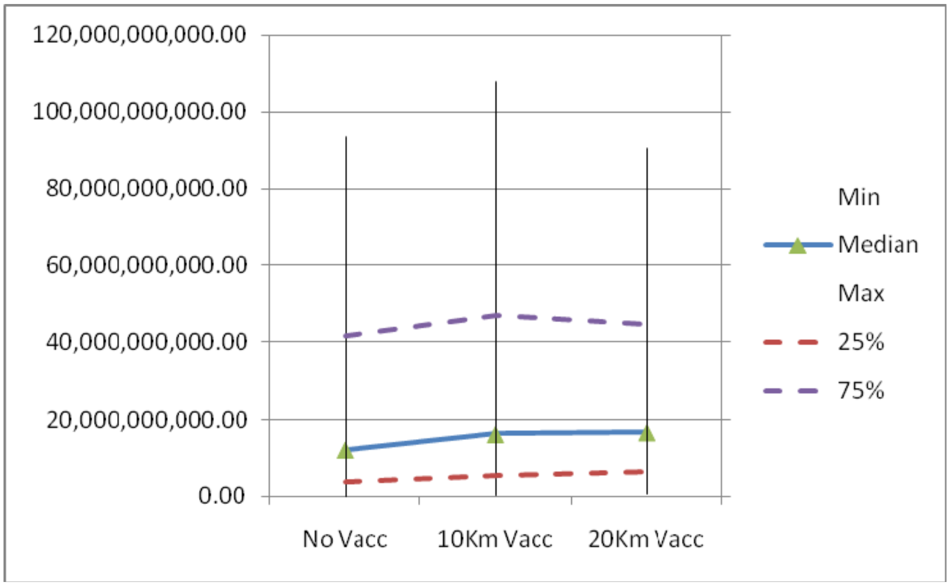

Figure 38. Spread of Cost of Disease Control Under Business as Usual for Alternative Vaccination

4.7.4.2. Lockdown

Under total lockdown of movements of animals, feed and milk in the region additional costs are incurred. Theoretically, this would be the policy that has the smallest risk of further spread of the disease. Unfortunately, such stringent movement restrictions could also result in higher levels of cost due to additional slaughter where feed cannot be brought in and indemnity payments for milk that must be dumped. Looking across the different delays in detection, Table 37 shows early detection still results in lower costs than later detection. Figure 39 shows the min, 25th percentile, median, 75th percentile and max. As the delay in detection increases the spread also increases.

Table 37. Cost of Disease Control Under Lockdown for Alternative Delays in Detection (Millions $)[13]

Lockdown	7 day Median	10 day Median	14 day Median	21day Median	22 day Median
dumping_indemnity	$9.2	$14.0	$15.2	$16.2	$18.2
disease_indemnity	$3.5	$10.9	$26.1	$81.9	$103.6
welfare_indemnity	$1,949.8	$3,136.8	$3,636.7	$4,416.8	$4,939.8
welfare_foregoneincome	$338.6	$544.6	$631.4	$766.8	$857.6
disease_foregoneincome	$2.4	$6.3	$14.7	$44.5	$60.9
disease_costsslaughter	$1,521.0	$4,779.1	$11,242.0	$34,816.7	$42,991.1
welfare_costsslaughter	$50,835.1	$81,784.4	$94,816.1	$115,156.0	$128,791.6
costcleaning_slaughter	$1.8	$63.9	$418.9	$4,553.1	$6,795.2
costsurv_herds	$34.6	$73.5	$128.8	$250.0	$278.7
cost_vacc	$1,043.4	$2,116.4	$3,049.5	$5,982.7	$6,912.0
total_lockdown	$55,892.2	$91,612.1	$98,961.4	$162,963.1	$188,387.6

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[13] Lockdown involves full movement restrictions on feed and milk shipments, where no movement is allowed for feed going in or milk going out. Indemnity payments are made for animals slaughtered and milk dumped as a result of this policy.

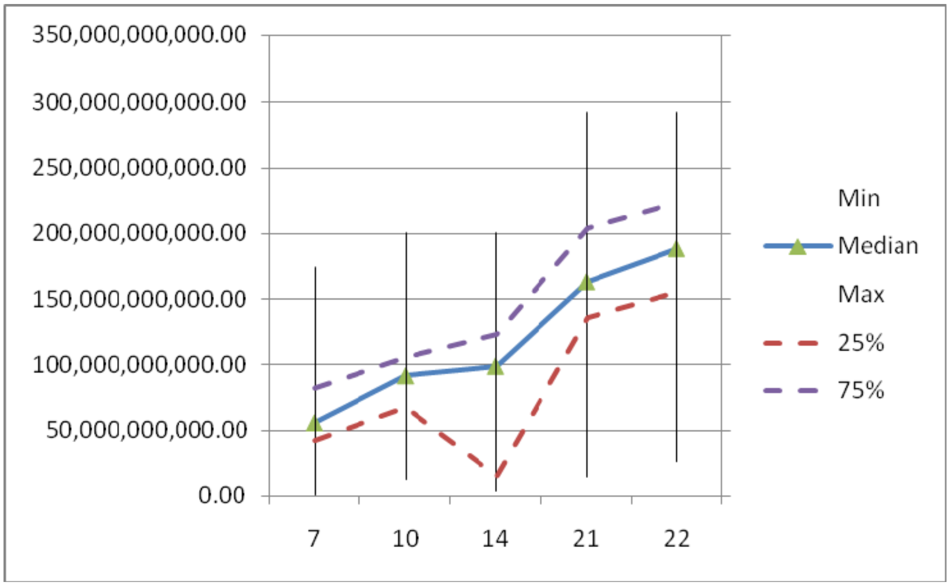

Figure 39. Spread of Cost of Disease Control Under Lockdown for Alternative Delays in Detection

For alternative vaccination scenarios, Table 38 shows no vaccination again yields the minimum total cost of disease control. However, unlike in the BAU results, this is followed by 20 Km ring vaccination then 10 km ring vaccination. Results are quite close across the vaccination scenarios though as can be seen in Figure 40.

Table 38. Cost of Disease Control Under Lockdown for Alternative Vaccination

Lockdown	No Vaccination Median	10 Km Vacc Median	20 Km Vacc Median
dumping_indemnity	$14,444,844	$14,600,258	$14,360,820
disease_indemnity	$25,818,334	$27,522,171	$27,046,753
welfare_indemnity	$3,512,588,965	$3,576,514,445	$3,525,549,955
welfare_foregoneincome	$609,847,748	$620,946,345	$612,098,006
disease_foregoneincome	$14,074,812	$14,364,441	$15,497,555
disease_costsslaughter	$10,841,631,280	$11,670,285,666	$11,818,576,473
welfare_costsslaughter	$91,581,121,932	$93,247,803,485	$91,919,044,211
costcleaning_slaughter	$413,082,791	$477,143,983	$464,488,458
costsurv_herds	$124,511,173	$128,959,656	$135,493,365
cost_vacc	N/A	$2,856,037,580	$3,384,640,248
total_lockdown	$108,687,546,625	$113,789,812,489	$111,744,359,127

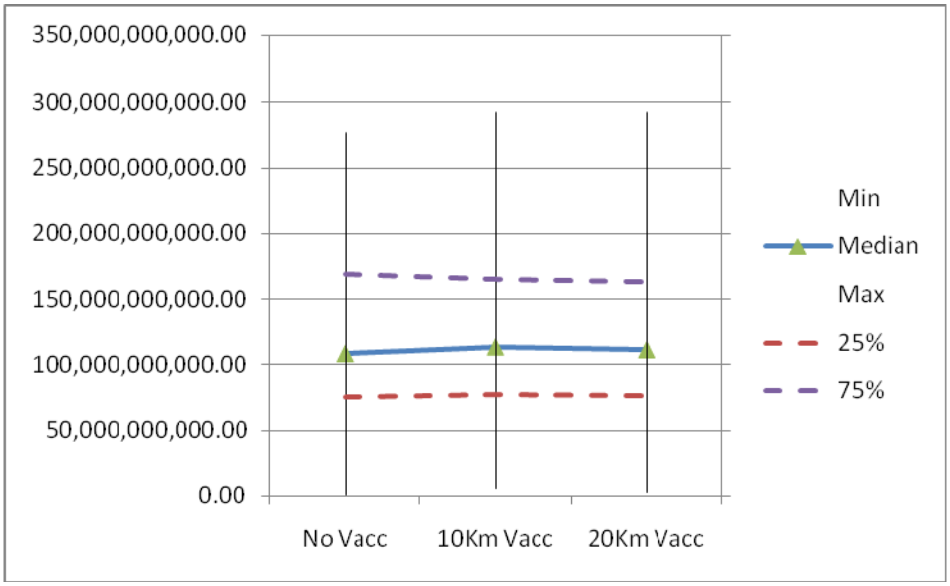

Figure 40. Spread of Cost of Disease Control Under Lockdown for Alternative Vaccination

4.7.4.3. Milk Dumping

A third movement restriction policy would be to allow feed trucks in, but not take the milk out. There may be several reasons for this. First, it may be decided that taking a final product that can carry the disease out of the movement restriction zone is too risky. Second, manufacturing operations may not wish to risk introducing the virus to a clean facility. Finally, even though it is assumed labs can provide a fast turnaround on the additional testing of milk that would be needed, it is possible that milk could not be tested fast enough to prevent spoilage.

A policy of dumping milk in the movement restriction zone is similar in terms of delays in detection. As shown in Table 39, early detection minimizes the cost of disease control. Figure 41 shows the spread is largest at 14 days delay in detection, but is reduced under the latest delays in detection.

Table 39. Cost of Disease Control Under Milk Dumping for Alternative Delays in Detection (Millions $)[14]

Dumping Only	7 day Median	10 day Median	14 day Median	21day Median	22 day Median
dumping_indemnity	$9.2	$14.0	$15.2	$16.2	$18.2
disease_indemnity	$3.5	$10.9	$26.1	$81.9	$103.6
disease_foregoneincome	$2.4	$6.3	$14.7	$44.5	$60.8
disease_costsslaughter	$1,521.1	$4,780.0	$11,242.0	$34,816.7	$42,991.1
costcleaning_slaughter	$1.8	$63.9	$418.9	$4,553.1	$6,795.6
costcleaning_fdtrucking	$0.0015	$0.0029	$0.0050	$0.0091	$0.0104
costsurv_herds	$34.6	$73.5	$128.8	$250.0	$278.6
cost_vacc	$1,043.4	$2,116.4	$3,049.5	$5,982.7	$6,912.0
additionalfeedcost	$135.9	$218.6	$297.9	$307.8	$344.2
total_dumpingonly	$2,437.7	$6,652.6	$19,777.6	$43,290.3	$55,616.0

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[14] Milk Dumping would prevent milk from leaving the movement restriction zone but allow to be brought in at a higher cost for cleaning and disinfecting to prevent excessive slaughter.

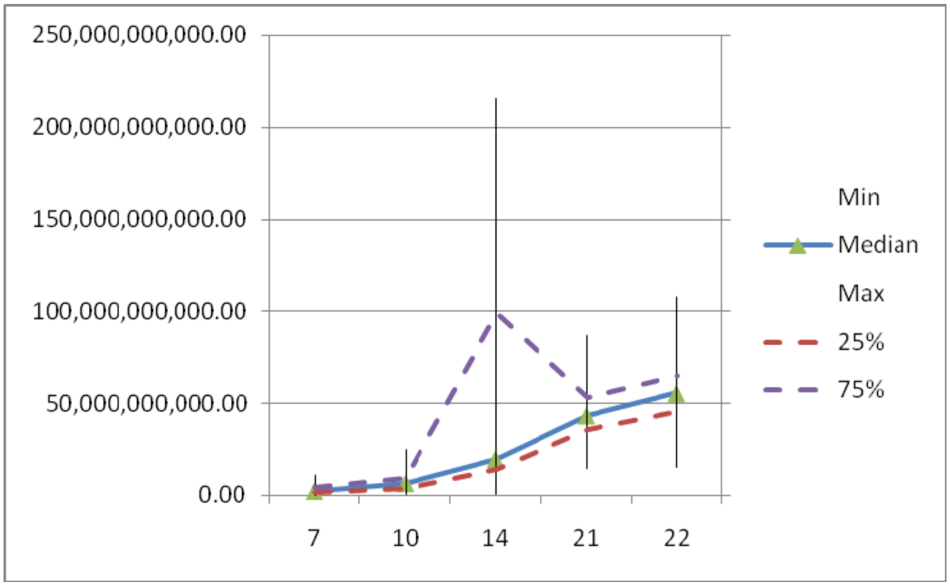


Figure 41. Spread of Cost of Disease Control Under Milk Dumping for Alternative Delays in Detection

Across different vaccination policies, Table 40 shows that the median total cost of disease control is minimized by using no vaccination. This is followed by 10 km vaccination and 20 km vaccination. However, the spread of the distribution of total cost of disease control is reduced more by 20 km vaccination over 10 km vaccination as shown in Figure 42.

Table 40. Cost of Disease Control Under Milk Dumping for Alternative Vaccination

Dumping Only	No Vaccination Median	10 Km Vacc Median	20 Km Vacc Median
dumping_indemnity	$14,444,843.62	$14,600,257.60	$14,360,819.81
disease_indemnity	$25,818,334.27	$27,522,171.03	$27,046,752.78
disease_ foregoneincome	$14,074,811.75	$14,364,441.01	$15,497,555.34
disease_ costsslaughter	$10,841,631,280.46	$11,670,285,665.88	$11,818,576,472.89
costcleaning_ slaughter	$413,082,791.00	$477,143,982.70	$464,488,458.20
costcleaning_ fdtrucking	$5,134.64	$4,879.15	$4,717.10
costsurv_herds	$124,511,173.32	$128,959,655.88	$135,493,364.64
cost_vacc	N/A	$2,856,037,579.56	$3,384,640,248.11
additionalfeedcost	$244,750,930.20	$249,205,143.60	$245,654,028.90
total_dumpingonly	$11,740,229,861.79	$15,883,074,388.56	$16,285,706,874.35

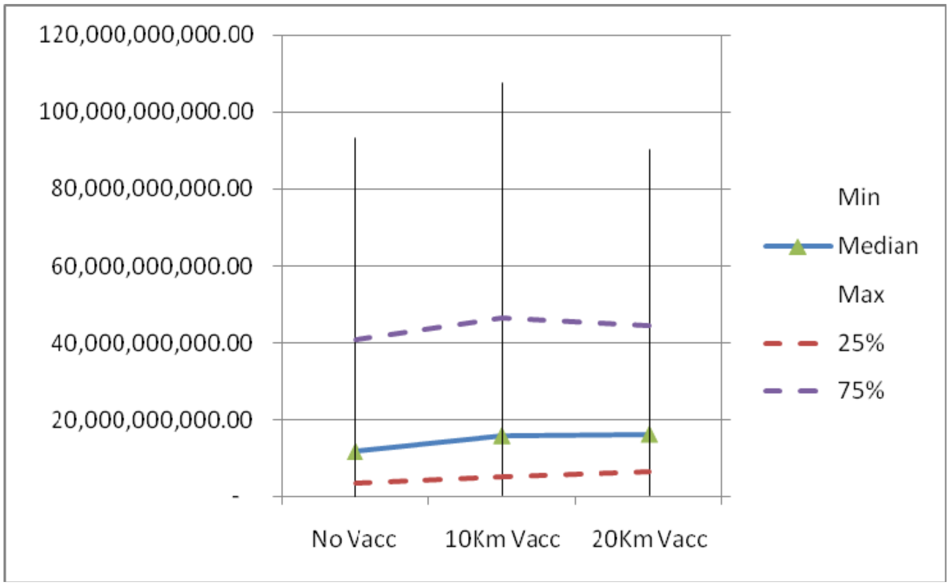


Figure 42. Spread of Cost of Disease Control Under Milk Dumping for Alternative Vaccination

4.7.4.4. Comparison Across Quarantine Zone Policies

The median cost of disease control is minimized by implementing a policy for milk dumping followed by business as usual. These two policies result in similar costs; however, a total lockdown results in the highest costs. Thus it is not worthwhile to take milk out of the movement restriction zone. However, it is worthwhile to allow feed in even at a higher cost. In fact, if just the welfare cost when feed is brought in is compared against the welfare cost when feed is not brought in as shown in Table 41, the cost of bringing feed in is outweighed by far by the cost of additional indemnity payments and forgone income for producers who must slaughter animals when feed is not brought in.

Table 41. Sum of Welfare Cost Categories Only (Million $)

	7 day	10 day	14 day	21day	22 day
welfarefd	$135.9	$218.6	$297.9	$307.8	$344.2
welfarenf	$53,123.4	$85,465.7	$86,065.2	$120,339.7	$134,589.0

Even when risk attitude is included in the ranking, both milk dumping and BAU are preferred to a total lockdown in a first degree stochastic dominance sense. Generalized stochastic dominance reveals that both risk neutral and risk averse decision makers prefer a milk dumping policy over a business as usual policy, but only very slightly.

4.8. Conclusions and Implications

This study of the California Central Valley provides results that are comparable to other economic studies of FMD done in that region, but the use of an integrated epidemic-economic framework provides greater detail that was has previously been provided. A study done by Ekboir provides a useful frame of reference as well as the most recent census of agriculture in California. This section will briefly provide evidence as to the reasonableness of results. Ekboir estimated the total cost of the outbreak to range from $6.7 to $13.5 billion in 1999. This did not include price changes and national economic surplus changes since his model was an input/output model. Thus this report is not only an update of the impacts of FMD in California, but also a more thorough examination compared to prior studies.

The median amount of disease related slaughter, herds under movement restriction and potential welfare slaughter increases as the delay in detection increases. Vaccination increases the median slaughter, but reduces the median number of herds subject to movement restrictions and consequently in danger of welfare slaughter. Vaccination does however appear to reduce the tail of the distribution of animals placed under movement restrictions.

National economic surplus losses increase as the delays in detection increase and also increase at the median with vaccination; however, when risk aversion is taken into account 20 kilometer ring vaccination becomes a preferred strategy as risk aversion rises. This indicates that policy makers may be willing to implement a policy with a higher median loss in order to avoid an extreme outcome.

Producers in California clearly suffer the largest levels of losses in the country from an outbreak in that region. However if only the national levels of welfare are examined, the losses to that region may be underestimated since other producers in the country gain from higher prices and lower feed grain costs. Similarly if only regional effects are considered without consideration of price changes than the losses will be overstated.

The costs of disease control are comparable to other studies done in this region. Looking across different quarantine zone policies, a policy of allowing feed into the region at an increased cost for cleaning and disinfection provides a lower cost than a policy of not allowing feed in due to the increased slaughter for welfare reasons. However, a policy of not allowing milk out of the region is preferred to taking milk out at a higher cost of testing and cleaning the tanker trucks. This is not an unreasonable conclusion if dairies have at least part of their feed needs on the farm, then fewer trips are needed to bring in sufficient feed. Also, as long as cows are still in production and the milk is simply being dumped in a safe manner somewhere inside the movement restriction zone the value of the dairy cow is not reduced. These quarantine zone results have interesting implications in terms of the producers' ability to prepare for an animal disease outbreak. Education programs for producers and policy makers should stress the importance of emergency preparedness plans that would allow dairies and other operations inside movement restriction zones to maintain the viability of their businesses throughout the time of restriction. However, this analysis of movement restriction zone policies is not without limitations. Ideally, these results would be fed back into the epidemic model since the implications of welfare slaughter on slowing the spread of the disease have not been taken into account.

5. ESSAY 4: INTEGRATING DECISION MAKER RISK AVERSION INTO ECONOMIC ANALYSES OF FMD OUTBREAKS

5.1. Introduction

Risk and uncertainty is a factor that must be considered in planning for animal disease outbreaks. One cannot readily observe the effects of FMD control strategy decisions using observed data as the incidence of FMD has fortunately not been extensive and regular in the US. The extent of the outbreak if/when it does happen in modern US livestock agriculture is uncertain. Many different strategies have been used in other parts of the world but their effects cannot be observed here since a US outbreak of FMD has not occurred since 1929. Uncertain parameters such as the contacts between susceptible animals in a region, environmental factors and human behavior can alter the size and extent of an outbreak. Such is true in the case of FMD outbreak simulations in Texas, which show outcomes vary by more than an order of magnitude under alternative event possibilities (Ward et al., 2007). In the face of a possible FMD outbreak it is important to study how control strategy decisions that can be made either before or during the outbreak would impact the associated economic loss. The objective of this essay is to determine how disease control strategies contribute to the resiliency of the livestock industry and how this may differ from the traditional view of control strategies as a means of minimizing the expected cost of the outbreak.

Few prior studies have examined the implications of risk and risk preference in economic ranking of disease mitigation strategies. Many studies choose to evaluate control strategies based on the average outcome (Ekboir; Paarlberg, Lee and Seitzinger; Schoenbaum and Disney; Ward et al. (2007); Rich and Winter-Nelson; Paarlberg et al.). This essay provides a unique contribution to the literature in that risk ranking techniques are applied to control strategy evaluation when a partial equilibrium economic model has been integrated with an epidemic model. A study by Elbakidze examined the implications of risk in the Texas High Plains, but did so using only the disease mitigation costs. This study found losses to the local cattle industry alone of up to $1 billion and a control strategy combination of slaughter, early detection and regular surveillance was dominant (Elbakidze, 2009). Here, rather than focusing on the local cattle industry loss, the national economic surplus loss as calculated from the integrated economic/epidemic simulation model introduced in essay 2 is used. The simulations evaluate an FMD outbreak in the Texas High Plains and use risk ranking methods to do a pair wise control strategy ranking including risk aversion on the part of policy makers. Recall from essay 2, epidemic models should capture the uncertainty and risk associated with the disease spread; however, economic models must deal with the implication of this risk in the broader economy as well as uncertainty related to consumer reaction, international market reaction, and domestic market response.

The strategies evaluated include varying time to availability of vaccination, surveillance intensity, and delays to detection of the first confirmed incidence of FMD. The work will be done using a three stage modeling approach involving using (1) the AusSpread epidemic disease simulator; (2) the ASM economic disease evaluation; and (3) a post processor economic/statistical calculator that carries out a risk evaluation over the various strategy outcomes. The AusSpread-ASM integration examines impacts on agricultural industry profitability—both in the infected region and in non-infected regions—as well as consumer surplus under a range of potential demand side shifts. However, the focus here will be on national surplus changes since policy making bodies would most likely set a response plan for the country ex ante. For more details on these models see essay 2.

In the consequent risk analysis, results will be examined in several ways. First, disease mitigation strategies will be ranked by effectiveness in reducing average losses due to the outbreak under the assumption that decision makers are risk neutral. Second, we will use standard statistical measures of risk to examine which strategies have the potential to be risk reducing strategies. Third, we will consider an expected utility based approach looking at distribution characteristics including examining breakeven risk aversion coefficients (BRACs) to determine the level of risk aversion at which decision makers will switch strategies.

5.2. Evaluation of Risk in Disease Control Alternatives

The evaluation of risk by a decision maker is subjective (Reutlinger). Subjective expected utility theory argues that if states "are not associated with recognizable, objective probabilities, consistency-like restrictions on preferences among gambles still imply that decision makers behave as if utilities were assigned to outcomes, probabilities were attached to states of nature, and decision were made by taking expected utilities" (Mas-Colell, Whinson and Green, pg. 205). In other words, even though we cannot observe probabilities, we can still use expected utility. Under subjective expected utility theory, risky alternatives will be weighed based on subjective probabilities imposed by the decision maker on the possible outcomes of the risky decision (Hardacker et al.). The epidemic model yields a simulated distribution of possible outcomes. This simulation model provides the data run through the economic model, developing the distribution of losses from animal disease.

The degree of a particular decision maker's aversion to risk is given by the risk aversion coefficient (RAC). If a risk aversion coefficient analysis stops at examining the expected levels of economic losses with no credence given to their embodied risk, this is an assumption that all decision makers are risk neutral—meaning they are indifferent to the chance of extreme outcomes and only care about the expected (or average) outcome. This is unlikely a realistic assumption in the context of animal disease, and one that must be relaxed in examining control strategies as a means of reducing risk, and consequently boosting sector resiliency. Most decision makers will likely be adverse to higher probabilities of large losses.

Decision makers who determine which control strategies to employ during an animal disease outbreak could compare the expected loss from the outbreak simulations to determine which strategy minimizes expected loss; however, this does not account for the risk of large loss outcomes. Consider two strategies, one with a low expected loss but a long right tail as we examine the loss pdf. If this were compared to a strategy with a higher expected loss, but a short right tail the decision maker who is minimizing expected loss would choose the first strategy despite the fact that it has a greater chance of an extremely high loss level. In FMD control strategy evaluations, this may not be reasonable given that producers and policy makers should wish to reduce the risk of the outbreak as well. The underlying theory in this essay is that operation managers will attempt to reduce not only expected loss but also the magnitude of "worst" outcomes. It is possible that a strategy may have *on average* a slightly greater loss, but are worthwhile in *reducing the chance of an extremely bad outcome*.

Strong assumptions are often made in order to discriminate among risky prospects including defining a range in which the risk aversion coefficient (RAC) must fall. This implies some knowledge of exactly how risk averse decision makers are; however, there is no way to observe the level of risk aversion making specifying the RAC range difficult. As a results it is often done using the results of other studies or setting the risk aversion coefficient rather arbitrarily. This is commonly done when using stochastic dominance with respect to a function or mean variance programming models (McCarl, 1988). Improperly specifying the RAC range (i.e. setting it too narrow or too wide) can cause misleading results that may imply certain strategies are never preferred, always preferred or that no ranking can be achieved. McCarl (1988) discussed an approach called the BRAC method, in which the data are explored to see what risk aversion coefficients differentiate among prospects under some specific assumptions. When using BRACs, one does not need to specify the RAC rather it is calculated given bounds that are based on various criteria related to the distribution. Here the confidence interval will be used to set the bounds. This methodology finds RACs that define a breakpoint at which a given distribution dominates. In other words, it finds the roots at which the expected utility between two strategies are equal.

More recently, this type of analysis has been programming into a Microsoft Excel add-in called Stochastic Efficiency with Respect to a Function (SERF). An advantage of the SERF method in calculating BRAC points is that, in addition to identifying where dominance between two alternatives switches, SERF allows for estimation of the utility-weighted risk premiums between alternatives to provide a cardinal measure for comparing the payoffs between risky alternatives (Richardson). These methods will be discussed in more detail in the methodology section.

5.3. Methodology

For each group of control strategy levels examined below, alternatives are compared using mean loss analysis, coefficient of variation (CV), standard deviation, stochastic dominance, and stochastic efficiency with respect to a function (SERF) utilizing breakeven risk aversion coefficient (BRAC) analysis. By using techniques incorporating not only the uncertainty related to the disease itself, but also the decision makers' attitudes toward that uncertainty a more realistic picture can be made as to why gaps exist between the ranking of control strategies based on minimizing the average epidemic loss and actual preference of control strategies in historical outbreaks. This in turn, provides a better understanding of the decision making dynamics in future outbreaks and can better inform policy decisions. This section will present each of these measures as well as their relative strengths and weaknesses as tools for risk rankings.

5.3.1. Mean, Standard Deviation, Coefficient of Variation

Perhaps the simplest way to examine and rank mitigation strategies would be to use simple statistical measures of the outcome distribution. Most studies have ranked strategies based on their ability to minimize the mean or median loss related to the outbreak. This study will also examine how strategies compare based on mean losses, but will recognize also the importance of risk as measured by the standard deviation and coefficient of variation.

The most basic way to examine the impact of uncertainty is to look at the standard deviation or coefficient of variation. Both of these are basic statistical risk measures, the difference being that standard deviation is an absolute measure of risk and coefficient of variation is a relative risk measure. The coefficient of variation may be more useful in this instance since the two alternatives may have widely divergent means and failure to normalize could result in an over or under estimation of the risk. Finally, examining the minimum and maximum of the range of losses gives an idea of how different strategies compare in reducing the extreme outcomes of the distribution. These risk methods are simple to calculate and can be used to determine if a strategy has the potential to be a risk reducing strategy, but results will rarely be clear as to whether one strategy dominates another as a means of reducing risk.

5.3.2. Stochastic Dominance

Stochastic dominance can be used to determine strategy choice under the weakest possible assumptions. Under stochastic dominance analysis a decision maker is given a choice between two alternatives and will choose the action that maximizes expected utility. In addition to the assumption of expected utility maximization, other assumptions are made included. First, alternatives are mutually exclusive, meaning one or the other must be chosen, but not a convex combination of both. This excludes the possibility of portfolio effects. Second, the stochastic dominance analysis is developed based on population probability distributions (McCarl, 2008). Population probability distributions are, in this case, simulated disease outcomes meaning they are subjective. This is a potential problem, but no observational data is available for US FMD outbreak losses.

First degree stochastic dominance would imply that if the expected value of one strategy (f) is greater than the expected value of another strategy (g) for every level of probability, then the non-satiation property would indicate that f is always at least as good as g and therefore preferred to g (McCarl, 2008). Although this is straight forward intuitively, it does not really add anything to the existing method of ranking strategies based on expected value. Furthermore, in animal disease analysis it is not very probable that one strategy will consistently outperform the other over a large simulation sample.

Second degree stochastic dominance requires two additional assumptions. First, the second derivative of utility with respect to the variable x (in this case losses) is negative everywhere implying diminishing marginal utility. Second, the integral of the difference between two cummulative distribution functions (CDFs) must be positive. This implies that CDFs can cross, but the difference in areas before they cross must be greater than the difference in areas after they cross (McCarl, 2008). This allows the ranking of strategies with one crossing, allowing ranking of strategies that would be undetermined under first degree stochastic dominance; however, the assumptions used are restrictive and will likely be problematic.

There are two primary problems with using stochastic dominance in this framework outlined in McCarl (2008). The first is the issue of non-discrimination or low crossings. If the distribution shows a vast improvement under all the observations but the lowest one, then stochastic dominance will not hold in any form. In other words, it ranks strategies close to the left hand side of the CDF. The second issue is that portfolios of control strategies cannot be considered. There are an infinite number of control strategy combinations that could be more effective when used together rather than used individually; however, under the mutual exclusivity assumption, one ignores this possibility. Finally, sample size of the simulation model iterations. This method is sensitive to outlyers and a too small sample may yield misleading results or the inability to make rankings using stochastic dominance. As a result of these problems, other methods have been developed that can be implemented here.

Generalized Stochastic Dominance (GSD) was developed by Meyer in 1997 as a way in which preferences are ranked such that dominance of one risky alternative is guaranteed over another between breakeven risk aversion coefficients (BRACs) (McCarl, 1996). GSD overcomes the problem of low crossings, but requires several assumptions. GSD does not need to be developed in much detail here since the BRAC method will not identify a strategy as being dominant that is not identified by GSD as dominant. Meaning, one cannot span a BRAC with GSD. Instead, the BRAC method will be developed in greater detail.

5.3.3. Breakeven Risk Aversion Coefficient Analysis

The goal of BRAC analysis is to find the level of a decision maker's RAC under which that decision maker will be indifferent between two alternatives. By finding these roots, a determination can be made as to which strategy would be preferred to the left of the BRAC and to the right of the BRAC. The basis for this method was derived by Hammond and fully developed by McCarl (1988) as a way to use data to determine what RAC level differentiates among all risky prospects under four principle assumptions: (1) constant absolute risk aversion (CARA) utility functional form; (2) mutually exclusive prospects; (3) discrete distribution; and (4) data free of sampling error. Hammond showed that given two alternatives which cross once that under these assumptions, there is a break-even risk aversion coefficient (BRAC) that differentiates between those two alternatives. Here an assumption is made on utility (i.e. it must be a form that exhibits CARA), but the RAC level can still vary between defined bounds.

5.3.3.1. Deriving the BRAC

Hammond begins by noting that the expected utility problem under the CARA assumption is a form of moment generating function. The moment generating function, which is used to characterize the distribution, can then be used to derive the roots of the RAC given a distributional assumption. If the assumption is that the loss distribution is *Normal*(r, u_t), the associated moment generating function can be defined for each control strategy (t). The variable (r) gives the constant absolute risk aversion coefficient (ARAC). Setting the moment generating functions equal for two alternative control strategies and solving for the value of r will yield at least one root at $r=0$ and a second root where

$$r = \frac{2(\overline{u}_f - \overline{u}_g)}{(\sigma_f^2 - \sigma_g^2)}$$

As a result, we no longer need to know a decision maker's RAC level, only whether this is a reasonable level given two bounds. This method still has two problems. First, the normality assumption may not hold for the distribution in question and second, the CARA assumption may not hold in reality. However, these assumptions will be made in order to further the examination of risk in control strategy choice.

There may be more than two roots; in fact, the number of roots will equal the number of times the two alternatives' CDFs cross. In McCarl's extension of Hammond's method, which looks at

$$\sum_i - e^{-rx_i} (f_i(x) - g_i(x)) = 0$$

and solves for the values of r at which this holds, roots will always be found at *r=0* and where $r = \infty$.

There is still a potential problem posed by sampling error. The FMD outbreak under a particular strategy was simulated 100 times in this analysis; however, this may not be a sufficient number of simulations to get a robust sample size. Other sampling issues are that when distribution means and variances get close together, the probability of improper conclusions can become quite high and using a moment generating function to find the dominance points is not as good as using an empirical distribution based method.

5.3.3.2. Finding Bounds

When examining levels of upper and lower bounds, a few points are worth noting. First, when $r_1 = 0$ and $r_2 = \infty$ we get second degree stochastic dominance, and when $r_1 = -\infty$ and $r_2 = \infty$ we get first degree stochastic dominance. It may not be reasonable to look at values ranging between negative infinity and positive infinity, rather there may be a reasonable range within which the analysis needs to be focused. Thus a rule has been established for finding those bounds. First, the bound levels of zero, negative infinity and positive infinity are discussed followed by a discussion of the bounding rules established by McCarl and Bessler.

If the RAC level falls anywhere in the negative range such that $-\infty \leq r(x) < 0$ then the this would indicate the preferences for someone who is risk loving or risk seeking. This type of individual will seek out situations in which uncertainty is high. In the context of animal disease it may be safe to rule out individuals seeking out strategies where there is a high probability of extremely high loss levels.

If the RAC level is exactly zero, then the decision maker is strictly risk neutral. This implies the decision maker will decide the portfolio of control strategies to use based strictly on minimizing the average loss, with no credence given to the importance of minimizing the outcomes in the tails of the loss distribution. This is how strategies have historically been ranked, but should be compared to how strategies are ranked if individuals weight their optimal control strategy decision with the risk of extreme outcomes. Such individuals are considered risk averse.

Risk aversion implies decision makers will wish to minimize the average loss under alternative control strategies, but they will also want to reduce the chance of an extreme outcome. Given the uncertainty inherent in the spread of FMD, the range of the possible outbreak outcomes can be quite large. If one were to visualize a distribution of simulated outbreak losses, the right tail would be quite long indicating that there is at least some chance of an "extreme" bad outcome with catastrophic losses such as what was seen in the UK in 2001. Strategies ranked simply on the mean or median may not take into account the influence of this tail on the policy choice among possible control strategies. If an individual is risk averse, their risk aversion coefficient will range such that $0 < r(x) \leq +\infty$.

It is possible then to set the range of RACs examined such that all RACs for risk neutral and risk averse individuals are examined. This would imply $r_1=0$ and $r_2=+\infty$, which is still a large range and may widely exceed the reasonable level of the upper RAC. Often one can define a narrower range in which the risk aversion coefficient (RAC) must fall. This is discussed in McCarl and Bessler. The bound conditions can be derived three ways.

- Where the certainty equivalent ignoring wealth is non-negative or equivalently where the risk premium is no greater than the mean
- Where the risk premium is bounded above by a confidence interval
- Where the risk premium does not exceed those found in applied MOTAD studies

This essay will focus on the second method, which utilizes the confidence interval. In this instance, McCarl and Bessler show that the bound on *r(x)* can be derived by making the assumption that the number of standard deviations in the confidence interval *(D)* is related to the risk premium such that the bound condition

$$r(x) \leq (2 * D) / \sigma_Y$$

By using this method, a bound is determined in which, under a normality assumption, the level of confidence for the BRAC can be derived as

$$D = (r(x) * \sigma(x)) / 2$$

The D can be looked up in the standard normal (Z) table to get the level of the confidence interval (McCarl, 2008).

5.3.3.3. Stochastic Efficiency with Respect to a Function

Recently, BRAC procedures have been built into a Microsoft Excel add-in called Stochastic Efficiency with Respect to a Function (SERF). An advantage of the SERF method in calculating BRAC points is that, in addition to identifying where dominance between two alternatives switches, SERF allows for estimation of the utility-weighted risk premiums between alternatives to provide a cardinal measure for comparing the payoffs between risky alternatives (Hardaker et al.). If no BRACs are found, then a message will be printed out indicating one distribution dominates everywhere. If BRACs are found, messages will be given identifying the dominant prospect over particular RAC ranges. Therefore, we combine both CDFs and SERF for each scenario so we can easily understand how dominant the mitigation strategy could be.

5.4. Case Study in the High Plains Concentrated Feeding Region

A region of the country vulnerable to FMD is the concentrated feeding region of the High Plains of Texas. This area is characterized by a large number of feedlots, varying in size from large company owned feedlots to smaller backgrounder feeders. Although beef cattle far outnumber other susceptible species, the area also has hog, dairy and sheep operations. This study particularly focuses on an eight county region that has a large number of feedlot operations.

The AusSpread Model and the ASM model with the included cost model were used for this analysis. For details on these models please refer to essay 2. In the following results, we are evaluating the mitigation strategy by using the concept of welfare comparisons among consumers, processors, and producers, and the concept of stochastic dominance with the preliminary average simulated High Plain data of economic modeling with the FASOM model by using GAMS. We use the same assumptions and the original 64 scenario settings with different three mitigation strategies outlined by Ward et al. (2007). The major differences will be the expansion of the economic consequences of the potential animal disease outbreak in the Texas High Plain area by estimating the welfare losses with and without using mitigation strategies from the perspectives of consumers, processors, and producers in the United States and in the specific geographic regions and the risk analysis. A more detailed report of the disease mitigation costing results can be found in Elbakidze et al.

5.5. Simulation and Experimental Results

The stamp out policy and movement restrictions were assumed to be standard (refer to essay 1); these two policies are well established as reducing disease spread. In the future, comparisons of alternative methods of enforcing these policies could be considered—for example ring slaughter versus targeted slaughter. However, the focus here is on three control strategies--detection, surveillance and vaccination. For each strategy two "levels" of enforcement are considered.

- *Detection*: For this strategy early detection occurring on day 7 after the first animal becomes sub-clinically infection is compared to late detection on day 14 after the first animal becomes sub-clinically infected.

- *Surveillance*: Regular surveillance were each premises under surveillance is visited twice a week to check for signs of FMD is compared to enhanced surveillance were each premises under surveillance is visited four times a week to check for signs of FMD. Since there is a cost per visit, enhanced surveillance will increase the cost per animal under surveillance, but the question is whether it reduces the overall impact of the disease.

- *Vaccination*: Regular vaccine availability implies vaccine is available and on site one week (7 days) after the day the disease is detected. This implies vaccination begins on day 14 under early detection and day 21 under late detection. Regular vaccine availability is compared to rapid vaccine availability were vaccine is available and on site on the day the disease is detected. This implies vaccination beings on day 7 for early detection and day 14 for late detection. Since current vaccination policy is a "vaccinate to die" policy, all animals vaccinated must be slaughtered.

5.5.1. Expected Welfare Gain/Loss Comparison under Different Mitigation Strategies

Rather than using the minimization of losses or maximization of gains in surplus to any one group, policy makers may instead choose to minimize losses of the disease outbreak over all groups. In other words, the goals of control strategy choice may be to minimize the national average economic surplus loss. This analysis would be valid in ranking control strategies as long as policy makers are risk neutral. The three control strategies are examined below using this criterion.

5.5.1.1. Early versus Late Detection

The literature indicates early detection should be preferable overall (Schoenbaum and Disney; Paarlberg, Lee and Seitzinger; Ekboir; Ward et al., 2007). In the expansion of the High Plains study results are mixed. Early detection resulted in a shorter epidemic length (on average 16 days less) and less herds slaughtered (on average 12 herds less), but economic results indicate it may not be an average national loss minimizing strategy.

For early versus late detection strategies, Table 42 gives the total surplus loss as well as the components that make up the total surplus loss. Under the early detection section, in parentheses, is the percentage change from late detection results. Consumers gain the most on average under early detection, except for when the disease outbreak initializes in a backyard operation. Thus early detection would be an appealing strategy to risk neutral decision makers seeking to maximize consumer gains. Early detection yields lower average losses in producer surplus when infections start in backyard operations but higher losses when infections start in large and small feedlots or large grazing operations. Over all infection points (average effect row), early detection results in a higher total loss by $160,000 on average (0.01% increase). Only infections beginning in backyard operations results in an overall decrease in the average national surplus loss from early detection.

Table 42. National Economic Surplus Gain/Loss Under Alternative Detection (Millions $2004)

	Early Detection			
	Change in Consumer Surplus	Change in Processor Surplus	Change in Producer Surplus	Total Change in National Surplus
Average Effect	158.48 (0.56%)	-13.46 (0.17%)	-945.18 (0.10%)	-800.16 (0.01%)
Large Feedlot IP	163.59 (2.28%)	-16.18 (18.22%)	-948.09 (0.15%)	-800.68 (0.04%)
Small Feedlot IP	156.02 (1.91%)	-11.02 (-15.70%)	-944.70 (0.55%)	-799.70 (0.02%)
Large Grazing IP	162.39 (1.15%)	-14.31 (17.33%)	-948.80 (0.01%)	-800.72 (0.04%)
Backyard IP	151.93 (-3.12%)	-12.33 (-16.61%)	-939.15 (-0.294%)	-799.55 (-0.04%)

	Late Detection			
	Change in Consumer Surplus	Change in Processor Surplus	Change in Producer Surplus	Total Change in National Surplus
Average Effect	157.60	-13.43	-944.17	-800.00
Large Feedlot IP	159.94	-13.68	-946.59	-800.34
Small Feedlot IP	153.09	-13.08	-939.50	-799.49
Large Grazing IP	160.53	-12.19	-948.66	-800.32
Backyard IP	156.83	-14.78	-941.92	-799.87

5.5.1.2. Rapid versus Regular Availability of Vaccine

Since the assumed vaccination policy is a “vaccinate to die” policy, all animals vaccinated are be slaughtered without entering the meat supply. The appeal of vaccination is as a retardant to disease spread, but at a higher cost in terms of animal life and dollar expenditure on disease control cost. Here, regular availability of vaccine is compared to rapid availability of vaccine in the hopes that having vaccine available more quickly would allow the disease to be contained to a smaller area. Rapid availability of vaccine supply resulted in a shorter epidemic length (on average 1 days less) and less herds slaughtered (on average 2 herds less), but again does not necessarily imply a smaller economic loss.

For rapid versus regular availability of vaccine, Table 43 gives the total surplus loss as well as components that make up the total surplus loss. Under the rapid vaccine availability column, in parentheses, is the percentage change from regular vaccine availability. Consumers gain on average slightly more when outbreaks begin in large feedlots under regular vaccine availability, but for other types of infection points consumers gain more under rapid vaccine availability. Producers lose less on average under regular vaccine availability for all infection points except large feedlots, where losses range from $945 million to $943 million for rapid vaccine availability and from $937 million to $947 million for regular availability. Rapid vaccine availability results in a $163,000 increase in national surplus loss on average across all infection points, or an increase of 0.03%. Only for large feedlot infection points does rapid vaccine availability reduce the average national surplus loss, but even then it is by a very small amount (0.004%). Risk neutral decision makers would not find vaccination to be an appealing policy to minimize the national economic surplus loss from an animal disease incursion.

Table 43. National Economic Surplus Gain/Loss Under Alternative Availability of Vaccine (Millions $2004)

	Rapid Vaccine Availability			
	Change in Consumer Surplus	Change in Processor Surplus	Change in Producer Surplus	Total Change in National Surplus
Average Effect	$157.17 (1.06%)	-$14.69 (13.13%)	-$942.58 (0.02%)	-$800.08 (0.03%)
Large Feedlot IP	$158.52 (0.11%)	-$13.38 (-11.67%)	-$945.38 (0.18%)	-$800.24 (-0.004%)
Small Feedlot IP	$154.63 (1.16%)	-$13.55 (-6.98%)	-$940.97 (0.34%)	-$799.89 (0.04%)
Large Grazing IP	$160.48 (3.54%)	-$17.27 (37.48%)	-$943.56 (0.14%)	-$800.29 (0.06%)
Backyard IP	$155.05 (1.24%)	-$14.55 (1.11%)	-$940.39 (0.23%)	-$799.89 (0.05%)
	Regular Vaccine Availability			
	Change in Consumer Surplus	Change in Processor Surplus	Change in Producer Surplus	Total Change in National Surplus
Average Effect	$155.52	-$12.98	-$942.38	-$799.85
Large Feedlot IP	$158.70	-$11.82	-$947.09	-$800.21
Small Feedlot IP	$152.85	-$14.57	-$937.83	-$799.54
Large Grazing IP	$154.99	-$12.56	-$942.23	-$799.80
Backyard IP	$153.15	-$14.39	-$938.24	-$799.47

5.5.1.3. Enhanced versus Regular Surveillance

In comparing enhanced versus regular surveillance, the benefit in terms of reduced disease outcomes is weighed against the increased cost of additional surveillance. Enhanced surveillance resulted in a shorter epidemic length (on average 1 days less), and less herds slaughtered (on average 1 herd less).

For enhanced versus regular surveillance strategies, Table 44 gives the total surplus loss as well as the components that make up the total surplus loss. Under the enhanced surveillance column, in parentheses, is the percentage change from regular surveillance results. Enhanced surveillance results in a lower consumer surplus gain for feedlots and backyard operations on average. For producers, the loss in surplus is lower on average when enhanced surveillance is employed in feedlot infection points. However, producers stand to lose greater amounts of surplus on average when enhanced surveillance is used and the infection point is a large beef grazing operation or a backyard operation. Over all infection points (average effect row), enhanced surveillance results in a lower loss by $120,000 on average (0.01% decrease). Infections beginning in large feedlots and large beef grazing operations results in an overall increase in the average national surplus loss from enhanced surveillance. So enhanced surveillance may be an appealing strategy to a risk neutral policy maker for reducing the average impact of the disease where the infection point is unknown.

Table 44. National Economic Surplus Gain/Loss Under Alternative Surveillance (Millions $2004)

	Enhanced Surveillance			
	Change in Consumer Surplus	Change in Processor Surplus	Change in Producer Surplus	Total Change in National Surplus
Average Effect	$159.39 (-0.89%)	-$13.60 (-0.52%)	-$945.99 (0.15%)	-$800.20 (-0.01%)
Large Feedlot IP	$158.48 (-6.33%)	-$13.89 (-1.34%)	-$944.77 (-1.19%)	-$800.18 (-0.11%)
Small Feedlot IP	$154.19. (-3.87%)	-$13.27 (1.52%)	-$940.53 (-0.71%)	-$799.62 (-0.04%)
Large Grazing IP	$165.87 (6.36%)	-$13.41 (19.40%)	-$953.35 (0.92%)	-$800.88 (0.11%)
Backyard IP	$159.03 (0.77%)	-$13.81 (-15.18%)	-$945.32 (0.37%)	-$800.11 (-0.01%)

	Regular Surveillance			
	Change in Consumer Surplus	Change in Processor Surplus	Change in Producer Surplus	Total Change in National Surplus
Average Effect	$160.84	-$13.67	-$947.49	-$800.32
Large Feedlot IP	$169.21	-$14.08	-$956.23	-$801.11
Small Feedlot IP	$160.41	-$13.08	-$947.33	-$800.00
Large Grazing IP	$155.94	-$11.23	-$944.64	-$799.93
Backyard IP	$157.80	-$16.29	-$941.76	-$800.24

5.5.2. Simple Statistical Ranking

The first examination of the risk of alternatives is simply comparing the standard deviation and coefficient of variation (risk measures). The min and max are also provided as a means of examining the spread of the distribution. Results for each of the three control strategies will be examined separately.

5.5.2.1. Early versus Late Detection

Consider Table 45 and Table 46, which show the results for early and late detection scenarios respectively across the four infection points considered (large feedlot, small feedlot, large beef grazing operation, and backyard operation) for the three groups that make up total US economic surplus (consumers, processors and producers).

Both processors and producers stand to lose surplus from the outbreak, while consumers stand to gain. The primary focus of this analysis will be on the producer losses. Looking at risk measures, standard deviation indicates that early detection yields less risk when infections start in large feedlots, small feedlots and large grazing operations for consumers and producers but more risk when infections start in backyard operations for consumers, producers and processors. Examining the coefficient of variation, which is a relative risk measure, consumers reduce risk through early detection for large feedlot, small feedlot and large grazing infection points but increase risk for a backyard infection point. Processors realize a smaller CV for infection points in large and small feedlots, but not large grazing operation or backyard infection points. Producers realize a smaller CV under late detection for large feedlot, small feedlot and large grazing infection points but a larger CV for backyard infection points.

These mixed results do not give a clear picture of whether the detection difference considered here (one week) is enough to make early detection act as a risk reducing strategy. More detailed analysis will be needed.

Table 45. Early Detection Summary Statistics (Millions $2004)

	Early Detection			
Large Feedlot IP	StDev	CV	Min	Max
Change in US Consumer Surplus	35.76	21.86	$26.46	$214.21
Change in US Processor Surplus	12.62	-77.97	-$44.88	$13.13
Change in US Producer Surplus	36.12	-3.81	-$1024.77	-$815.26
Small Feedlot IP				
Change in US Consumer Surplus	40.57	26.00	$26.46	$200.41
Change in US Processor Surplus	8.28	-75.06	-$15.20	$13.13
Change in US Producer Surplus	40.85	-4.32	-$998.55	-$815.26
Large Grazing IP				
Change in US Consumer Surplus	34.81	21.43	$26.46	$214.21
Change in US Processor Surplus	10.25	-71.61	-$44.88	$13.13
Change in US Producer Surplus	35.29	-3.72	-$998.55	-$815.26
Backyard IP				
Change in US Consumer Surplus	41.12	27.07	$26.46	$200.41
Change in US Processor Surplus	12.04	-97.61	-$44.88	$13.13
Change in US Producer Surplus	40.87	-4.35	-$1024.77	-$815.26

Table 46. Late Detection Summary Statistics (Millions $2004)

	Late Detection			
Large Feedlot IP	StDev	CV	Min	Max
Change in US Consumer Surplus	39.27	24.56	$26.46	$214.21
Change in US Processor Surplus	11.14	-81.41	-$44.88	$13.13
Change in US Producer Surplus	38.94	-4.11	-$998.55	-$815.26
Small Feedlot IP				
Change in US Consumer Surplus	42.69	27.89	$26.46	$200.41
Change in US Processor Surplus	11.74	-89.75	-$44.88	$13.13
Change in US Producer Surplus	43.46	-4.63	-$1024.77	-$785.58
Large Grazing IP				
Change in US Consumer Surplus	37.30	23.23	$26.46	$200.41
Change in US Processor Surplus	7.567	-62.03	-$15.20	$13.13
Change in US Producer Surplus	37.40	-3.94	-$998.55	-$815.26
Backyard IP				
Change in US Consumer Surplus	38.23	24.37	$26.46	$200.41
Change in US Processor Surplus	11.27	-76.22	-$44.88	$13.13
Change in US Producer Surplus	40.19	-4.27	-$1024.77	-$785.58

5.5.2.2. Rapid Vaccine Availability versus Regular Vaccine Availability

Table 47 and Table 48 provide summary statistics for rapid and regular vaccine availability respectively. Recall that rapid vaccine availability did not appear to be an expected loss minimizing strategy, so the question becomes whether or not it is a risk reducing strategy.

Beginning with the standard deviation of the loss distribution for consumers, rapid vaccine availability reduces the absolute risk for infection points in small feedlots, large grazing operations and backyard operations but increases risk for large feedlot infection points. Similarly, for processors, rapid vaccine availability reduces absolute risk when infection points are small feedlots, large grazing operations and backyard operations but increases risk for large feedlot infection points. For producers, absolute risk is reduced under rapid vaccine availability for infection points in large grazing operations and backyard operations but not for infection points in feedlots.

Examining the relative risk through the CV, consumers risk is reduced through rapid vaccine availability for infection points in small feedlots, large grazing operations and backyard operations but is increase for an infection point in a large feedlot. For processors, rapid vaccine availability reduces relative risk for infection points starting in large feedlots and backyard operations, but larger for infection points in small feedlots and large grazing operations. Finally, for producers, relative risk is reduced under rapid vaccine availability for large feedlot infection points but increased for infection points in small feedlots, large grazing operations, and backyard operations.

Overall results are once again mixed, but seem to indicate that for the majority of potential infection points vaccine may have merit as a risk reducing strategy particularly when consumers gains are maximized or processors losses are minimized. For producer losses results are more mixed.

Table 47. Rapid Vaccine Availability Summary Statistics (Millions $2004)

	Rapid Vaccine Availability			
Large Feedlot IP	SD	CV	Max	Min
Change in US Consumer Surplus	41.27	26.03	$26.46	$214.21
Change in US Processor Surplus	11.55	-86.36	-$44.88	$13.13
Change in US Producer Surplus	40.31	-4.26	-$998.55	-$815.26
Small Feedlot IP				
Change in US Consumer Surplus	40.35	26.09	$26.46	$200.41
Change in US Processor Surplus	10.79	-79.66	-$44.88	$13.13
Change in US Producer Surplus	41.99	-4.46	-$998.55	-$785.58
Large Grazing IP				
Change in US Consumer Surplus	38.04	23.70	$26.46	$214.21
Change in US Processor Surplus	13.74	-79.55	-$44.88	$13.13
Change in US Producer Surplus	39.76	-4.21	-$998.55	-$785.58
Backyard IP				
Change in US Consumer Surplus	39.27	25.33	$26.46	$200.41
Change in US Processor Surplus	12.22	-83.99	-$44.88	$13.13
Change in US Producer Surplus	41.03	-4.36	-$1,024.77	-$815.26

Table 48. Regular Vaccine Availability Summary Statistics (Millions $2004)

	Regular Vaccine Availability			
Large Feedlot IP	SD	CV	Max	Min
Change in US Consumer Surplus	38.33	24.16	$26.46	$200.41
Change in US Processor Surplus	7.79	-65.89	-$15.20	$13.13
Change in US Producer Surplus	38.34	-4.05	-$998.55	-$815.26
Small Feedlot IP				
Change in US Consumer Surplus	41.02	26.84	$26.46	$200.41
Change in US Processor Surplus	12.97	-89.04	-$44.88	$13.13
Change in US Producer Surplus	41.97	-4.48	-$1,024.77	-$785.58
Large Grazing IP				
Change in US Consumer Surplus	44.98	29.02	$26.46	$214.21
Change in US Processor Surplus	12.35	-98.32	-$44.88	$13.13
Change in US Producer Surplus	43.45	-4.61	-$998.55	-$815.26
Backyard IP				
Change in US Consumer Surplus	44.16	28.83	$26.46	$200.41
Change in US Processor Surplus	12.02	-83.58	-$44.88	$13.13
Change in US Producer Surplus	46.03	-4.91	-$998.55	-$785.58

5.5.2.3. Enhanced versus Regular Surveillance

In comparing enhanced versus regular surveillance, economic loss results are shown in Table 49 and Table 50. Enhanced surveillance yields significantly higher absolute risk as measured by standard deviation across all infection points when examining consumer gains. For processors, enhanced surveillance yields higher absolute risk for infection points in feedlots, but lower absolute risk for infection points in large grazing operations and backyard operations. For producers, the standard deviation is consistently higher when enhanced surveillance is employed implying a higher level of absolute risk.

Enhanced surveillance also yields a higher consumer gain CV for infection points in feedlots, but lower CV for infection points in large beef grazing operations and backyard operations. Processors' loss CV indicates a smaller level of relative risk under enhanced surveillance for feedlots, but a larger level of relative risk under enhanced surveillance for infection points starting in large grazing operations and backyard operations. Finally, producers follow the same pattern in which the CV indicates a smaller level of relative risk under enhanced surveillance for feedlots, but a larger level of relative risk under enhanced surveillance for infection points starting in large grazing operations and backyard operations.

Taken together these results indicate that, overall, national losses would be reduced when enhanced surveillance is employed for feedlot infection points. This may not be unreasonable given that, although more animals are suspect when infections begin in feedlots, there may be fewer *herds* that are under surveillance when feedlots are infection points. The costs to surveillance are on a per herd basis. However, it is unknown at the time an outbreak occurs, typically, exactly what type of operation is the infection point so more detailed analysis is needed.

Table 49. Enhanced Surveillance Summary Statistics (Millions $2004)

	Enhanced Surveillance			
Large Feedlot IP	SD	CV	Max	Min
Change in US Consumer Surplus	41.97	26.48	$214.21	$26.46
Change in US Processor Surplus	12.48	-89.80	$13.13	-$44.88
Change in US Producer Surplus	40.91	-4.33	-$815.26	-$998.55
Small Feedlot IP				
Change in US Consumer Surplus	42.85	27.79	$200.41	$26.46
Change in US Processor Surplus	11.01	-82.94	$13.13	-$44.88
Change in US Producer Surplus	44.26	-4.71	-$785.58	-$998.55
Large Grazing IP				
Change in US Consumer Surplus	29.26	17.64	$200.41	$26.46
Change in US Processor Surplus	5.50	-41.00	$13.13	-$15.20
Change in US Producer Surplus	31.00	-3.25	-$815.26	-$998.55
Backyard IP				
Change in US Consumer Surplus	29.26	17.64	$200.41	$26.46
Change in US Processor Surplus	5.50	-41.00	$13.13	-$15.20
Change in US Producer Surplus	31.00	-3.25	-$815.26	-$998.55

Table 50. Regular Surveillance Summary Statistics (Millions $2004)

	Regular Surveillance			
Large Feedlot IP	SD	CV	Max	Min
Change in US Consumer Surplus	23.78	14.06	$200.41	$84.21
Change in US Processor Surplus	3.97	-28.16	$0.01	-$15.20
Change in US Producer Surplus	27.37	-2.86	-$866.34	-$998.55
Small Feedlot IP				
Change in US Consumer Surplus	33.98	21.18	$200.41	$26.46
Change in US Processor Surplus	8.85	-67.68	$13.13	-$44.88
Change in US Producer Surplus	34.85	-3.68	-$815.26	-$1024.77
Large Grazing IP				
Change in US Consumer Surplus	42.27	27.10	$200.41	$26.46
Change in US Processor Surplus	8.84	-78.67	$13.13	-$15.20
Change in US Producer Surplus	41.07	-4.35	-$815.26	-$998.55
Backyard IP				
Change in US Consumer Surplus	42.27	27.10	$200.41	$26.46
Change in US Processor Surplus	8.84	-78.67	$13.13	-$15.20
Change in US Producer Surplus	41.07	-4.35	-$815.26	-$998.55

5.5.3. Risk Aversion Analysis

The risk aversion analysis was done since examining the mean levels of economic losses with no credence given to their embodied risk is an assumption that all decision makers are risk neutral—meaning they are indifferent to the chance of extreme outcomes and only care about the expected (or average) outcome. Also, the simple statistical measures of risk lead to inconclusive results.

Results in this section will be presented by control strategy but will also be broken into two parts. The first part will be an examination of the CDFs for first or second degree stochastic dominance, and the second part will use SERF analysis to find the BRACs at which preference between alternative levels of control strategies switches. The lower bound risk aversion coefficient was set as risk neutral individuals (LRAC=0) and the upper bound was set using the standard deviation of the distribution of losses. The upper bound was approximately 1 for total US losses (where standard deviation ranged between 9 and 10) for each of the control strategies considered, so this was used for the upper risk aversion coefficient in the BRAC analysis in all three control strategies.

5.5.3.1. Early versus Late Detection

In the analysis of standard deviation and coefficient of variation, the results for whether early detection is a risk reducing strategy are mixed. This section will apply more advanced analysis to determine whether early detection is a preferred strategy from a risk reduction standpoint. As shown in Figure 43, neither first nor second order stochastic dominance can be used to rank early and late detection strategies because the CDFs cross multiple times for every infection point; however, this is difficult to tell give the lines are sometimes too close to tell whether they are touching or not. So, the BRAC analysis is used to determine the RAC levels at which preferences switch back and forth between the two strategies.

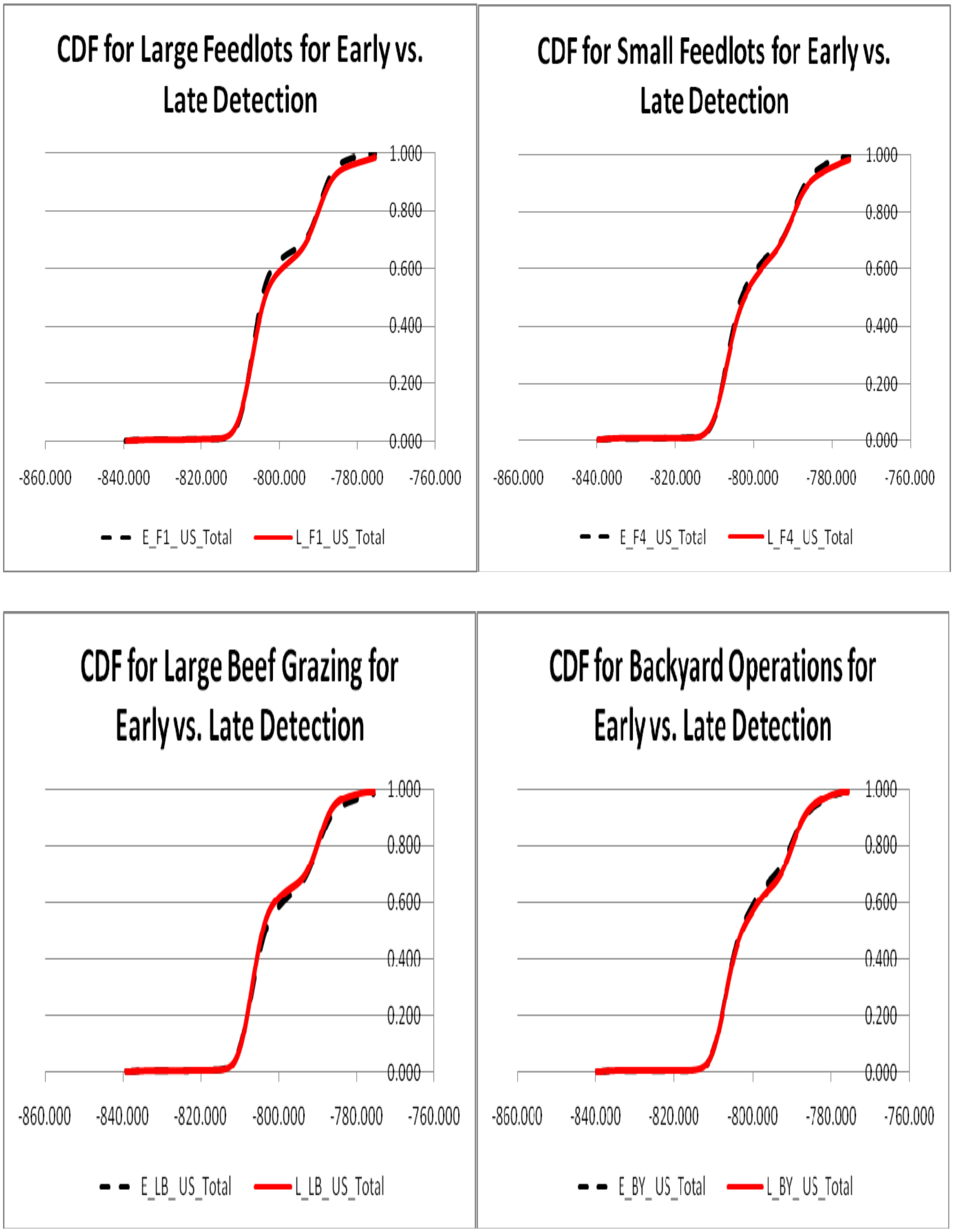


Figure 43. CDFs for Early vs. Late Detection

Given the sensitivty of BRAC analysis to outlyers, a single iteration that resulted in an outlyer in every case was removed, resulting in a distribution based on 99 points. Examining all RACs lying between zero and 1, the preference switch point will depend on the infection point. Recall that early detection does not in general result in lower expected losses, but does appear to have the potential to reduce risk. The BRAC analysis shows that, in general, risk averse agents do not gain enough from early detection to more than offset the larger expected losses except in when infections begin in backyard operations. Backyard operations were found to have the potential for very large outbreaks in some iterations. This corresponds to the examination of the summary statistics shown earlier.The switch occurs at a smaller level of risk aversion for small feedlot incursions as opposed to large grazing incursions. To make these results more intuitive, the BRAC points can be translated into confidence intervals using the formula presented earlier. Results are as shown in Figure 44.

The results shown for the Texas High Plains as they relate to detection are somewhat anomalous. It may be that the inclusion of greater trade impacts or a larger sample size would yield results more in line with the intuitive conclusion that, since fewer animals are slaughtered under early detection, it should be more preferable. Further examination of this issue would be an area of future research in the study of FMD in the Texas High Plains.

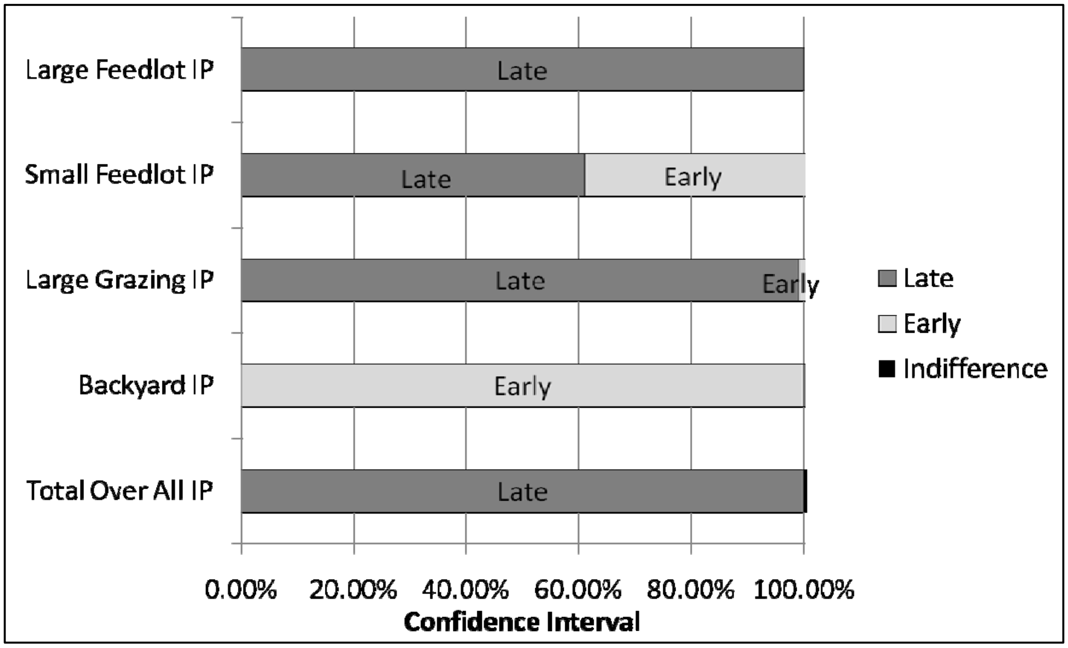


Figure 44. BRAC Points for Early vs. Late Detection

5.5.3.2. Rapid versus Regular Availability of Vaccine

In the analysis of standard deviation and coefficient of variation, indicators pointed to a potential reduction of risk from rapid availability of vaccine; however, regular availability was preferred for risk neutral decision makers. Examining the CDFs for each of the four infection points under alternative vaccine availability presented in Figure 45, first and second stochastic dominance cannot be applied except potentially in the case of large grazing infection points.

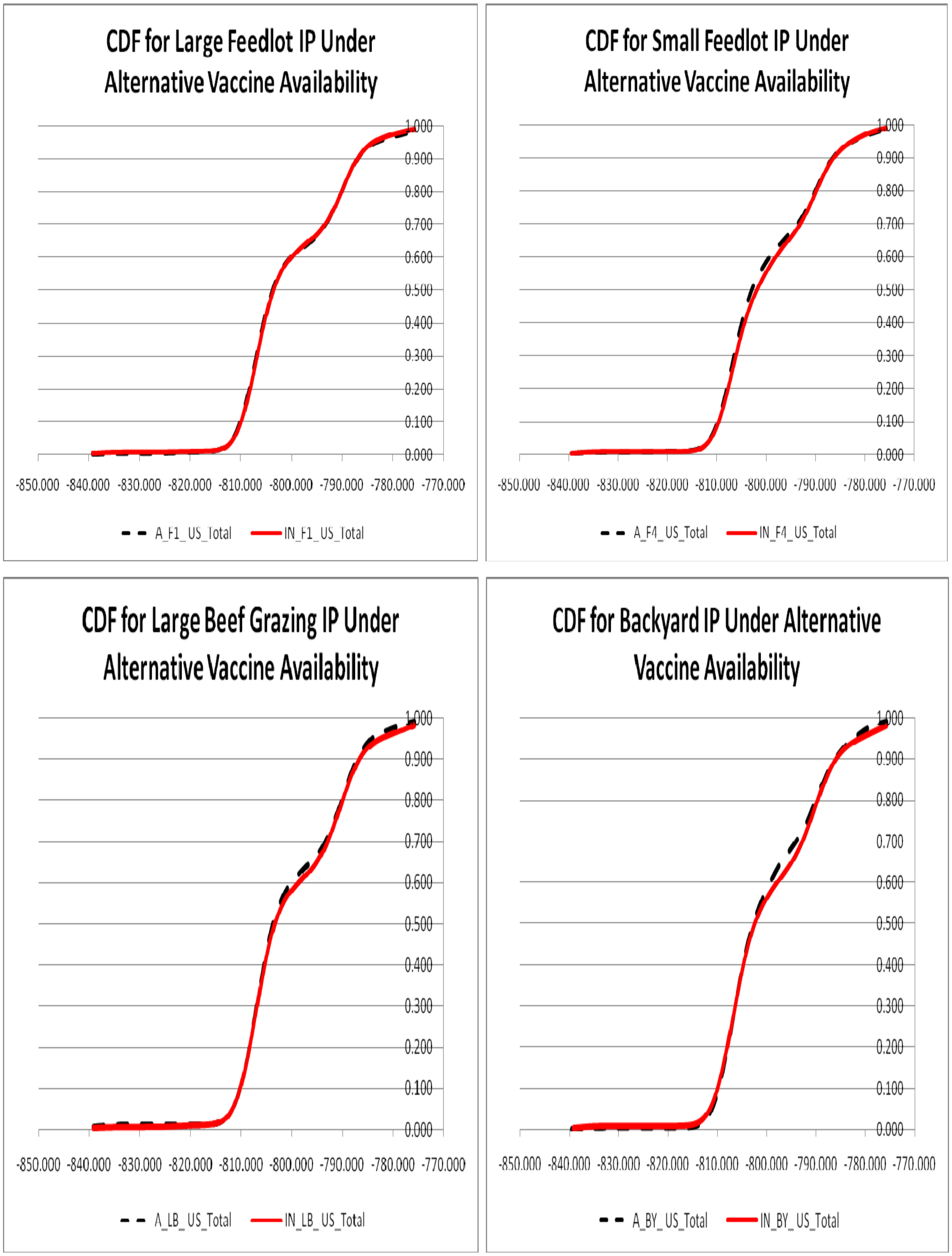


Figure 45. CDFs for Rapid vs. Regular Vaccine Availability

As risk aversion increases, a switch to preference for rapid vaccine availability occurs for all infection points. Large feedlot and backyard infection point cases have the earliest switch at a RAC level at 0.07 and 0.06 respectively. Large grazing infection point cases have the latest switch at a little less than a RAC level of 0.883. Overall infection points, there is still a preference for rapid vaccine availability as risk aversion rises. To make the results more intuitive, Figure 46 illustrates the confidence intervals at which the preference for vaccine availability switches. These results indicate that rapid vaccine availability decreases the risk of extreme outcomes compared to regular vaccine availability. If the goal of rapid vaccine use is to reduce the overall impact of the disease, even at a higher average cost, then it appears to be attainable in the High Plains simulations.

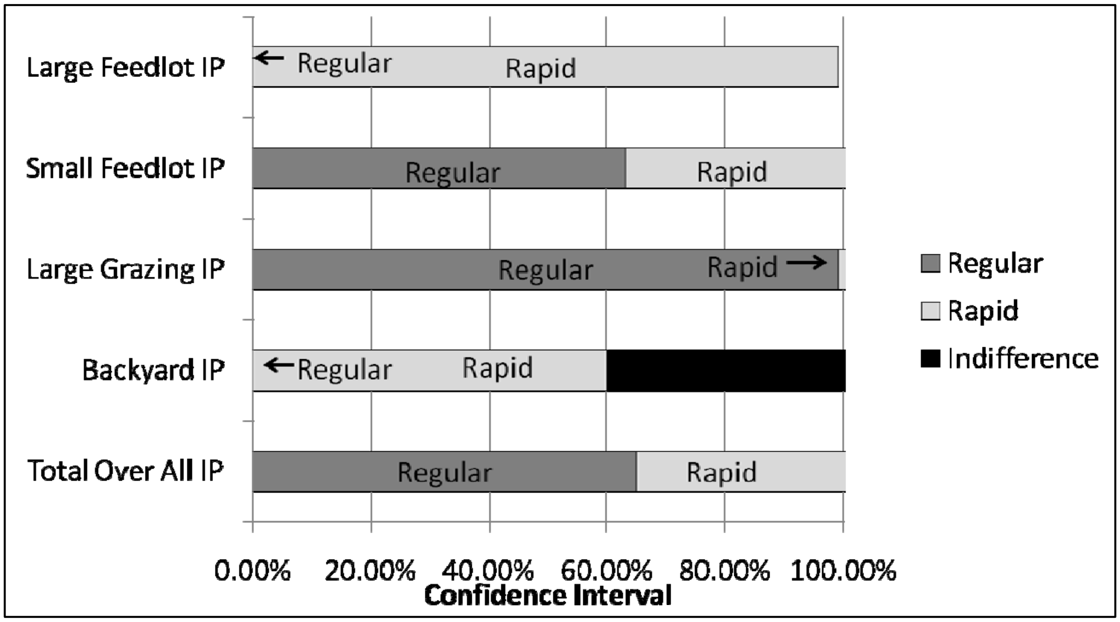
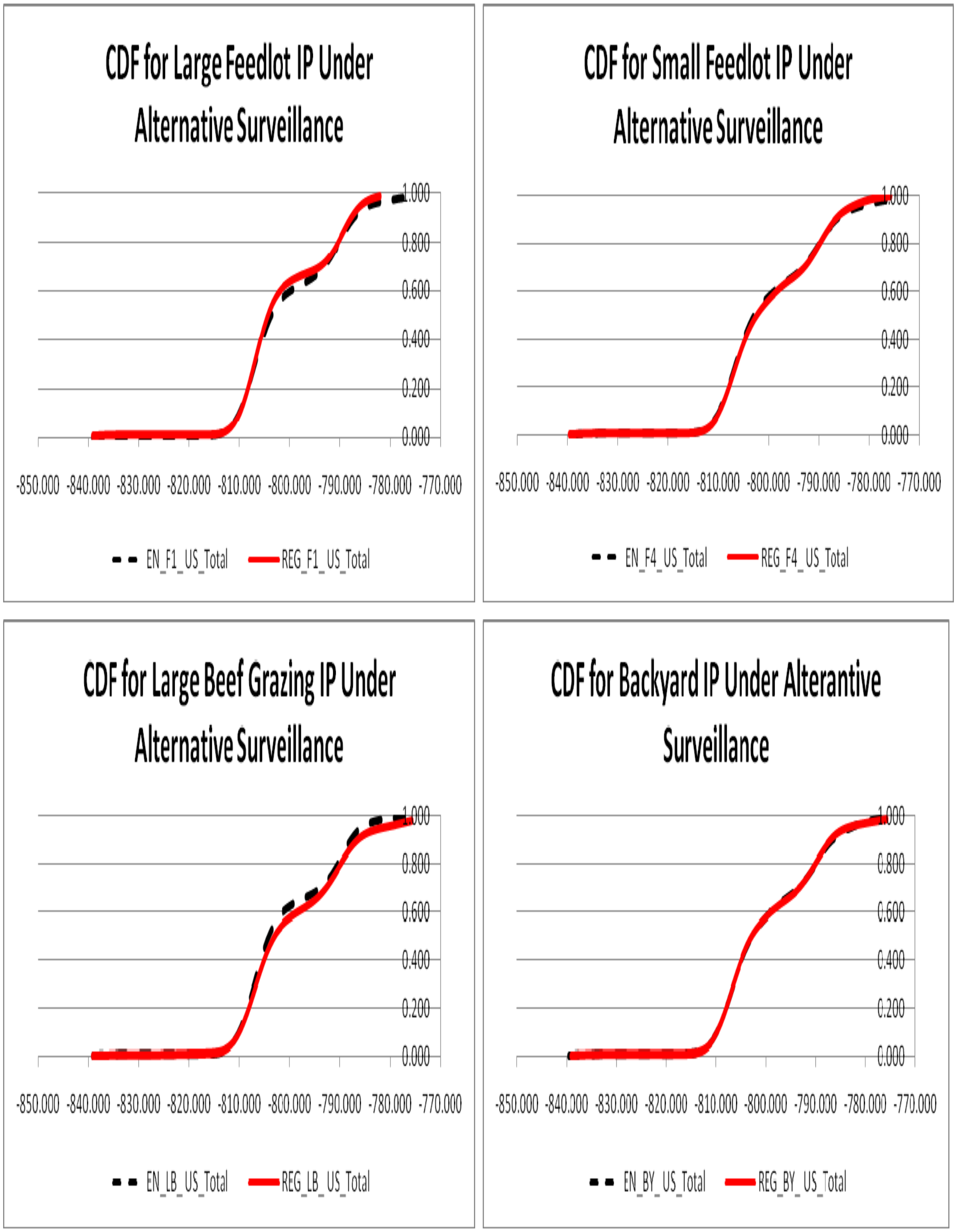


Figure 46. BRAC Points for Rapid vs. Regular Vaccine Availability

5.5.3.3. Enhanced versus Regular Surveillance

Enhanced surveillance had mixed results as a risk reducing control policy. Examining the CDFs for alternative surveillance in Figure 47, the CDFs much to close together to really tell using this method of one strategy dominates the other.

For a large feedlot infection point, enhanced is always preferred to regular. This corresponds to the evidence provided in the risk summary statistic analysis and expected national loss analysis. For a large beef grazing operation infection point regular surveillance is always preferred to enhanced surveillance. Again this corresponds to previously presented evidence. Figure 48 illustrates the confidence intervals corresponding to BRAC points for enhanced versus regular surveillance. These results may not be unreasonable intuitively. Large feedlot incursions may mean fewer herds are under surveillance, making the additional expense worthwhile. Large grazing operations are more scattered and may have fewer numbers per herd, making additional surveillance less effective but more costly comparatively. In a small feedlot or backyard infection point, regular is preferred for risk neutral and slightly risk averse individuals. As risk aversion rises the benefits of enhanced surveillance as a risk reducing control strategy cause a switch in preferences to occur for these infection points. However, looking across all infection points, regular surveillance is preferred. This may indicate that enhanced surveillance is not an overall risk reducing strategy.



CDF for Large Feedlot IP Under Alternative Surveillance

CDF for Small Feedlot IP Under Alternative Surveillance

CDF for Large Beef Grazing IP Under Alternative Surveillance

CDF for Backyard IP Under Alterantive Surveillance

Figure 47. CDFs for Enhanced vs. Regular Surveillance

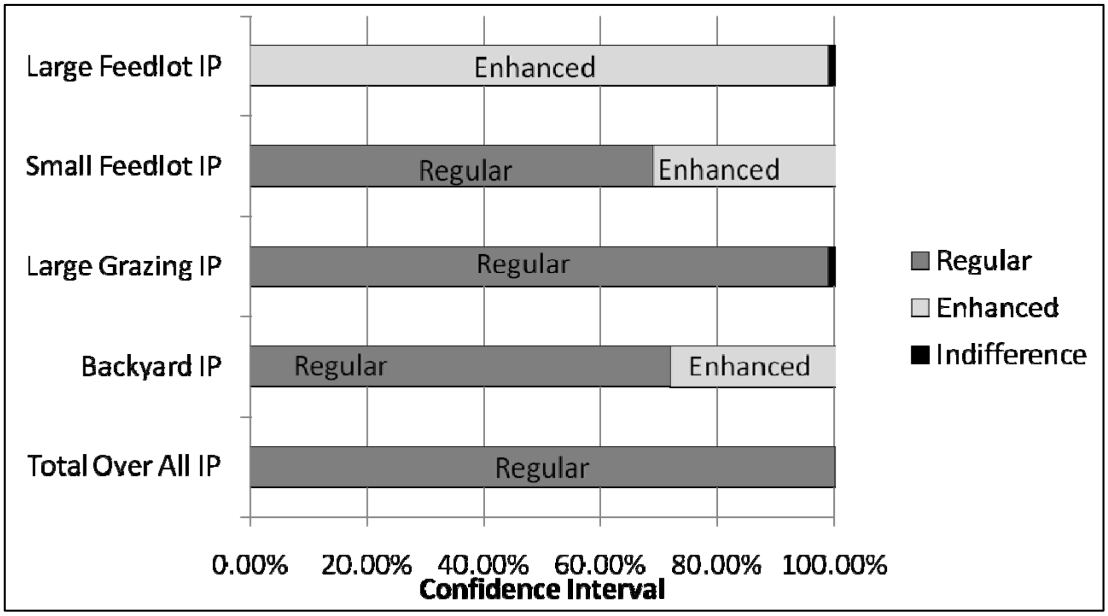


Figure 48. BRAC Points for Alternative Surveillance

5.6. Summary and Conclusions

It can be concluded that the region studied is highly vulnerable to an animal disease outbreak but there are control options available that will reduce the losses associated with an outbreak and increase sectoral resiliency. Results suggest that some strategies may become preferable from the standpoint of reducing risk and thereby increasing resiliency. Furthermore, these may not be the same strategies that minimize the expected national loss from the disease outbreak.

Early detection had the greatest impact epidemiologically, and still has merit as a strategy in increasing resiliency, which provides justification for examining systems and producer education promoting early detection. In large grazing and small feedlot infection point herds, as well as outbreaks starting in backyard operations the risk reducing benefits of early detection more than outweigh the higher expected national surplus losses. However, these results are anomolous and may be the result of small sample size or not properly including trade. Thus, early detection may be a preferable strategy from a livestock industry resiliency standpoint, but results are inconclusive.

Vaccine availability results suggested that, in general, improved vaccine availability during an incursion was not a cost effective mitigation option when seeking to minimize the average loss. Small feedlot, large beef and backyard operation index herds have a reduction in standard deviation from rapid vaccine availability. However, as risk aversion rises across all incursion points a switch in preference to rapid vaccine availability occurs despite the higher expected national surplus losses. Thus, having vaccine available faster does appear to be a resiliency increasing control strategy.

Enhanced surveillance proved to reduce national welfare losses for outbreaks starting in large feedlots and backyard operations, but it only reduces standard deviation of national welfare losses in beef grazing operation index herds. Both large and small feedlots incursions lead to a preference for enhanced surveillance as risk aversion rises as well as backyard infection points, but for large beef infection point herds there is a preference for regular surveillance as risk aversion rises. This may indicate a strategy to reduce risk in areas with large feedlots. However, mixed results do not lead to a clear conclusion as to whether enhanced surveillance is a risk reducing strategy for the High Plains.

This essay provides a jumping off point for a more detailed examination of the role of risk attitude in determining control strategy choice. Such analysis provides justification for examining other control strategies and portfolios of control strategies. Further research could include a more complete and detailed analysis for different detection levels, targeted and ring vaccination and in different types of regions from the concentrated beef feeding region in the High Plains. Agricultural policy design for FMD prevention and mitigation can utilize the analysis we currently have in making policy decisions for anticipation, response and recovery from a disease outbreak in concentrated feeding regions.

This work is not without limitations. First, the treatment of trade in the economic loss examination was not thorough. Rather the numbers presented here are local losses not including the impacts of international trade restrictions. Second, simply examining outbreak impacts on a national level may not be the proper criterion on which policy would be based. Rather, it may be the minimizing risk in the regional producer loss, for example, on which policy decisions are based. Finally, the number of control strategies considered could be expanded to look at a more diversified response options portfolio and the sample size exposes results to sample size bias issues discussed in the methodology section.

6. ESSAY 5: MARKET RESPONSE- THE ROLE OF INFORMATION UNCERTAINTY IN EXACERBATING FUTURES MARKET RESPONSE TO UNCONFIRMED ANIMAL DISEASE

6.1. Introduction

Foreign animal diseases such as foot-and-mouth disease (FMD) pose a significant threat to the US economy. Current policy in the event of an FMD outbreak involves high levels of slaughter reducing aggregate meat and livestock supply, international export market closures and trade barriers, and other significant sources of local and national revenue losses[15]. The last two sources of damages to the economy stretch beyond and often exceed the direct disease mitigation costs and value of animals lost. For example, lost revenue from tourism was the largest loss category in the 2001 UK FMD outbreak (UK National Accounting Office, 2002).

There is a considerable amount of uncertainty related to the threat of FMD since a confirmed incident has not occurred in the US since 1929. Uncertainty exists in the probability of disease occurrence, how fast it will spread, how quickly it will be contained and the magnitude of the impacts on demand and supply as well as the indirect costs relating to the disease outbreak. Given this uncertainty, the magnitude of damage to the economy is mostly unknown but is expected to be large. All of this uncertainty should be captured in the reaction of the livestock futures market that functions as a medium for setting price expectations at a given time in the future given information currently available (Leuthold, 1974).

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[15] It is possible that a there could be a shift in domestic demand for meat upon confirmation of an FMD outbreak, but a study from the 2001 UK event has shown the demand reaction to be small in magnitude and short in duration (Chopra and Bessler) and work done on meat recalls have shown that medium sized beef and pork recalls only have a marginally negative impact on futures prices where results are not robust across recall size and severity (Lusk and Schroeder).

Livestock futures markets are shown to react quickly to confirmations of Bovine Spongiform Encephalopathy (BSE) discoveries in the US (Tse and Hackerd; Jin, Power and Elbakidze) and also to have small negative reactions to meat safety recalls (Lusk and Schroeder). These are both situations in which real events occurring at the time were expected to influence livestock and meat demand in the future. However, the level of response that is expected from a rumor of animal disease that is unconfirmed has not been addressed in the literature. If the information provided to traders indicates strongly that an outbreak is likely, they may respond to that information in the same way they would an animal disease or meat safety information that is confirmed.

The purpose of this study is to explore the implied volatility, persistency and rationality of futures market reactions to animal disease information uncertainty. This is achieved using data reflective of a widely publicized rumor of FMD based on a test performed at a Kansas sale barn in March 2002. This rumor turned out be false 48 hours later. It led to plummeting market prices of cattle futures and a loss in market value estimated at $50 million (Cupp et al.). Furthermore, in an attempt to understand the nature of the price reaction to the shock, an examination of whether the market exhibits herding behavior and/or momentum trading is done. These behaviors could cause the reaction to be greater in magnitude or more persistent than would otherwise be expected. Examining the livestock futures contracts' movement in reaction to a disease rumor also provides insight into the dynamics of how traders will respond to information related to animal disease in the future.

The remainder of this essay is organized as follows. First, an overview of the relevant literature on information uncertainty in the futures market, herding and momentum trading as well as its application to the current problem is presented followed by an overview of the FMD rumor in question. Next, futures price data will be used to examine the volatility, persistency and rationality of response to the rumor. Finally, general summary and conclusions are discussed as well as ways this study will be expanded in the future.

6.2. Literature Review: Information Uncertainty, Herding and Momentum Trading

Information uncertainty plays an important role in explaining futures market price and volume movements. Unscheduled announcements of news impacting markets lead to an increase in traders' uncertainty about future prices (Ederington and Lee). This in turn causes an increase in the implied volatility of the futures prices. However, the traders' reaction to news may not be irrational. It is a specific type of information uncertainty that leads to over or under-reaction by traders.

Herding behavior has been given several definitions that primarily differ in whether agents involved move simultaneously or sequentially. Most authors have defined herding as the simultaneous trend of agents to move into and out of a market/asset rather than follow their own beliefs and information (Lakonishok, Shleifer and Vishny; Avery and Zemsky; Hwang and Salmon; Tse and Hackard; Baur; Walter and Weber). Others have pointed out that the trades occur sequentially since traders cannot buy and sell at the exact same time; someone must move first. These authors define herding as agents following each other into and out of a market/asset *over some period of time* rather than following their own beliefs and information (Nofsinger and Sias; Sias; Agudo, Santo, and Vicente; Lin and Swanson). This study applies the latter definition of herding.

Avery and Zemsky explore the role of information in herding behavior. There are three types of information uncertainty that impact the level and duration of a shock in the futures market: value uncertainty about how the asset value will change, event uncertainty about the existence of event, and composition uncertainty on accuracy of information received. In the case of the FMD rumor, the value uncertainty is the lack of nearby precedent. Since the last FMD case in the US dates back to 1929, there is no recent example to develop an expectation of the magnitude of futures market reaction in the US; although, the reaction can reasonably be expected to be negative. Event uncertainty pertains to whether the test would be negative for at least some parties involved. The composition uncertainty may exist due to media speculations and rumors about the event. If both the value and composition uncertainties exist, then herding behavior may occur; however, when the composition uncertainty exists the herding behavior may lead to significant short term price distortions. This is because traders will have a "mistaken but rational belief that most traders possess very accurate information" (Avery and Zemsky).

Herding behavior has a rich theoretical and empirical literature. While the former has provided considerable plausibility for the existence of herding, the evidence of herding is mixed. The theoretical literature on herding applicable to this problem focuses on a situation where traders' information is positively, cross-sectionally correlated (Froot, Scharfstein and Stein; Hirshleifer, Surahmanyam and Titman) and herding behavior is irrational (Lakonishok et al.; Walter and Weber). This will occur in the context of "event related" herding where traders tend to move together in order to offset extreme volatility or uncertainty about the market in the future based on some event (Lin and Swanson).

Empirical work on herding has focused on specific stocks/securities/funds with mixed results. Herding behavior is empirically detected among foreign investors moving into and out of the U.S. markets (Lin and Swanson), investors in both Chinese A shares and Chinese B shares, especially among Chinese domestic investors (Tan et al.), investors in German mutual funds (Walter and Weber), Spanish equity funds (Agudo, Santo and Vicente, 2008) and Taiwan securities (Chen, Wang and Lin). Chang, Cheng and Khorana, who find herding in Taiwan and South Korea as well as a small amount in Japan, conclude that herding would be more likely in emerging markets as no evidence of herding was found in the US or Hong Kong equity markets. Experience also appears to factor into the tendency to herd, where more experienced fund managers have a lower tendency to herd (Menkhoff, Schmidt and Brozynski). Alternatively, Wermers finds little evidence of herding in mutual fund managers and Gleason. Mathur and Peterson find no evidence of herding among exchange traded funds. Herding during large scale extreme events like the Asian financial crisis has received no support from the literature (Baur).

This study will specifically define herding as the tendency of futures traders to buy (sell) futures contracts over some period of time based on the actions of other traders rather than on any private information about the disease shock. This has several implications, particularly that some traders will obtain information before others giving them an advantage. Several studies have concluded that it is obtaining information early, rather than the accuracy of that information, that yields higher returns for a trader (Froot, Scharfstein and Stein; Hirshleifer, Surahmanyam and Titman; Avery and Zemsky). Huberman and Regev find evidence of herding when positive information became widely available, even though that information was previously available through scholarly publications. They posit that traders acted on noise (e.g. the prevalent information among traders at the time like a rumor of animal disease) trader behavior rather than expert opinion information made available five months earlier.

One would expect, once the information uncertainty is cleared up (meaning a negative test is reported) that mispricing should stop and prices should recover. In fact Tse and Hackard note that “once the market maker learns about event uncertainty and allows prices to adjust, herding disappears”. Hong and Stein note another market behavior called momentum trading that could help explain any continued drop after the news of the negative test was publicized.

Following the assumptions of Hong and Stein, consider two types of traders: "newswatchers" that do not condition on current or past information in making their forecasts and "momentum traders" who rely on information from previous trades to set price forecasts. Both types of traders are boundedly rational--meaning they cannot observe all information perfectly and do not have unlimited computational capacity--and both make forecasts based on signals they privately observe on fundamentals. The difference is in the use of information and conditioning on past trades. Momentum trading means investors follow their own lagged trades (Sias). Hong and Stein conclude that newswatchers may under-react to new information, but will never overreact if they alone are in the market. However, when momentum traders enter the market they will try to profit from newswatchers' under-reaction resulting in an eventual overreaction as more momentum traders try to take advantage of the opportunity. As a result, early momentum traders can make money but they impose a negative externality on later momentum traders who lose money.

Momentum trading may occur simultaneously with herding behavior. For the purposes of this paper, this indicates a tendency of futures traders to buy (sell) futures contracts over some period of time based on the actions of other traders and lagged returns rather than on any private information about the disease shock. Although the Hong and Stein model is primarily theoretical, Sias and Tse and Hackard offer empirical applications of momentum trading in conjunction with herding analysis. Both find evidence of momentum trading and herding. Sias notes however that even when investors are momentum traders this does not necessarily explain a great deal of herding behavior.

The work on futures markets' reaction to an incident of animal disease is sparse in the literature. U.S. live cattle futures prices were found to be negatively affected by BSE cases in the U.K. (Paiva) and by the 2003 U.S. BSE case (Schlenker and Villas-Boas; Jin et al.). However, all these studies are based on a confirmed case of animal disease. No studies have been done to determine whether strong rumors of animal disease will affect livestock futures markets and whether such rumors will trigger herding and momentum trading. Furthermore, no studies have been done specifically for FMD, which has certain characteristics quite different from BSE (e.g. FMD cannot be transmitted to humans). Huberman and Regev suggest that it is possible that traders in the livestock futures pits could trade based on rumor noise rather than waiting for an official announcement, which makes investigation on the reaction of futures markets to rumors of animal disease relevant and important. This study focuses in particular on one case of an FMD test in Holton, Kansas.

6.2.1. Rumor of FMD

In 2004, there were 689 tests for vesicular diseases (which includes FMD) done in the US (USDA-APHIS, 2005). The reason so many tests are performed is that the physical manifestations of disease symptoms are very similar to other, more benign mouth problems caused by burrs and mold in feed. However, if news media reports a particular test widely it can be mistaken as a sign that FMD has been found in the country.

There have been three US cases when tests were widely publicized and a reaction allegedly occurred in the livestock futures, including: a March 28, 2001 test group of six hogs at a slaughter facility in North Carolina; a March 16, 2001 test group of cattle at a sale yard in Idaho; and a March 12, 2002 test group of nine cattle at a sale barn in Kansas. However, for the first two cases the impacts of the test-related publicity on livestock futures were confounded by extraneous but relevant events. In particular, the United Kingdom FMD outbreak started on February 20, 2001 and lasted until September 30, 2001. The Netherlands FMD outbreak occurred from March 21 to April 22, 2001. Around the same time there were outbreaks in France and Ireland as well. Even though market news reports claim livestock futures markets reacted to the tests in North Carolina (DeCola; Cote and Thacker) and Idaho (Hedberg; Cote and Thacker), it may be very difficult to determine the true scope and length of the reaction given the other perturbations to the market from foreign events. This study focuses on the March, 2002 Kansas case.

On March 12, 2002 a veterinarian noticed and reported possible signs of FMD in a sale barn at Holton, Kansas. Upon further monitoring of the animals, the veterinarian felt confident this was likely not to be an FMD outbreak as evidenced by horses on the premise having similar symptoms (Cattle Buyers Weekly, 2002a). Tests for FMD on nine cattle were immediately carried out on the same day, while the other 16 cattle still housed at the sale barn were quarantined starting between 6:30 and 7:00 p.m. on March 12th pending the results (Cattle Buyers Weekly, 2002a). Since the tests and quarantine occurred after trading hours in Chicago it can be inferred that the rumor would not have affected trade on March 12th.

Exactly how and when on March 13th the rumor reached traders is uncertain, based largely on speculation in the newspapers. *Agweek* reports that by the morning of March 13th "an Iowa radio station was reporting the possibility of a foot-and-mouth outbreak in Kansas. Chicago traders heard the rumors and cattle markets nose-dived" (Hutchinson News). Another source speculates that the rumor was passed through word of mouth from a local cattle broker attending the sale to a broker working with traders in Chicago, and from there the trading floor (Corn). The general agreement of all news sources though is that some traders heard the rumor after trading hours on the 12th, but largely the rumor was circulated in the live cattle pits early in the trading day on March 13th. Such publicity allegedly was the cause when live cattle April futures limited down dropping 1.12 cents to 74.50 cents a pound (Cote and Thacker) as traders swiftly responded to the information. The markets then recovered slightly by the end of the trading day. A *Wall Street Journal* article published on March 14 quoted floor trader Jim Rose with R.J. O'Brien and Associates as saying, "If the preliminary results are negative, we should have a sharp rally" (Cote and Thacker).

Negative results for the tests were reported by the evening of March 13th. However, instead of “a sharp rally”, prices dropped once again on Thursday morning, March 14. Traders continued to sell resulting in live cattle futures falling the limit on the 14th, dropping 1.3 cents to a two month low of $73.20 cents per pound (Cote). By the end of the day, prices were trending slowly back up in response to the negative test result.

It is possible that a trader or small group of traders manipulated the market to make a greater profit from the trade. Since prices in cattle futures are expected to plunge should a FMD outbreak occur, traders that with a short position could potentially have made quite a bit of money out of the rumor. The National Cattlemen's Beef Association (Bloomberg News) and the Kansas State Attorney General (Milburn) demanded an investigation on market manipulation. One was performed but failed to provide solid evidence of manipulation (Cattle Buyers Weekly, 2002b). Futures Trading Commission chairman James Newsom made a public statement concerning the investigation on the events around March 13th, "We have found no deliberate activity of anyone to try and manipulate those markets. We didn't see any aggregated net positions that were of a big surprise to us" (Bloomberg News). Thus we are left with the idea that traders did not necessarily manipulate the situation knowingly, and so they must have felt their movement in the market was appropriate given the information available to them.

6.3. Data

To examine the market events occurring in association with the rumor, four meat commodities were included in the analysis: live cattle, feeder cattle, lean hogs and pork bellies. Live cattle are animals that have reached their mature slaughter weight and are about to enter the food chain. Feeder cattle are lighter weight cattle that will likely enter the feedlots, but are not yet ready to slaughter. It is expected that live cattle futures prices will be more sensitive to information as consumers and foreign markets would likely perceive them as being more threatening to the safety of the meat product. Since FMD is contagious to swine, two swine/pork futures contracts are also examined. Lean hogs are swine that have reached their mature slaughter weight and are about to enter the food chain. Pork bellies are the only post-slaughter livestock futures contract considered here.

Futures intra-day transaction data was obtained from the Chicago Mercantile Exchange (CME) on live cattle, feeder cattle, lean hogs and pork bellies for all futures contracts trading between February 28, 2002 and March 27, 2002. Observations are on the futures price at a given day and time for every contract traded in that month. In order to get a broader viewpoint on the incident, daily data was also collected from Datastream© through the Texas A&M Library Services. Daily data included settlement price, daily open, daily close, daily high and low as well as volume traded on futures contracts of the four livestock commodities for the period of January 1st, 1988 to December 31st, 2002[2]. The daily dataset is spliced such that the information listed is for the nearest futures contract; the transition from one futures contract to the next is made upon the current nearest contract reaching maturity.

There are a few limitations that are data related preventing the most thorough analysis of this problem possible. First, intra-day volume data could not be obtained. This prevents an econometric measure of momentum trading from being established. Second, analysis done on the more extensive daily dataset does not contain the level of detail needed to determine whether herding and momentum trading exist normally in the market. This would require a more extensive intra-day trading dataset.

6.4. Results

This section is split into two parts -- a clinical analysis in the style of Tse and Hackard and an econometric expansion to more fully quantify the impacts of the rumor.

6.4.1. Clinical Analysis

Table 51 presents summary statistics for the daily data series divided into three time periods: pre-event from 1 October, 2001 to 27 February, 2002; event-window from 28 February to 28 March, 2002; and post-event from 29 March to 31 December, 2002. [16]

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[16] Although I have daily futures prices dated back to January 1st, 1988, I present the summary statistics by pre- and post-event periods as well as event window periods starting from October 1st, 2001 and ending on December 31, 2002. The reasons are the UK FMD outbreak lasted until September 30, 2001 (NAO, 2002) and Canada confirmed its first endemic BSE case on May 20, 2003. However, the preceding media speculation of the infected cow's diagnosis started in January (Tse and Hackard 2006; Highplain Midwest Agriculture Journal). Thus, we truncate the daily data at both ends.

Table 51. Summary Statistics for Daily Data on the Nearest Futures Contract for Feeder Cattle, Live Cattle, Pork Bellies and Lean Hogs

	Pre-event periods (N=108) (10/1/2001-2/28/2002)				Event-window periods (N=20) (2/28/2002-3/27/2002)				Post-even periods (N=199) (3/28/2002-12/31/2002)			
	Mean	std.	Min.	Max.	Mean	Std.	Min.	Max.	Mean	Std.	Min.	Max.
	Feeder cattle											
Settlement price	84.18	1.90	78.15	88.08	80.46	1.47	78.33	82.48	79.05	3.23	71.23	85.45
High price	84.54	1.90	78.95	88.50	81.06	1.36	78.73	82.88	79.47	3.12	72.73	85.60
Low price	83.72	1.92	78.15	87.85	80.27	1.50	78.10	82.40	78.61	3.30	69.85	85.15
Volume	2549	999	989	5803	3014	1102	750	5776	2206	969	78	6560
	Live cattle											
Settlement price	69.85	3.42	61.75	76.38	73.01	2.25	69.70	75.88	68.15	5.38	59.40	79.63
High price	70.18	3.37	62.30	76.53	73.70	2.13	70.08	76.08	68.49	5.25	60.35	79.90
Low	69.35	3.53	61.75	75.95	72.75	2.24	69.55	75.68	67.68	5.38	59.33	79.15
Volume	16483	5028	7870	32368	18717	7544	3620	33962	14911	4649	433	32952
	Pork bellies											
Settlement price	74.75	3.27	66.08	81.50	79.44	2.53	76.28	83.50	70.63	9.07	51.83	89.03
High price	75.59	3.14	67.05	82.95	80.50	2.48	77.00	84.20	71.46	8.86	54.40	89.35
Low price	73.70	3.23	64.93	80.60	78.77	2.38	75.75	82.40	69.40	8.96	51.83	88.50
volume	714	242	324	1595	705	262	263	1281	548	264	31	1200
	Lean hogs											
Settlement price	54.18	3.90	47.58	62.73	56.02	2.79	52.55	60.35	45.95	6.84	30.05	60.40
High price	54.62	3.86	47.85	62.80	56.64	2.67	52.88	60.43	46.60	6.85	30.20	61.10
Low price	53.59	3.97	46.70	61.85	55.73	2.78	52.30	59.70	45.34	6.88	29.40	60.10
volume	7059	2407	2390	16290	8184	2900	849	11611	7761	2541	204	17121

The results show that the average settlement price was higher and the average daily trading volume was greater in the event periods than in the pre- and post-event periods for all four commodities except that feeder cattle contracts on average had a higher price in the pre-event periods compared with other periods. However, the movement of daily settlement prices may cover the true intra-day price movement if the market has a large reaction but recovers by the end of the trading day. Furthermore, livestock cycles, seasonality, and price trends may play roles in the price comparison between three periods. To better understand the price movement possibly related to the FMD rumor, we use both daily and minute data on futures contracts for the event window and expand the clinic analysis in finer details.

Figure 49 and Figure 50 plots movement of prices, rate of returns, and volume of futures contracts on feeder cattle, live cattle, pork bellies, and lean hogs during the event-window period (February 28 to March 27, 2002). The price volatility can be indicated by the daily high/ low price range given by the solid vertical lines and by the standard deviation of intra-day prices based on the minute data represented by dashed lines with triangles. The direction and level of price movements is indicated by the daily average prices based on the minute data and the rate of returns based on the daily settlement prices.

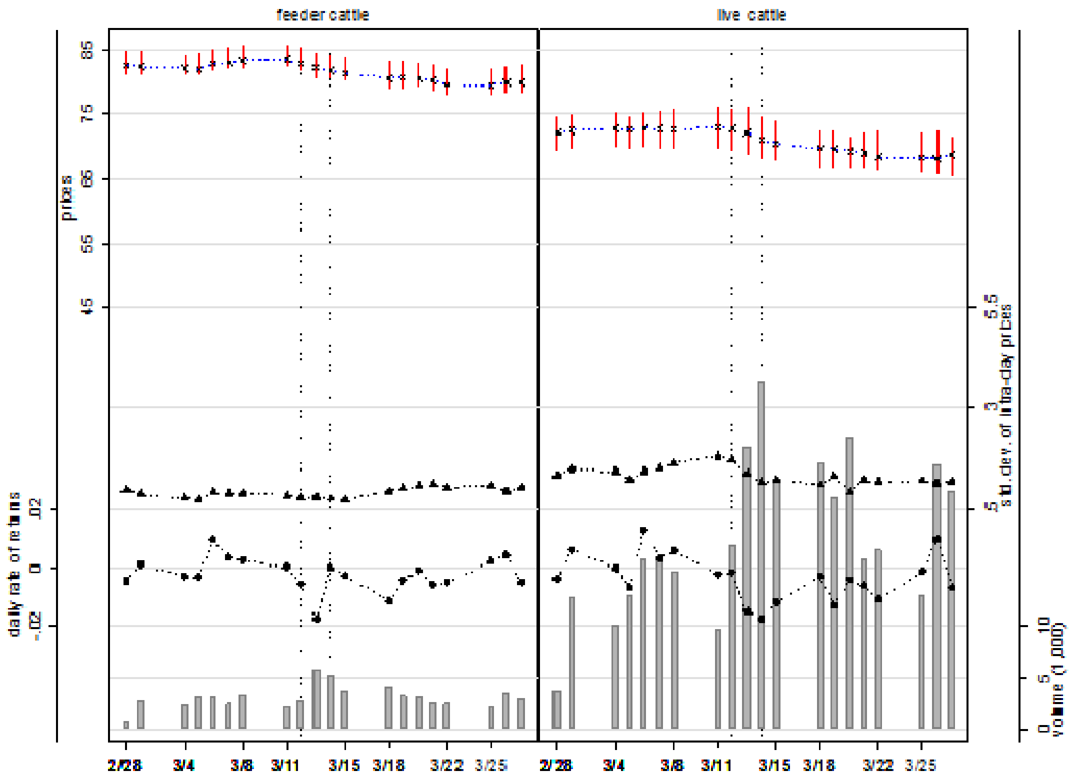

Figure 49. Price and Volume Movement of Feeder Cattle and Live Cattle Contracts During the Event Period (2/28 - 3/27/2002)[17]

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[17] For Figures 49-50, price information consists of daily high and low prices (vertical lines for each trade day); daily average price (asterisks); standard deviation of intra-day prices (triangles); daily rate of returns based on daily settlement prices (squares); and daily trading volumes (vertical bars). Vertical dotted lines represent events dates of March 12th where the rumor of FMD diseases started to spread and March 14th when the negative results went public.

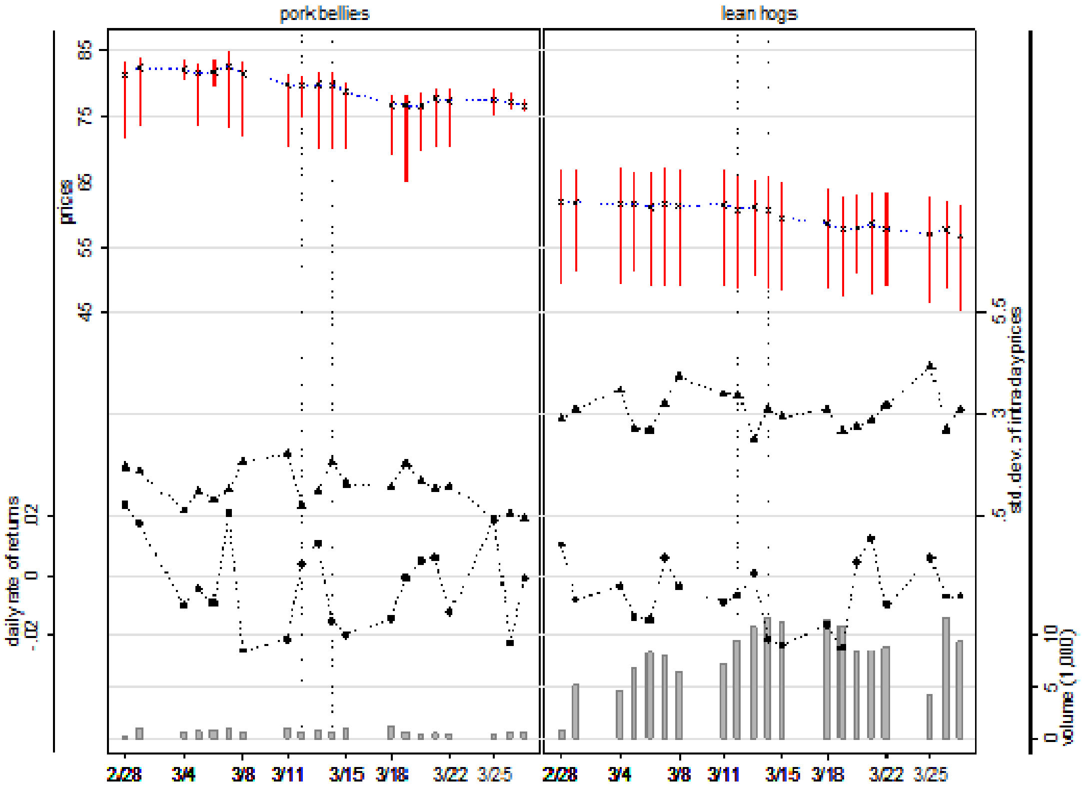

Figure 50. Price and Volume Movement of Pork Bellies and Lean Hogs Contracts During the Event Period (2/28 - 3/27/2002)

Lean hog futures contracts show the most volatility in prices, followed by pork bellies and live cattle, while feeder cattle contracts show the least. All four markets seem to move together during the period in which the rumor occurred; however, pork bellies seem to be less correlated than the other three commodities. In the feeder cattle and lean hog markets, returns fell post-rumor but recovered to previous levels by the end of the 14th. Prices in these two markets continue to trend down after the rumor, although this could be reflective of the gradual decline in prices that typically occurs during mid to late March. The reaction in the live cattle market is more persistent, with returns not recovering to pre-rumor levels until the 18th of March. Pork bellies on the contrary see increasing rates of returns during the 13th, but fell on the 14th and stayed low until the 19th. This may reflect a lag in the reaction in the pork bellies market, which could be explained either as momentum trading, a spillover effect, or non-event related volatility. The comparison on daily trading volumes suggests that the rumor as well as the negative test result trigger greater transactions in all types of futures contracts, especially in the cattle futures markets.

In all four markets a small spike in volume can be seen on March 13th and 14th. In addition, all of the live animal contracts also show a drop in rate of return and price on these two days. This corresponds with the ex post reports that the rumor started circulating early in the trading day on the 13th. These patterns indicate the presence of herding behavior given the information uncertainty of the rumor and in particular the presence of composition uncertainty (Avery and Zemsky). In feeder cattle and lean hog futures there is an indication that rates of return had started to fall prior to the rumor, which may be reflective of reports that feeder placements could be a potential explanation for the drop. An econometric analysis is conducted below to formally detect herding behavior. Momentum trading does not imply herding (Sias) but it may aggravate the effects of herding, so momentum trading is examined separately.

Momentum trading is defined as the tendency of investors to use information from the last period to make trades in this period. In the context of this study, momentum trading would be identified where the return in period *t* depends on the information received in the previous period (*t - 1*) rather than the current one. No measures of momentum trading given in the literature can be used here since they depend on observing the number of traders in the market; rather, momentum trading is examined here through clinical analysis of daily data.

The negative test results were returned on the evening of March 13th; recovery would be expected to start on March 14th. However from Figure 49, the only market to show recovery in the rates of return was the feeder cattle market. Live cattle and lean hog futures' rate of return fell lower for those days. A continued drop in returns would reflect the presence of momentum traders acting on the previous days' information and return trends rather than seeking the most current information; the negative test result announcement. Some live cattle and lean hog traders had not assimilated the new information, and were instead trying to take advantage of the previous days' trend. The traders who continue to drive the negative trend would then be momentum traders. Pork belly futures returns fell on the 14th as well, but they were not continuing a price decline rather starting a price decline. This may be more indicative of a spillover effect or natural volatility than momentum trading.

The clinical analysis gives motivation to further quantify the presence of market volatility and some persistency in response to the rumor as well as to formally explore herding behavior triggered by the rumor using econometric analyses. Such econometric analysis to a great extent will control for livestock cycles, seasonality, and price time trends allowing a better understanding of the price movements possibly related to the FMD rumor.

6.4.2. Econometric Analyses

The econometric analyses are split into two sections. The first explores the volatility and persistency of the reaction to the rumor using a vector error correction model (VECM). The second explores the evidence of herding behavior by adapting a herding measure used in prior studies to livestock futures trading.

6.4.2.1. Analysis of Persistency and Volatility of the Impacts using a VECM

Financial time series data often exhibits non-stationarity. Commonly used are the (Augmented) Dickey-Fuller (DF) tests and Philips-Perron (PP) test, which examines the null hypothesis of a unit root against the alternative of a constant deterministic trend. An alternative is the Zviot and Andrews (ZA) unit root test, which allows for one possible structural shift in mean, trend, or both (Zivot and Andrews). If data is stationary in differences a VAR can be used to model the prices series. However, a VECM is more appropriate when the data also exhibits cointegration. The number of price series is denoted by *n* and the time period by *t*. Based on the Johansen's cointegrated vector autoregression (VAR) model with *k* lags (Johansen), the data generating process of Y_t that is a *n*-by-1 vector of price series, can be modeled as a VECM with *k*-1 lags:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_{t-i} + \sum_{l=1}^{J} \theta_l D_l + e_t ,$$

where ΔY_t is a n-by-1 vector of futures commodity price differences, Y_{t-i} is the vector of lagged own futures commodity prices, Π is the n-by-n conintegration rank matrix, Γ is a n-by-n matrix of parameters on the lagged price differences, D_l is a set of seasonal dummy variables, and *e* is a n-by-1 vector of pricing innovations (Lütkepohl and Kträtzig). The seasonal dummy variable accounts for the yearly production cycle influence on futures prices.

The parameter matrix Π can be further decomposed such that $\Pi=\alpha\beta'$ where betas contain the cointegrating equation and alphas the speed of adjustment (Lütkepohl and Kträtzig). So, $\Pi\ Y_{t-1} = (\alpha\beta')Y_{t-1} = \alpha(\beta' Y_{t-1})$ where $\beta' Y_{t-1}$ is an *r* x 1 vector of error correction terms and α's coefficients would determine the size of the effects of the *r* error correction terms in the four equations of the VECM (Magee). In other words, α show the short run response in β given a shock in the long run where there are *r* long run relationships in the series. The constant is captured in β but dummy variables have been moved outside of β. The VECM is estimated using generalized least squares.

There are at least two ways to determine the optimal lag length (*k*) and the rank of the cointegration vector (*r*). The conventional approach is to use system-based likelihood ratio (LR) tests to sequentially determine them in two steps. First, using information matrices to determine the lag length; and then use trace tests to determine the rank of cointegration vectors (Johansen). However, since the true model is rarely known this procedure may lead to model specification problems that ultimately involve trade-offs between model parsimony and fit (Wang and Bessler). Recently, "model selection" methods based on information criteria that simultaneously determine the optimal lag length and the cointergration rank have been proposed and implemented as an alternative to the conventional two-step procedure (Phillips and McFarland; Aznar and Salvador; and Baltagi and Wang). The system based approach is popular due to its sound theoretical basis, computational simplicity, and superior performance relative to some other estimators (Brüggemann and Lütkepohl). However, there are at least three advantages of the model selection method. First, it jointly estimates the cointegration rank and the optimal lag length in a VAR (Phillips). Second, the model selection method relieves researchers from the arbitrary choice of an appropriate significance level in contrast with formal hypothesis testing used in system-based LR tests. Third, Chao and Phillips and Wang and Bessler provide simulation evidence to show the model selection methods based on information criterion give at least as good fit as system-based LR tests. We cross validate the results on the optimal lag length and the cointegration rank using both methods.

As shown in Table 52, all three unit root tests (DF, PP and ZA tests) fail to reject the null hypothesis that the futures prices in levels contain a unit root at the 5% level of significance for feeder cattle, pork bellies and lean hogs. The same tests are then applied to the first order differences of each prices series, whereby the unit root hypothesis is reject at the 1% level of significance. Therefore, the evidence suggests that daily settlement prices of futures contracts of feeder cattle, pork bellies, and lean hogs contain a unit root (they are nonstationary) in levels but their first order differences are stationary. The only exception is live cattle, in which the level prices are stationary.

Table 52. Tests for Non-Stationary of Daily Settlement Prices of Futures Contracts[18]

	Dicky Fuller test		Philip-Perron test		Zivot Andrew test	
	Level	difference	Level	Difference	level	difference
Feeder cattle	-2.09	-59.49***	-2.07	-59.48***	-3.44	-24.78***
Live cattle	-3.90***	-60.44***	-3.93***	-60.44***	-6.07***	-60.47***
Pork bellies	-2.49	-58.62***	-2.59	-58.61***	-4.11	-25.10***
Lean hogs	-3.00	-59.48***	-3.02**	-59.46***	-3.91	-26.70***

Based on Table 53, we conclude that the optimal lag length is one and cointegraton rank is two using the conventional two-step procedure. However, if the underlying VAR is of lag one, it suggests no lag in the corresponding VECM. The common practice is to impose a lag of two for the underlying VAR. Given the lag of two, the cointegration rank is two. Furthermore, the values of information criterion are fairly close between the lag length equals to 1, 2, 3, and 4. Based on the model section approach using Hannan and Quinn (HQ) information metric, the optimal lag length is one and the cointegration rank is three. However, those HQ information values are very close. Unfortunately, there is no consistence between these two approaches, but due to the advantages of the model selection approach, the final VECM is based on $k = 2$ and $r = 3$.

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[18] The asterisks, ** and ***, indicate 5% and 1% significance levels, respectively. The critical value is -2.86 at the 5% significance level and -3.43 at the 1% level for both Dickey Fuller tests and Pillip Perron tests; and -4.80 at the 5% significance level and -5.43 at the 1% level for Zivot Andrews' test allowing one structural break at the unknown date.

Table 53. Optimal Lag Length and Cointegration Rank

Determine the optimal lag length of the underlying VAR (*k*)				
Lag length	Schwarz information Criterion (SIC)	Akaike information criterion (AIC)	Hannan and Quinn (HQ)	
k = 0	15.80	15.80	15.80	
***k* = 1**	**-1.85**	**-1.88**	**-1.87**	
k = 2	-1.83	-1.88	-1.86	
k = 3	-1.79	-1.87	-1.85	
k = 4	-1.77	-1.87	-1.84	
Determine the cointegration rank (*r*) using trace tests				
	r = 0	*r* = 1	*r* = 2	*r* = 3
Trace stat.	101.96	52.06	**20.75**	5.89
5% critical value	(61.21)	(40.49)	(23.46)	(6.40)
Simultaneously determine the optimal lag length (*k*) and the conintegration rank (*r*) using model selection methods based on HQ information criteria[19]				
	r = 1	*r* = 2	*r* = 3	
k = 1	9.5061	9.5033	**9.5027**	
k = 2	9.5143	9.5115	**9.5109**	
k = 3	9.5297	9.5273	9.5266	
k = 4	9.5432	9.5409	9.5402	

After fitting an appropriate VECM, examination of deviations of the forecasted prices from the actual prices is performed. These deviations quantify the size and persistency of the FMD rumor impact on the futures markets. Figure 51 plots the actual (line with squares) and forecasted (line with asterisks) prices of futures contracts during the event-window period.

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[19] A cointegration rank of r = 4 could also have been tested for the completeness using the HQ information criteria. However, since a rank of r = 3 is found this has not been done in this essay.

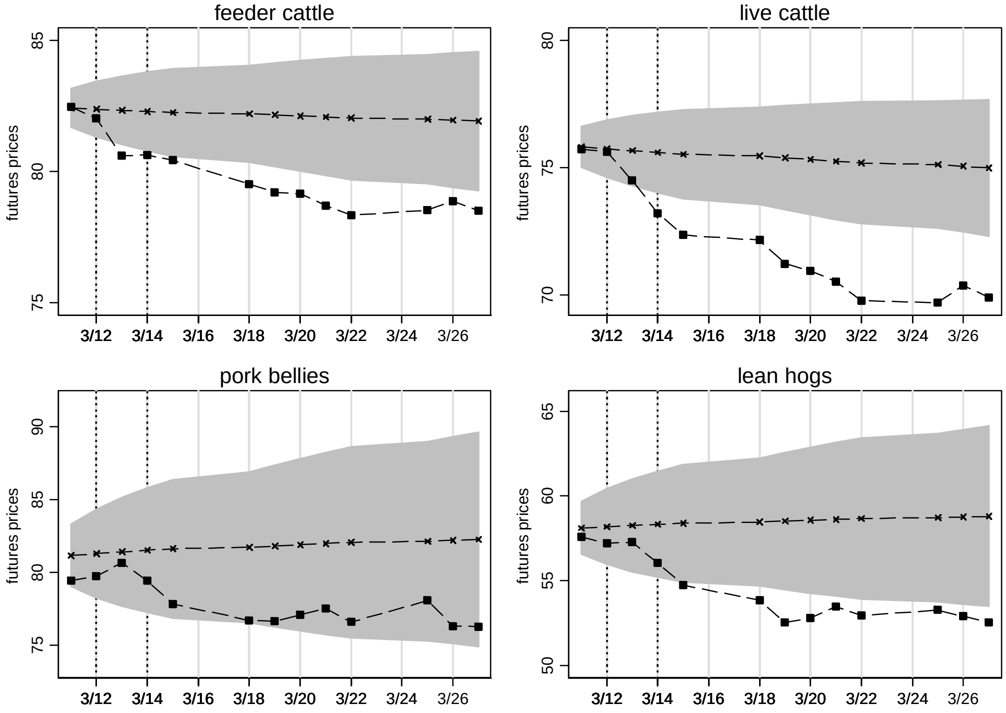

Figure 51. The Impacts of the FMD Rumor on Futures Prices of Feeder Cattle, Live Cattle, Pork Bellies and Lean Hogs[20]

The difference between these two lines reflects the impact of the FMD rumor. Figure 51 shows that feeder cattle, lean hogs and particularly live cattle actual futures prices move significantly outside of the 90% confidence interval of forecasted prices. The movement out of the confidence interval on the 13th in the two cattle futures shows a quick response to the rumor in those commodities. Lean hogs did not track out of the confidence interval until the 15th. This could represent a lagged response to the rumor, potentially a spillover effect from the cattle futures markets [3]. Pork bellies stay within

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[20] The shaded area represents the confidence interval of the forecasted settlement prices of futures contracts at the 10% significance level. The dashed lines with stars and squares indicate the forecasted and actual settlement prices.

the 90% confidence interval. This market has historically more price volatility than the other three.

Figure 51 also illustrates the persistence of the shock as evidenced by prices continuing to remain below the 90% confidence interval. Actual prices do come close to moving back into the interval for feeder cattle and lean hogs but live cattle have persistently low prices until the end of March. Overall, the results suggest that the FMD rumor statistically reduced the futures price of feeder cattle, live cattle, and lean hogs on March 13. The negative trend persisted on March 14th even though the negative test results came out. The incident may well have been a trigger for the downward price cycle earlier in the year than expected. However, the incident was not found to have a significant impact on prices of pork bellies contracts.

6.4.2.2. Analysis on Herding Behavior Resulting from the Rumor

Econometric measures for herding have attempted to capture the patterns in the cross section of traders over time in order to examine whether they follow each other into trades (Sias). Several authors have proposed measures for quantifying herding behavior (Lakonishok, Shleifer and Vishny; Christie and Huang; Sias). The Lakonishok, Shleifer and Visney and Sias herding measures were designed to track how many investors bought or sold in a particular security.

Ideally, we need to know how many traders were buying (selling) during the event window to investigate the possibility of herding and momentum trading. Such data is unavailable. However, the clinical analysis suggests that the daily trading volume did increase during the event window. Given the increased volume, a negative association between the dispersion of returns and the position in the distribution of extreme returns is used to infer herding behavior. Recall that herding implies reduced levels of return dispersions as traders move together in a particular direction during times of market stress. By looking at the tails of the distribution--reflecting the focus on periods of market stress--this measure of herding focuses on whether traders exhibit rational behavior (higher dispersions) or herding behavior (lower dispersion). This follows the methodology for measuring herding proposed by Christie and Huang, which is concerned with whether or not individual returns can indicate herding during periods of market stress. Dispersion in this case is the average difference in the returns at a particular moment to the mean returns in the livestock futures market:

$$S = \sqrt{\frac{\sum_{t=1}^{T}(r_t - \bar{r})^2}{T-1}}$$

where r_t is the observed return based on at the minute data within day t and the daily average return is denoted by $\bar{r}$. However, as Christie and Huang point out low dispersions by themselves do not guarantee the presence of herding. To examine whether herding has occurred, the extreme tail levels of dispersion are identified by using the following regression:

$$S_t = \alpha + \beta_1 \cdot D_t^L + \beta_2 \cdot D_t^U + \varepsilon_t,$$

where the two dummy variables D_t^L and D_t^U indicate whether the daily return lies in the lower or upper tails of the distribution. The constant α represents the average dispersion of the sample except for the area covered by the two indicators. The error term would capture any effects on the dispersion not related to the two dummy variables, which might include the effect of the season. For example, in March live cattle markets are expected to being their yearly downward trend in response to feedlot placements. The error term would capture this effect.

If the signs of β_1 and β_2 are positive, then the returns movements are consistent with rational behavior; however, if they are negative it is consistent with irrational herding behavior (Christie and Huang). Intuitively, a negative value on the lower tail coefficient would indicate that during times of unusually low daily returns the dispersion of returns would decrease meaning traders are moving together. This would indicate they are trading based on the common knowledge of the "herd" rather than on individual knowledge.

We would not necessarily expect the values of β_1 and β_2 to be equal; in fact, Christie and Huang found that, across several different industries, the values of β_1 were more uniform than β_2 which had a larger distribution. Furthermore, in their examination of monthly data they found estimates of β_2 to be three to six times greater than estimates of β_1 indicating asymmetry in the two coefficients is to be expected. The hypothesis that these two coefficients are equal is not tested here, but could be in future research for completeness.

Since the same event, the rumor of foreign animal disease, may affect futures prices of four commodities, we use Zellner's seeming unrelated regression approach to estimate a system of equations consisting of the regression equation for each commodity as specified in the equation for herding above. In the equation for each commodity, the dummy variables D_t^L and D_t^U equals one if the daily rate of returns falls into the one or 99 percentile in its distribution. The statistic of the Breusch-Pagan test of independence (11.43) exceeds the critical value of the chi-distribution with six degrees of freedom (10.64) at the 10% significance level (see the last row in table 4). The Breusch-Pagan test suggests that the SUR is appropriate since the variance of error terms exhibits heteroskedasicity. The results presented in Table 54 suggest that herding behavior exists when the rate of returns falls in the low tail of the distribution for feeder cattle, live cattle, and lean hogs futures but it is only statistically significant for live cattle and lean hogs at the 10% significance level.. Furthermore, asymmetric patterns of herding behavior are observed in livestock futures markets across different commodities as well as comparing between the rate of returns in the lower and upper tails.

Table 54. Zellner's Seemingly Unrelated Regression to Detect Herding Behavior During the Event Period[21]

Zellner's seemly unrelated regression of four equations				
	feeder cattle	live cattle	pork bellies	lean hogs
1 percentile of rate of returns	-0.001	-0.008***	0.003	-0.014*
	(0.002)	(0.002)	(0.006)	(0.007)
99 percentile of rate of returns	-0.001	0.001	0.004	-0.003
	(0.002)	(0.002)	(0.004)	(0.005)
Constant	0.013***	0.025***	0.014***	0.069***
	(0.001)	(0.001)	(0.002)	(0.002)
R-squared	0.03	0.01	0.08	0.10
No. of OBSs	20	20	20	20
Breusch-Pagan test of independence	chi2(6)=11.44		p-value = 0.08	

6.5. Conclusions and Implications

Both the confirmation and/or rumor of a foreign animal disease pose a significant threat to US agriculture. A rumor of FMD introduces non-trivial information uncertainty into the livestock futures market. This uncertainty can lead to changes in prices and price volatility, as well as trigger herding behavior and momentum trading. Although many tests for vesicular diseases are done in the US each year, tests done on March 12, 2002 in Holton, Kansas had an impact on futures prices in feeder cattle, live cattle and lean hog contracts on March 13th as well as March 14th, despite the fact that negative test results were announced before start of trade on March 14th. Prices did rebound near the end of the trading day, indicating the test results information had been assimilated. After the fact, an investigation was conducted that concluded no undue manipulation had occurred so an alternative explanation for the price impact is needed.

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[21] The asterisks *, ** and *** indicate 10%, 5% and 1% significance levels, respectively.

This study examined the persistency and volatility of the futures price of livestock commodities impacted by FMD: feeder cattle, live cattle, pork bellies and lean hogs. Lean hog and pork belly contracts showed the most volatility, but little persistence. Live cattle and feeder cattle had lower levels of volatility, but while feeder cattle recovered within a week live cattle took much longer. This study proposes the existence of herding behavior and momentum trading on the part of livestock futures traders during this period contributed to the rumor price shock. Clinical analysis would seem to reveal herding behavior in feeder cattle, live cattle and lean hog livestock futures and momentum trading for live cattle and lean hog livestock futures. A more formal econometric analysis of herding behavior leads to evidence of herding behavior in live cattle and lean hogs.

The occurrence of herding behavior and momentum trading could be reflective of the nature of FMD and the expected response should the test be positive. FMD does not contaminate meat products; they are still fit for human consumption. There are still the restrictions put in place by international trade but domestic consumption is still possible so the impacts in pork belly contracts is more likely to be small compared to live animals. Information uncertainty may have been greater for live animal contracts for several reasons. The current stamp out policy would lead to mass slaughter of live animals coming in either direct or indirect contact with a disease carrier. This means any live animal at the time of the positive FMD test could be placed under immediate quarantine, slaughtered and the carcass disposed of. Thus the evidence of herding and momentum trading in live cattle and lean hogs particularly--since they are the closest to slaughter and therefore have the greater value--may be a reasonable conclusion given information uncertainty related to the FMD rumor. Although not significant in the econometric analysis, feeder cattle also showed clinical evidence of herding. As previously stated, momentum trading can lead to an over-reaction because of information uncertainty. The conjunction of herding behavior and momentum trading evidence for live cattle and lean hog futures could explain the large price and rate of returns drop observed during the event window and the persistency of the shock.

There are other possible explanations for a price decline in live cattle during this period: lower than expected cash live cattle trade, a slight drop in box beef values, speculation and feedlot placements. It could be argued that the rumor of FMD gave traders a reason to sell; however, even if the market was primed for a seasonal downturn the rumor appears to have caused the downturn to be steeper than expected or reasonable under ordinary circumstances. Herding and momentum trading provide plausible explanations for the over-reaction that occurred.

This analysis is by no means comprehensive. It is intended to serve as a starting point for further expansion to explore information uncertainty, herding and momentum trading in the context of animal disease. Ideally, future work would identify whether there is herding behavior in livestock futures markets in general, as well as whether and how the animal disease outbreaks or the rumors of them enhance or attenuate herding behavior. The small data sample limited the ability to test for herding and momentum trading more generally; a further analysis based on a year of minute data rather than a month will help us better identify whether there is a tendency toward herding and momentum trading in livestock futures. Further analysis includes the examination of information spillover into related commodities like corn or soybeans contracts and the examination of other maturity months than the nearest one.

7. CONCLUSION

Animal disease poses a significant threat to US livestock agriculture, this much is clear from the literature on outbreaks around the world. Foot-and-mouth disease poses a particular threat due to its status as a highly contagious, economic disease. Modeling the impacts of animal disease means more than just counting the number of head slaughtered; it also means determining how other parts of the agricultural sector are impacted by the disease and developing ways to assess impacts. This dissertation has contributed to the improvement of US preparedness for avoiding and/or dealing with animal disease outbreaks by:

- Assessing the economic and epidemic consequences of select FMD related strategies and in the process
    - Developing a more generally useful deterministic modeling approach that integrates an economic sector model with an epidemic model so as to capture impacts more fully across the US agricultural sector by including the inter-relationships among markets
    - Extending the framework into a risk setting to improve understanding of how risk and uncertainty impact FMD response policies and livestock markets again developing a methodology that can be used in other studies
- Examining the way that false information releases can influence livestock futures markets

Essay 1 sets the stage for the FMD analysis showing the danger presented by FMD through both its impact in other parts of the world and the potential damage it could cause in the US. Since trade restrictions are such a large part of the outbreak impact, hog sectors and beef sectors are at particular risk. Sheep and dairy sectors do not have a large international market presence; however, the domestic losses from the dairy sector's production of high value outputs would be significant. This essay also presents a discussion of potential control strategies that can be used for the eradication of FMD. Several of these control strategies are evaluated in essays 2, 3, and 4.

Essay 2 presents the integrated economic/epidemic modeling approach developed in the study. It first reviews the literature on integrated economic/epidemic modeling and the economic justification for various modeling approaches, and then presents the modeling methodology developed for the assessments in essays 3 and 4. The integrated model utilizes a partial equilibrium economic approach, which allows assessment of impacts in vertically and horizontally linked markets, consumers and producers, and domestic and international markets within a single framework. This is a unique contribution among animal disease assessments since most have examined limited market setting without considering the entire agricultural sector. In particular they have generally modeled the livestock sector and select related sectors. Essay 2 also does graphical economic analysis of expected outcomes guiding both the modeling scope and developing expectations for the nature of the results found later in the strategy evaluations.

Essay 3 carries out a strategy assessment using the methodology developed in essay 2. Specifically, it is a case study of FMD strategy analysis in the context of the California central valley dairy industry. California is particularly susceptible to animal disease outbreaks due to the importance of agricultural production to the state's economy. California's value of agricultural products was valued at $33 billion in 2007. The study focuses particularly on simulating an outbreak in the dairy industry, a $6.9 billion sales industry in a state that produces 22% of the nation's milk supply. Control strategies considered are alternative detection and vaccination approaches.

Results indicate that earlier detection is always a best response strategy in terms of reducing epidemic size, disease control cost, and national welfare loss. They also show vaccination increases slaughter, as would be expected given US "vaccinate to die" policy. However, vaccination reduces the number of head placed under movement restrictions. Implications of this extend beyond the size of the outbreak. By keeping the quarantine zone as small as is reasonable, it lessens the welfare slaughter potential.

Vaccination does come at a higher economic national surplus loss and disease control cost. Examining the distribution of losses and accounting for risk attitude on the part of policy makers, I find that vaccination is a risk reducing strategy. This implies the undesirable tail of the distribution of losses is reduced such that there is less chance of an extremely bad outcome.

Producers suffer the most from the outbreak, but simulation evidence suggests that producers in some non-infected regions gain from the outbreak. In dairy production regions outside of California, producers gain from the outbreak. However, for regions with hog production (an FMD susceptible species and therefore subject to trade restrictions) producers have losses due to international trade restrictions. These results can be traced back to the expected outcomes outlined in the economic theory section of essay 2.

Essay 3 then turns to an examination of the cost of the potential outbreak and how that cost might vary depending on the quarantine zone policy put in place. Of the three policies considered (Lockdown, Milk Dumping and Business as Usual), the lockdown policy that those concerned only with minimizing disease spread risk would choose results in a significantly higher cost. However, Milk Dumping results in a not unreasonable cost and would still reduce vectors for disease spread (milk, milk trucks, milk processing facilities, and personnel).

Essay 4 reports on the extension of the approach into a risk context examining how risk attitudes impact control strategy decisions, in this case in the context of the High Plains of Texas. This essay extends an earlier study that the author was involved with to examine the ranking of control strategies under risk aversion. This is done by applying breakeven risk aversion coefficient methods to the distribution of losses from the integrated high plains model. Results suggest that of the three control strategies examined (detection, surveillance and vaccination), both early detection and rapid vaccination have merit as risk reducing strategies or equivalently as strategies that if used would increase the resiliency of the sector. Enhanced surveillance may be a resiliency increasing activity under some outbreak situations, particularly when outbreaks begin in large feedlots.

Finally essay 5 examines how market information and in this case false information affects demand and market response. Using a well publicized rumor of FMD in Kansas in 2002, an attempt was made at determining whether animal disease information would significantly and negatively impact livestock futures prices. Furthermore, would that impact be rational or the product of "noise" in the media and among other traders. Results suggest that the false information did have an impact in the futures market, and that traders did respond as if the information were true. There was evidence of herding behavior and indicators of momentum trading that indicate the live cattle and lean hog markets are particularly at risk.

Overall this dissertation has shown that strategies can be used to enhance FMD preparedness. Outbreak simulations under strategies reveal likely large economic consequences, affecting the livestock sector as well as vertically integrated sectors (meat) and horizontally integrated sectors (feed grains), but producers in the infected region are significantly impacted as shown in essay 3. Furthermore, producers in other regions stand to gain from an outbreak.

Although no quantitative work was done directly comparing a simple cost based or input output based analysis to the partial equilibrium structure used here, the results of essay 3 and the theoretical discussion on economic modeling in essay 2 indicate that the underlying assumptions of partial equilibrium analyses would be most appropriate for FMD outbreaks. Risk and uncertainty cannot be assumed away in the economic modeling portion of integrated modeling; rather, economics has theory and tools available that allow us to include considerations in this area into the modeling we do as shown in essays 4 and 5.

In terms of limitations, there is still much work that could be done for animal disease modeling. In particular the approach and analysis in essay 3 could be improved by considering several factors. First, the international trade assumptions could be improved. The assumption is that the disease is confined to California but that all US opportunities to export were lost. However a zoning policy might be able to be employed to reduce international trade losses. In particular, the pork trade would not be as affected if zoning were put into place. The assumption that livestock and livestock product exports are reduced to autarky levels is a worst case scenario that would be more applicable to a multi-region outbreak rather than a regionalized outbreak.

Second, the quarantine zone analysis is strictly economic with no feedback into the epidemic model. Ideally, if there is no movement of trucks into or out of the quarantine zone (lockdown or milk dumping) this reduction in disease spread vectors would be modeled through the epidemic model as well. It is for this reason that the previously described impacts through the ASM model were assessed using the business as usual cost calculations for the disease mitigation costs. At this time there is no feedback loop to account for the reduced disease spread from stopping movements of services.

Third, only the short run aspects of the outbreak were examined. Essentially, the "year 0" or the year of the outbreak were examined without looking the 5-10 years into the future to determine when or if the livestock sector would recover from the outbreak. This long run analysis would particularly be important given international trade impacts and the time it will take to regain market share after export restrictions are put in place by our current export partners.

Like essay 3, a limitation of the analysis done in essay 4 is that international trade implications need to be better addressed in deriving the distribution of losses used in the risk analysis. The results were derived without taking into account extensive trade restrictions, which are a significant source of risk for US livestock agriculture. It is possible that rankings and BRAC levels may change given a significant threat of export market closures around the country.

Essay 5 has two significant limitations. First, data limitations prevent a more stringent measure of momentum trading from being used. Second, there are other possible explanations--based on market fundamentals-- that could explain a decreasing trend in livestock prices during that time; however, the decline was such that it is difficult to justify only from fundamentals.

In terms of further work, what is clear is that the threat of animal disease--FMD in particular--is very real to the US agricultural sector and there is still much work to be done to assess vulnerability and outbreak related strategies would be over the short and long run. Further aspects not discussed in essay 3, but that could be examined in the future, are the implications this would have on tourism and commercial traffic important to the California economy. Furthermore, the costs of human suffering and lost wages from movement restriction policies could be explored.

Also the results of essays 3 and 4 could be extended by explorations of the balance between ex ante investment and ex post response. In order to have rapid vaccine availability, the capability to replicate the vaccine in the US would have to be developed ex ante. This means laboratory equipment, trained personnel, and approved facilities strategically located around the country. Similarly, early detection would mean investment in diagnostics equipment and personnel in laboratories as well as the possibility of a random, mandatory testing procedure in vulnerable regions. Although these issues are not specifically modeled in this dissertation, the results presented here provide motivation for the further examination of balance issues.

It is possible that essay 5 could be expanded in three ways to further explore the issues presented. First, where intraday data on price and volume are available, the tests for the presence of herding and momentum trading could be repeated to see if this is a characteristic of the live cattle and lean hog futures market. Second, this method could be applied to other instances where animal disease uncertainty impacted futures markets. A recent example, where data may be more available, is the H1N1 outbreak and subsequent implications for lean hog and pork belly markets despite the fact that no hogs were sick and there was no danger of disease spread through pork consumption. Third, this model could readily be applied to a case where an animal disease is confirmed. An examination of livestock futures' responses to the rumor of an animal disease that was later confirmed, and a comparison to responses when the rumor was refuted, is helpful for policy implications and crisis management.

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APPENDIX

7.1. Programming Explanation

Up to this point, essay 2 has attempted to provide intuition and justification for integrated economic/epidemic modeling approach taken. At this juncture, a more detailed explanation of the programming related to an integrated model is presented. Since the two models are very similar, only the DADS-ASM integrated model is presented.

7.1.1. Define Scenarios

The first step is in defining scenarios. The scenarios defined for the DADS-ASM study are discussed in detail in essay 3. Scenarios are specified using the set "altruns" and the subset "altrun" specified earlier.

7.1.2. Integrate the DADS Model Output Results

Since the DADS-ASM model runs the full set of epidemic iterations from the DADS model through the economic model, a mapping linking each scenario and its individual iteration number is made. Also included in this mapping is the more descriptive scenario name "fmdscenarios" and the name coming from the epidemic model dataset "newscenarioname".

```
set mapscenario(altrun, iter, fmdscenarios, newscenarioname)
```

At this juncture the Epidemic data set flowing from DADS is brought into ASM as well as the basic premises data from the DADS model. The premises data is used to transform the epidemic simulations output from animal population changes in terms of herds impacted to percentage of the population in the region impacted.

```
parameter  EpiDataComplete(newscenarioname,iter,id,inputfield)
$include DADS_epi_scenariosStoch
parameter premisedata(id,inputfield) table of premise specific data from put file;
$include DADS_premise_data
```

The next step is to perform some simple adjustments to transform premises level data into animal level data. This requires first a definition of the herd types in the DADS model, second a set of assumptions on the animal mix in each herd type, and third a breakdown of herd types into three general size categories. The reason for the third step is that FMD costs will vary by premises size, necessitating knowledge of which premises ("id") falls into a particular size category.

9.1.2.1. Defining the DADS Model Herd Types

The types of herds in the DADS model are defined as well as the numeric code assigned to a particular type description. The numeric code is all that occurs in the epidemic model results, so it is important to define the herd types. The herd types defined for the DADS-ASM integration are as follows:

```
set farmtype the types of farms in the epi data
 / SmBeef           small beef grazing operation
   LgBeef            large beef grazing operation
   SmDairy          small dairy farm
   MdDairy          medium dairy farm
   LgDairy          large dairy farm
   SmDairyCalfr     small dairy calf raiser
   LgDairyCalfr     large dairy calf raiser
   SmSwine          small hog operation
   LgSwine          large hog operation
   Goat             goat producer   (meat and milk)
   Sheep            sheep prouducer (meat and milk)
   Backyard         an operation with less than 10 head
   Saleyard         an animal sales facility
/;

parameter premisetype(farmtype) description of premises
 /SmBeef            1
  LgBeef            2
  SmDairy           3
  MdDairy           4
  LgDairy           5
  SmDairyCalfr      6
  LgDairyCalfr      7
  SmSwine           8
  LgSwine           9
```

```
   Goat                    10
   Sheep                   11
   Backyard                12
   Saleyard                13
/;
```

9.1.2.2. Calculating Herd Mix

In order to take the appropriate proportion of death loss out of each budget, particularly for beef cattle budgets, broad herd types can be broken down into animal categorizations. This step was not as important for the DADS-ASM integration since there are only two beef operation types in the model. However, for the AusSpread-ASM integration there are not only beef cattle grazing operations but also feedlot operations. Still, in both models a breakdown of herds into individual animal types is used to calculate indemnity payments and foregone income. In the Texas High Plains, this information was collected via survey and gathering statistics work by Sherwell. For details, see Ward et al. (2007). Since similar work has not been done in California, it is assumed that the mix of animals in similar herd types will not vary greatly between the two regions. Table 55, Table 56, and Table 57 provide the breakdown of herds for beef cattle, dairy, swine, small ruminant and backyard operations.

Table 55. Animal Mix Assumptions in Beef and Dairy Herds (Sherwell)

Herd Type	600 lb steer	600 lb heifer	800 lb steer	800 lb heifer	1000 lb steer	1000 lb heifer	1200 lb steer	1200 lb heifer	1400 lb steer	1400 lb heifer	Milk Cow
Sm Beef	0.17	0.17	0.11	0.11	0.21	0.21	0.01	0.01	0	0	0
Lg Beef	0.17	0.17	0.11	0.11	0.21	0.21	0.01	0.01	0	0	0
Sm Dairy	0	0.15	0	0.18	0	0.17	0	0	0	0	0.5
Med Dairy	0	0.15	0	0.18	0	0.17	0	0	0	0	0.5
Lg Dairy	0	0.15	0	0.18	0	0.17	0	0	0	0	0.5
Sm Dairy Calf Raiser	0.2	0.2	0.1	0.2	0.1	0.2	0	0	0	0	0
Lg Dairy Calf Raiser	0.2	0.2	0.1	0.2	0.1	0.2	0	0	0	0	0
Backyard	0.24	0.24	0.1	0.1	0.3	0.1	0.1	0	0	0	0
Saleyards	0.11	0.07	0.24	0.016	0.20	0.11	0.05	0.03	0.02	0.01	0

Table 56. Animal Mix Assumptions in Hog Herds (Sherwell)

Herd Type	Sows	Boars	Piglet	Feeder Pig	Gilts	Barrows
Sm Swine	0.3	0.3	0.15	0.14	0.1	0.01
Lg Swine	0.3	0.3	0.15	0.14	0.1	0.01

Table 57. Animal Mix Assumptions in Sheep Flocks (Sherwell)

Herd Type	Ewes	Rams	Male Lambs	Female Lambs	Male Yearlings	Female Yearlings
Sheep	0.31	0.1	0.13	0.12	0.23	0.11
Goats	0.31	0.1	0.13	0.12	0.23	0.11

9.1.2.3. Including Premises by Size

For an FMD outbreak, most costs are assumed to have two parts. The variable portion of cost is on a per head basis; however, there is often assumed to be a fixed portion of cost that will depend only on the general category of the size of the herd. Such a cost would be the cost of surveillance, in which a particular herd is visited by an animal health professional to check for symptoms of FMD. Another example would be the cost of appraising a herd for slaughter. As long as the fixed cost for a particular herd size is known as well as the average number of head for a herd of that size, these fixed costs can be transformed into a per animal cost. This simplifies adjusting the ASM budget. The herd sizes defined here are a small herd, a medium herd and a large herd size. The average number of head in these herds are 100, 450 and 800 respectively.

A mapping is created to link each scenario ("newscenarioname") and iteration ("iter") with the premises impacted in that simulation ("id") and the farmtype and herd size. The mapping named "link" sorts premises in the California study region into the small, medium and large categorizations.

```
set link(newscenarioname,iter,id,farmtype,herdsize) map;
loop(mapscenario(altrun, iter, fmdscenarios, newscenarioname),
**SMALL
link(newscenarioname,iter, id, farmtype, "smallherd")=no;
loop( (id)$premisedata(id,"type"),
   loop(farmtype$(premisedata(id,"type")= premisetype(farmtype)),
       if(premisedata (id,"all_stock") lt herdsizedefinition("smallherd"),
            link(newscenarioname,iter, id, farmtype, "smallherd")=yes;)));

**MEDIUM
link(newscenarioname,iter, id, farmtype, "medherd")=no;
loop( ( id)$premisedata(id,"type"),
   loop(farmtype$(premisedata(id,"type")= premisetype(farmtype)),
       if((premisedata (id,"all_stock") le herdsizedefinition("medherd"))
     and (premisedata (id,"all_stock") ge herdsizedefinition("smallherd")),
            link(newscenarioname,iter, id, farmtype, "medherd")=yes;)));

**LARGE
link(newscenarioname,iter, id, farmtype, "largeherd")=no;
loop( ( id)$premisedata(id,"type"),
```

```
  loop(farmtype$(premisedata(id,"type")= premisetype(farmtype)),
     if((premisedata (id,"all_stock")gt herdsizedefinition("largeherd")),
          link(newscenarioname,iter, id, farmtype, "largeherd")=yes;)));
);
```

7.1.3. Fix Animal Populations

In order to simulate an episodic FMD outbreak, the first step is to fix the animal populations so we have short term fixed herd locations. We largely restrict this to the breeding herds. First, the set containing the animal categorizations "*animal*" must be split into those affected by FMD and those unaffected by FMD. The animal set elements that are locked are: "*Sheep*", "*CowCalf*", "*Dairy*", and "*FeederPigProduction*". As shown in Figure 21. ASM Beef Cattle Flow Chart to Figure 24 animals flow through the budgets. Animal death shocks and performance degradation shocks will be placed in this flow as appropriate to the herd type being slaughtered, vaccinated or quarantined.

Note, animal production is also locked for non-impacted animals to prevent land from changing uses to produce more of this type of production in the short term. Again, this is necessary for the assumption of episodic disease to prevent the model from finding a new long term equilibrium. Table 58 provides the breakdown of FASOM animal categories into locked and non-locked sets.

Table 58. ASM Spatially Locked Herd Types

Spatially Locked ("allfixedanimal")	Not Spatially Locked ("notfixedanimal")
FMD Affected Sheep CowCalf Dairy Hog Farrow to Finish Feeder Pig Production **Non-FMD Affected** Horses and Mules Produce Turkey Broiler Egg	**FMD Affected** Feedlot Beef Yearlings Feedlot Beef Calves Pig Finishing Steer Calf Stocker Heifer Calf Stocker Steer Yearling Stocker Heifer Yearling Stocker

After the sets of locked and non-locked animals have been defined, the production can be set such that the model is spatially locked down. This is done inside the scenario loop so that for each non-base scenario the production is locked. The base scenario is assumed to be a "business as usual", no outbreak scenario.

First, the positive variable "AGLVSTBUDGETNSPR" that defines the levels of livestock budgets in the welfare maximization objective function of the program need to be given upper and lower bounds for non-spatially locked animal sets. Since all of the animal categorizations in this set are expected to reduce from the animal disease outbreak, but should be prevented from falling below zero the variable for this set of animals is bounded by zero below and the pre-outbreak level from above as shown in the two lines of programming below.

```
AGLVSTBUDGETNSPR.lo(period,agreg,notfixedanimal,livetech,eftech)
          $agregsperiod(period,agreg)
           =0;

AGLVSTBUDGETNSPR.up(period,agreg,notfixedanimal,livetech,eftech)
          $agregsperiod(period,agreg)
           =max
(0.01,saveAGLVSTBUDGETlev(period,agreg,notfixedanimal,livetech,eftech));
```

In addition, the lower bound should be prevented from going above the defined upper bound. The following code prevents this from happening.

```
loop((period,agreg,notfixedanimal,livetech,eftech),
       if(AGLVSTBUDGETNSPR.up(period,agreg,notfixedanimal,livetech,eftech)
         <AGLVSTBUDGETNSPR.lo(period,agreg,notfixedanimal,livetech,eftech),
          if(AGLVSTBUDGETNSPR.up(period,agreg,notfixedanimal,livetech,eftech)<0,

AGLVSTBUDGETNSPR.up(period,agreg,notfixedanimal,livetech,eftech)=0.0001);
          if(AGLVSTBUDGETNSPR.lo(period,agreg,notfixedanimal,livetech,eftech)<
             AGLVSTBUDGETNSPR.up(period,agreg,notfixedanimal,livetech,eftech),
             AGLVSTBUDGETNSPR.lo(period,agreg,notfixedanimal,livetech,eftech)
=max(AGLVSTBUDGETNSPR.up(period,agreg,notfixedanimal,livetech,eftech)*0.999
9,0));
         ));
```

For animals that are fixed spatially, the levels are fixed at the pre-outbreak levels, which is retained in the parameter saveAGLVSTBUDGETlev. Again this is done for each non-base scenario.

```
    AGLVSTBUDGETNSPR.fx(period,agreg,allfixedanimal,livetech,eftech)
      $agregsperiod(period,agreg)
       =saveAGLVSTBUDGETlev(period,agreg,allfixedanimal,livetech,eftech);

loop((period,agreg,allfixedanimal,livetech,eftech),
    if(AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)
     <AGLVSTBUDGETNSPR.lo(period,agreg,allfixedanimal,livetech,eftech),
      if(AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)<0,

AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)=0.0001);
      if(AGLVSTBUDGETNSPR.lo(period,agreg,allfixedanimal,livetech,eftech)<
        AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech),
        AGLVSTBUDGETNSPR.lo(period,agreg,allfixedanimal,livetech,eftech)

=max(AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)*0.9999,
0)); );


    if(AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)
     <AGLVSTBUDGETNSPR.lo(period,agreg,allfixedanimal,livetech,eftech),
      if(AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)<0,

AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech)=0.0001);
      if(AGLVSTBUDGETNSPR.lo(period,agreg,allfixedanimal,livetech,eftech)<
        AGLVSTBUDGETNSPR.up(period,agreg,allfixedanimal,livetech,eftech),
        AGLVSTBUDGETNSPR.lo(period,agreg,allfixedanimal,livetech,eftech)=0);
     ));

loop((lockedanimals,fixanimal,natmixitem)
    $(sameas(lockedanimals,natmixitem)
    or unitlivestock(lockedanimals,natmixitem)
    or unitlivestock(fixanimal,natmixitem)),
  livmixgrouping(livemixg,natmixitem)=no);
```

7.1.4. Defining Costs

The control strategies built in that can be employed depending on the scenario are slaughter, surveillance, and vaccination with additional options for “vaccinate to live” strategies and welfare slaughter. For each budget there is a section for additional direct costs of for "carcass disposal" and "disease management". These costs are assumed to be zero until levels are assigned to them inside the scenario loop. The cost of herd appraisal, carcass disposal includes the cost of euthanasia, cleaning and disinfection, and carcass removal. The cost of disease management includes the cost of vaccination, indemnity payments for animals slaughtered, forgone income for the time the premises are depopulation until it can be repopulated, and surveillance of herds to check for signs of the disease.

Also included in this cost number are the additional costs associated with restricting the movements of animals such as the additional costs to clean and disinfect trucks bringing feed in and milk out. If movement restrictions are very strict such that the movement of feed and other goods/services in and out of the zone is not possible, this would capture the additional cost of slaughter or lost value of milk and other products that spoil inside the movement restriction zone.

- Surveillance costs were calculated according to herd size using fixed costs of being under surveillance and per visit costs of testing the herd.
- Culling costs were calculated as a sum of euthanasia, carcass disposal, cleaning and disinfection and herd appraisal costs. These were multiplied by the estimate of herds slaughtered from the industry loss section above.
- Vaccination costs were calculated based on per animal vaccination costs and fixed per herd vaccination costs according herd size.

The specific cost categories calculated vary slightly between the integration of DADS-ASM and the integration of AusSpread-ASM, so the details behind the calculations will be saved for essay 3. However, the goal is to reach a per animal cost calculation for each scenario based on the individual assumptions and simulated animal disease outbreak.

7.1.5. Regional Location

Since the disease is assumed to be confined to a particular region, that region must be defined for the ASM model. This is a relatively simple process requiring only one line of code. This code for the outbreak assumed to occur in California is:

```
set affectedregion(allreg) this is the region affected in this run  /"CaliforniaN"/;
```

This subset of the full set of ASM sub-regions can then be used in place of allreg where appropriate to confine the disease shock to the region of interest. In the case of the Texas outbreak the "affected region" is "TxHiPlains".

7.1.6. Epidemic Data Transformation

As discussed earlier, the epidemic gives the status of each herd as to whether it is susceptible, sub-clinically infectious, infectious, removed/recovered, quarantined and/or vaccinated. The epidemic model does not stop moving forward in time from the initial infection until the disease is eradicated. The economic model moves in year time steps, so as long as the disease is eradicated within a year, the total epidemic results are integrated into the annual economic model. Therefore, the data that is moved into the economic model is the state of herds at the end of the epidemic model period. Since a "stamp out" policy is assumed as well as a "vaccinate to die" strategy when vaccination is used, the two states of herds in the model after the disease period is over is either susceptible or removed (dead). During the outbreak herds may have been subject to disease mitigation activities like vaccination and quarantine; this also must be transformed into a proportion of herds affected number. The ASM code performing the transformation from epidemic herd data to ASM regional percent changes is discussed as follows. First, the statuses possible in the epidemic data are defined as well as the numeric indicator in the "status" column of the data that is connected to that status. This number is used to sort data into the particular status groups. Mitigation activities are listed as a subset.

```
set status the potential status of each herd in the affected region
```

```
/susceptible
 dead
 vaccinated
 quarantine
/;

set herdcomponent(status) assign the value corresponding to each status
/susceptible    0
 dead           3
 vaccinated     1
 quarantine     1
/;

set mitigate (status) the disease mitigation strategies
/ vaccinated
  quarantine
/;
```

A simple mapping is created to indicate the linkage between the region of interest and the status of herds in that region.

```
set percentlink(allreg,status) the link to calculate percent of herd lost
/ "CaliforniaN" . susceptible
  "CaliforniaN" . dead
  "CaliforniaN" . vaccinated
  "CaliforniaN" . quarantine
/;
```

The first step in calculating the percentage change in the region is to define the total population in that region. This is done to confirm that the epidemic model captures enough of the premises in that region to assure the percentages calculated can be applied. This number is compared against the USDA-NASS data for the region of interest. It is not unexpected that the number in the epidemic model may be slightly larger than the number reported in the NASS data since some premises cannot be reported due to confidentiality issues. The inventories are calculated for all premises types and for individual premises types.

```
parameter totalinventory the total inventory of all susceptible animals in region;
totalinventory=sum(id,premisedata(id,"all_stock"));
```

```
parameter animalinventory(animal,allreg) the total inventory by type of animal;

    animalinventory("sheep","CaliforniaN")
       =sum((id)
         $((premisedata(id,"Type") eq 10)
         or (premisedata(id,"Type") eq 11)),
         premisedata(id,"all_stock")) ;

     animalinventory("cowcalf","CaliforniaN")
       =sum((id)
          $((premisedata(id,"Type") eq 1)
          or (premisedata(id,"type") eq 2)
          or (premisedata(id,"Type") eq 12)
          or (premisedata(id,"Type") eq 13)),
      premisedata(id,"all_stock"));

     animalinventory("Dairy","CaliforniaN")
       =sum((id)
         $((premisedata(id,"Type") eq 3)
         or (premisedata(id,"Type") eq 4)
         or (premisedata(id,"Type") eq 5)
         or (premisedata(id,"Type") eq 6)
          or (premisedata(id,"Type") eq 7)),
       premisedata(id,"all_stock"));

     animalinventory("Feederpigproduction","CaliforniaN")
       =sum((id)
         $((premisedata(id,"Type") eq 8)
           or (Premisedata(id,"Type") eq 9)),
        premisedata(id,"all_stock"));
```

Second, the number of animals that are dead or have received a particular control strategy treatment are sorted out of the epidemic data. The total number of animals slaughtered for disease control purposes are calculated as well as the breakdown of animal slaughtered for particular herd types. These are captured in the following parameters in the DADS-ASM integration. Note that due to the importance of dairy in California the premises quarantined and vaccinated are specifically broken out. Also, the numbers of head that are at risk for welfare slaughter are calculated.

```
parameter statusinventory(iter,affectedanimals,newscenarioname,allreg,herdcomponent)
          numberslaughteredtotal(iter,newscenarioname,allreg,herdcomponent)
          diseasecontrol(iter,newscenarioname,allreg,mitigate)
          diseasecontroldairy(affectedanimals,newscenarioname,allreg,mitigate)
          dairypremisesquarantined(newscenarioname,allreg,mitigate)
          welfareligiblenCA(iter,newscenarioname,allreg);

*effects on the herd (number of head)
loop(mapscenario(altrun, iter, fmdscenarios, newscenarioname),
       numberslaughteredtotal(iter,newscenarioname,"CaliforniaN","dead")
           =sum(id$(EpiDataComplete(newscenarioname,iter,id,"status") eq 3),
           premisedata(id,"all_stock"));

       statusinventory(iter,"sheep",newscenarioname,"CaliforniaN","dead")
            =(sum((percentlink("CaliforniaN","dead"),id)
            $(premisedata(id,"all_stock")
            and(EpiDataComplete(newscenarioname,iter,id,"status")eq 3)
            and((premisedata(id,"type") eq 10)
                or (premisedata(id,"Type") eq 11))),
           premisedata(id,"all_stock")));

       statusinventory(iter,"cowcalf",newscenarioname,"CaliforniaN","dead")
            =(sum((percentlink("CaliforniaN","dead"),id)
            $(premisedata(id,"all_stock")
            and(EpiDataComplete(newscenarioname,iter, id,"status") eq 3)
            and((premisedata(id,"type") eq 1)
               or (premisedata(id,"type") eq 2)
               or (premisedata(id,"type") eq 12)
               or (premisedata(id,"type") eq 13))),
           premisedata(id,"all_stock")));

       statusinventory(iter,"dairy",newscenarioname,"CaliforniaN","dead")
            =(sum((percentlink("CaliforniaN","dead"),id)
            $(premisedata(id,"all_stock")
            and(EpiDataComplete(newscenarioname,iter,id,"status")eq 3)
            and((premisedata(id,"type") eq 3)
               or (premisedata(id,"type") eq 4)
               or (premisedata(id,"type") eq 5)
               or (premisedata(id,"type") eq 6)
               or (premisedata(id,"type") eq 7))),
           premisedata(id,"all_stock")));

       statusinventory(iter,
"feederpigproduction",newscenarioname,"CaliforniaN","dead")
```

```
    =(sum((percentlink("CaliforniaN","dead"),id)
    $(premisedata(id,"all_stock")
     and(EpiDataComplete(newscenarioname,iter,id,"status")eq 3)
     and (premisedata(id,"type") eq 8)
     or (premisedata(id,"type") eq 9)),
    premisedata(id,"all_stock")));

diseasecontrol(iter, newscenarioname,"CaliforniaN","vaccinated")
    =(sum((percentlink("CaliforniaN","vaccinated"),id)
    $(EpiDataComplete(newscenarioname,iter,id,"vaccinated") gt 0),
    EpiDataComplete(newscenarioname,iter,id,"vaccinated")));

 diseasecontrol(iter, newscenarioname,"CaliforniaN","quarantine")
    =(sum((percentlink("CaliforniaN","quarantine"),id)
    $(premisedata(id,"all_stock")
     and EpiDataComplete(newscenarioname,iter,id,"quarantine")
     and (EpiDataComplete(newscenarioname,iter,id,"status") eq 0)),
    premisedata(id,"all_stock")));

  diseasecontroldairy("dairy",newscenarioname,"CaliforniaN","quarantine")
     =(sum((percentlink("CaliforniaN","quarantine"),id)
     $(premisedata(id,"all_stock")
     and(EpiDataComplete(newscenarioname,iter,id,"quarantine"))
     and (EpiDataComplete(newscenarioname,iter,id,'status') eq 0)
     and((premisedata(id,"type") eq 3)
        or (premisedata(id,"type") eq 4)
        or (premisedata(id,"type") eq 5)
        or (premisedata(id,"type") eq 6)
        or (premisedata(id,"type") eq 7))),
    premisedata(id,"all_stock")));

   diseasecontroldairy("dairy",newscenarioname,"CaliforniaN","vaccinated")
     =(sum((percentlink("CaliforniaN","vaccinated"),id)
     $(premisedata(id,"all_stock")
     and(EpiDataComplete(newscenarioname,iter,id,"vaccinated"))
     and((premisedata(id,"type") eq 3)
        or (premisedata(id,"type") eq 4)
        or (premisedata(id,"type") eq 5)
        or (premisedata(id,"type") eq 6)
        or (premisedata(id,"type") eq 7))),
    EpiDataComplete(newscenarioname,iter,id,"vaccinated")));

dairypremisesquarantined(newscenarioname,"CaliforniaN","quarantine")=
    sum(id
```

```
          $(premisedata(id,"all_stock")
          and(EpiDataComplete(newscenarioname,iter,id,"quarantine"))
          and (EpiDataComplete(newscenarioname,iter,id,'status') eq 0)
          and((premisedata(id,"type") eq 3)
            or (premisedata(id,"type") eq 4)
            or (premisedata(id,"type") eq 5)
            or (premisedata(id,"type") eq 6)
            or (premisedata(id,"type") eq 7))),
         1);

       welfareligiblenCA(iter,newscenarioname,'CaliforniaN')=sum(id$
         (epidatacomplete(newscenarioname,iter,id,"days_qt") gt feeddays
         and epidatacomplete(newscenarioname,iter,id,"status") eq 0 and
         premisedata(id,'all_stock') gt 50),premisedata(id,'all_stock'));

);
```

Now the percentage slaughtered, vaccinated, quarantined or at risk for welfare slaughter in the regional animal populations can be calculated. These calculations are captured in several parameters where

- "effectsonherd" parameter gives the percent slaughtered,
- "effectsonherdDC" parameter gives the percent vaccinated or quarantined, and
- "effectsonherdDCdairy" parameter breaks out vaccination and quarantine specifically for dairies in California.

The scalar "factor1" is used to scale the inventory up or down if the epidemic model captures more or less geographic area than the region covered in the ASM definition. For example, if the epidemic model only included premises in an 8 county area, but the ASM model includes premises in a 18 county area, the NASS data could be used to calculate the "factor1" value to scale the total inventory up to account for this difference. In the DADS-ASM model this value was set to 1.

```
parameter effectsonherd(newscenarioname,affectedanimals,allreg, herdcomponent)
        effectsonherdDC(newscenarioname,allreg,herdcomponent)
        effectsonherdDCdairy(affectedanimals,newscenarioname,allreg,mitigate) ;
```

```
*the percentage of the total herd population that falls into each herd component category
loop(mapscenario(altrun, iter, fmdscenarios, newscenarioname),

      effectsonherd(newscenarioname, affectedanimals,'CaliforniaN',herdcomponent)
         $(animalinventory(affectedanimals,"CaliforniaN"))
          =(statusinventory(iter,affectedanimals,newscenarioname,
        "CaliforniaN",herdcomponent)
          /(animalinventory(affectedanimals,"CaliforniaN")*factor1(affectedanimals))
         );

       effectsonherdDC(newscenarioname,"CaliforniaN","vaccinated")
         $(diseasecontrol(iter, newscenarioname,"CaliforniaN","vaccinated")
          and(totalinventory))
          =(diseasecontrol(iter, newscenarioname,"CaliforniaN","vaccinated")
          /(totalinventory)
         );

        effectsonherdDC(newscenarioname,"CaliforniaN","quarantine")
         $(diseasecontrol(iter, newscenarioname,"CaliforniaN","quarantine")
          and(totalinventory))
          =(diseasecontrol(iter, newscenarioname,"CaliforniaN","quarantine")
          /(totalinventory)
         );

      effectsonherdDCdairy("dairy",newscenarioname,"CaliforniaN","quarantine")
        =(diseasecontroldairy("dairy",newscenarioname,"CaliforniaN","quarantine")
          /(animalinventory("dairy","CaliforniaN")*factor1("dairy")));

     effectsonherdDCdairy("dairy",newscenarioname,"CaliforniaN","vaccinated")
        =(diseasecontroldairy("dairy",newscenarioname,"CaliforniaN","vaccinated")
          /(animalinventory("dairy","CaliforniaN")*factor1("dairy")));

   );
```

Finally, the percentage changes are linked to the region of interest.

```
loop((newscenarioname,affectedanimals,allreg,herdcomponent)$
    effectsonherd(newscenarioname,affectedanimals,allreg,herdcomponent),
    affectedregion(allreg)=yes;);
```

7.1.7. The Scenario Loop

Once the cost per head of disease mitigation and carcass disposal and the percentage change in the regional population due to disease mitigation have been calculated for every scenario and stochastic replication case, the budgets in ASM are adjusted to impose the disease shock. The scenario loop begins by indicating that the loop will run over all alternative runs ("altrun") of the model using the mapping between the FMD scenario group and the alternative runs set. If the alternative run is the base run, then no animal disease shock is imposed and the model solves as it regularly would; however, when the alternative run is one in which an animal disease shock has been imposed the following adjustments are made.

9.1.7.1. Adjusting "Other Costs" in the ASM budgets

Cost calculations get outbreak costs to a per animal basis. These costs are then used to inside the scenario loop to increase the "other costs" line item of the livestock budgets for the affected animals as follows.

```
*Disease Management
   livestockbud("CaliforniaN",affectedanimals,livetech,eftech,'diseasemanagement')
         $sum(primary
$livestockbud("CaliforniaN",affectedanimals,livetech,eftech,primary),1)
                     = losses(newscenarioname,"costdiseasemgmt");

*Cost of Slaughter
  livestockbud("CaliforniaN",affectedanimals,livetech,eftech,'carcassdisposal')
         $(sum(primary
$livestockbud("CaliforniaN",affectedanimals,livetech,eftech,primary),1))
                         = losses(newscenarioname,"costcarcassdisposal") ;
```

9.1.7.2. Adjusting Animal Output in ASM Budgets

The adjustment in the ASM budgets for each affected animal group are explained as follows.

9.1.7.2.1. Cow/Calf Budget

The animal output from the cow/calf budget is steer calves and heifer calves. These calves go into subsequent grazing operations. In the case of the DADS-ASM integration, only the cow/calf budget is adjusted rather than any of the stocker or feedlot budgets. This assumption is based on an examination of the beef cattle herd types typical of central and northern California where the outbreak happens. The output per cow in the affected region is reduced by the proportion of the animals killed that were in beef grazing operations.

```
livestockbud("CaliforniaN","cowcalf",livetech,eftech,"HeifCalve")
$(livestockbud("CaliforniaN","cowcalf",livetech,eftech,"HeifCalve")
and effectsonherd(newscenarioname,"cowcalf","CaliforniaN",herdcomponent))
      =(livestockbud("CaliforniaN","cowcalf",livetech,eftech,"HeifCalve")
         -(livestockbud("CaliforniaN","cowcalf",livetech,eftech,"HeifCalve")*
            effectsonherd(newscenarioname,"cowcalf","CaliforniaN","dead"))
       );
```

9.1.7.2.2. Dairy Budget

The output from the dairy budget is dairy calves and milk, both must be reduced to reflect the animal disease shock. The reduction in dairy calves later impacts the number of cattle available for slaughter. The reduction in milk production will affect the supply of processed milk products available.

```
livestockbud("CaliforniaN","dairy",livetech,eftech,"DairyCalves")
$(livestockbud("CaliforniaN","dairy",livetech,eftech,"DairyCalves") and
effectsonherd(newscenarioname,"dairy","CaliforniaN",herdcomponent))
=(livestockbud("CaliforniaN","dairy",livetech,eftech,"DairyCalves")
    -(livestockbud("CaliforniaN","dairy",livetech,eftech,"DairyCalves")*
     (effectsonherd(newscenarioname,"dairy","CaliforniaN","dead"))))
  );

*handle milk lost
livestockbud("CaliforniaN","dairy",livetech,eftech,"milk")
$(livestockbud("CaliforniaN","dairy",livetech,eftech,"milk") and
effectsonherd(newscenarioname,"dairy","CaliforniaN",herdcomponent))
 =(livestockbud("CaliforniaN","dairy",livetech,eftech,"milk")*
    (1-effectsonherd(newscenarioname,"dairy","CaliforniaN","dead"))
   );
```

9.1.7.2.3. Sheep Budget

Sheep and goats are both accounted for in the adjustment made to the sheep budget. There are two outputs from this budget, meat and wool. The reduction in meat is imposed by reducing the pounds of slaughter lambs and the wool is similarly reduced using the percent slaughtered calculation. Although sheep and goats are used for milk production as well, this is not accounted for in the ASM model.

```
livestockbud("CaliforniaN","sheep",livetech,eftech,"LambSlaugh")
$(livestockbud("CaliforniaN","sheep",livetech,eftech,"LambSlaugh") and
effectsonherd(newscenarioname,"sheep","CaliforniaN",herdcomponent))
= (livestockbud ("CaliforniaN","sheep",livetech,eftech,"LambSlaugh")
  -livestockbud ("CaliforniaN","sheep",livetech,eftech,"LambSlaugh")
  *(effectsonherd(newscenarioname,"sheep","CaliforniaN","dead"))
                    );

*handle wool loss
livestockbud("CaliforniaN","sheep",livetech,eftech,"wool")
$(livestockbud("CaliforniaN","sheep",livetech,eftech,"wool") and
effectsonherd(newscenarioname,"sheep","CaliforniaN",herdcomponent)
 =(livestockbud("CaliforniaN","sheep",livetech,eftech,"wool")*
     (1-(effectsonherd(newscenarioname,"sheep","CaliforniaN","dead")) )
   );
```

9.1.7.2.4. Hog Budget

The final budget that must be adjusted is the hog budget. In this case, an assumption has been made that the majority of hog production in the impacted region of California is the production of feeder pigs that will then be finished elsewhere. This assumption is based on an examination of hog operations presented in the 2007 Ag Census Report.

```
*no replacements taken out in hogs
livestockbud("CaliforniaN","feederpigproduction",livetech,eftech,"feederpig")
$(livestockbud("CaliforniaN","feederpigproduction",livetech,eftech,"feederpig") and
effectsonherd(newscenarioname,"FeederPigProduction","CaliforniaN", herdcomponent))
=(livestockbud("CaliforniaN","feederpigproduction",livetech,eftech,"feederpig")
-livestockbud("CaliforniaN","feederpigproduction",livetech,eftech,"feederpig")
  *(effectsonherd(newscenarioname,"FeederPigProduction","CaliforniaN","dead"))
  );
```

9.1.7.3. International Trade

Thus far, only the supply side adjustment required to impose an animal disease shock has been discussed. Another component is the demand side adjustment that must be made in response to international trade restrictions on US non-pasteurized meat and dairy products as a result of FMD. These impacts have been shown to be quite large, particularly for countries that are leading exporters of meat products (Pritchett, Thilmany and Johnson). The imposition of trade restrictions has been simplified as a scalar reduction in US exports of affected products, where the scalar level is set as either no trade restrictions (0), a full trade block on those products (1), or a reduction in proportion to the production of the affected state (some number greater than zero but less than 1). This last option would reflect the use of zoning the disease to limit export restrictions to those products from the affected region (trade regionalization).

Outside of the scenario loop, the affected products (pork, fed beef, non-fed beef, and lamb) are defined and the scalar is created. Then inside the scenario loop, the quantity of US exports is adjusted for these products.

```
commodsupdem('US_exports','US',affectedproducts,'quantity') =
      commodsupdem('US_exports','US',affectedproducts,'quantity')*zone_regions;
```

9.1.7.4. Solving the Model

Finally the ASM is solved for the base scenario and each scenario and stochastic replication run in the epidemic model to reflect the animal disease shock. The resulting output is a distribution of national and regional economic impacts from the animal disease. This distribution can then be used in additional economic analysis to ascertain the impact of the disease under the assumptions and control strategies examined.

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