ASSESSMENT OF U.S. AGRICULTURE SECTOR AND HUMAN VULNERABILITY TO A RIFT VALLEY FEVER OUTBREAK

A Thesis

by

RANDI CATHERINE HUGHES

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

MASTER OF SCIENCE

May 2011

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	Bruce A. McCarl
Committee Members,	David A. Bessler
	Amy Hagerman
	Bo Norby
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ABSTRACT

Assessment of U.S. Agriculture Sector and Human Vulnerability to a Rift Valley Fever Outbreak. (May 2011)
Randi Catherine Hughes, B.S., Texas A&M University
Chair of Advisory Committee: Dr. Bruce A. McCarl

Foreign animal disease outbreaks can cause substantial economic losses. Policy makers need information on both the vulnerability of the food supply to disease epidemics and the impacts of alternative protection actions. This research focused on the assessment of the U.S. agricultural sector and human vulnerability to a Rift Valley Fever (RVF) outbreak and the value of a select set of alternative disease control strategies. RVF is a vector-borne, zoonotic disease that affects both livestock and humans; thus both animal and human consequences of an outbreak were examined.

This research was conducted in two parts. Livestock impact assessment used an integrated epidemic/economic model to examine the extent of RVF spread in the animal population and its consequences plus the outcome of implementing two different control strategies: emergency vaccination and larvicide vector control. The number of infected, aborted, and dead animals is best controlled by coupling vaccination along with larvicide, but results in the second highest median national welfare loss. Therefore, careful decisions must be made as to what actions should be taken.

Total national producer welfare is reduced with each scenario, and is more severe than the total national welfare loss (producer, consumer, and processor together). Consumer welfare is increased with each scenario due to a drop in prices of some commodities, and in some instances, an increase in supply as well. The majority of the national welfare loss can be attributed to the producers' and processors' loss in welfare. The highest damages are seen in the regions of the outbreak such as the South Central (SC). Other regions such as the Corn Belt, Lake States, and South East regions also see high damages due to price changes. The outbreak did not have substantial price effect on dairy products, but did have noticeable price changes for live cattle such as heifer calves, stocked yearling, and dairy calves. Prices for substitutes such as pork, chicken, and turkey experienced a price reduction, which can also be a factor resulting in consumer welfare gains.

Human impact assessment utilized an inferential procedure for estimating the human consequences which comprise of a cost of illness calculation to assess the dollar cost of human illnesses and deaths, as well as a Disability Adjusted Life Year calculation to give an estimate of the burden of disease on public health as a whole. With potential costs above $2 billion for human illness, and with this number not accounting for loss or damages to other sectors of the economy, it can be highly probable that investing in a human vaccination campaign can be cost-effective and possibly cost-reducing.

This cost along with the economic loss of the agriculture sector suggests substantial potential losses to the U.S. if this hypothetical situation were to become reality. Combining total loss estimates from the cost of illness and ASM models, potential damage of a RVF outbreak could range from 121 million to 2.3 billion US 2010$. The results of this study show the economic damages of an outbreak in the livestock population being much greater relative to the outbreak in the human population (roughly 16 times greater). It should be pointed out that both cost estimates are most likely under estimated. The animal outbreak is not incorporating all susceptible livestock (e.g. hogs and goats), and the human illness is not incorporating other damages to society (e.g. damages due to loss of tourism). By providing estimates on the potential economic outcomes, policy makers can better choose where, when, and how to invest their resources.

DEDICATION

To

My best friend

Francisco Fraire-Dominguez,

For guiding me in the right direction.

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I would like to thank my committee chair, Dr. Bruce McCarl, for his helpful advice and guidance he provided not only to me, but to my family throughout my masters degree. I am honored and privileged to have been able to work under his supervision. I would also like to extend a sincere gratitude to Dr. Amy Hagerman, for her vast support and never ending guidance, patience, and advice throughout my thesis. This thesis would not have been possible without her.

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

1. INTRODUCTION

Animal disease outbreaks can cause substantial economic losses to the agricultural sectors (as reviewed in Elbakidze et al. (2009), Hagerman (2009), and Junker et al. (2008)). Outbreaks can come about as a result of intentional or unintentional behavior, and may disrupt agricultural commodity and related markets. If the disease is a zoonotic disease, infection can spread from animals to humans and vice versa and additional consequences arise for human health and health care expenditures. Although the U.S. has had less severe animal disease outbreaks than those occurring in many other countries, this does not necessarily mean that the U.S. food supply chain is safe from disease related threats. Therefore, assessments of disease outbreak impacts and control methods are potentially valuable in support of policy decision making regarding protection from and management of disease-related incidents.

This research focuses on the assessment of the U.S. agricultural sector and human vulnerability to a Rift Valley Fever (RVF) outbreak plus the value of alternative disease control strategies. Since RVF is a zoonotic disease, human susceptibility to infection, which may result in hemorrhagic fever among other illnesses (CDC 2010), as well as livestock susceptibility must be assessed. Thus, this research will examine not only the consequences felt through livestock losses and other livestock related effects, but also the human consequences. This research will proceed in two parts:

1. An integrated epidemic/economic model will be used to examine the outcome of implementing different control strategies in Southeast Texas. Specifically, this study will look at vaccination and larvicide for disease intervention, used both independently and jointly.

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

2. An inferential procedure will be used to estimate human consequences. This will consist of a cost of illness calculation assessing the dollar cost of human illnesses and deaths as well as a Disability Adjusted Life Year (DALY) calculation to estimate overall public health cost. Information from another vector-borne disease, West Nile Virus (WNV) will be used to infer the extent of RVF spread in the human population.

The study will yield information on base human and livestock vulnerability to RVF as well as, on the livestock side, the potential benefits of disease impact mitigation activities. This information will hopefully aid policy makers in evaluating control strategy decisions and recommending response actions regarding potential RVF outbreaks.

1.1 Objective

Little is known about the livestock and human vulnerability to RVF in the US. The objective of this study is to develop information on the potential livestock and human vulnerability to RVF by assessing economic consequences. In addition, the economic implications of using a number of control strategies for RVF are examined. The results will provide information in support of policy decisions addressing the prevention or response to a RVF epidemic.

The study employs a two part procedure. The first part is an epidemic-economic analysis of RVF's consequences on the US livestock industry. A fundamental question for RVF or any other animal disease is what actions, ex-ante or ex-post, can be taken to reduce vulnerability/risk to or damages from disease? Assessment of livestock industry vulnerability and the implications of select outbreak control strategies in potential reducing vulnerability is vital in consideration of that question (see the discussion in Elbakidze et al. 2009). Vulnerability is measured by the difference from a baseline of no disease compared to epidemic outcomes with no extraordinary intervention (allowing the disease to run its course). Alternatively, control strategies such as vaccination or vector control can be used to reduce the consequences of the outbreak compared to when such measures are not undertaken. Specifically, this study analyzes the impact of using a vaccination campaign, and pursuing vector (mosquito) control using larvicides, as well as using vaccination and larvicide together.

The second part of the study will assess human vulnerability to RVF in terms of human illness and mortality. This will be done by estimating potential economic losses associated with human illnesses and deaths as the disease is first introduced into the human population, and as the disease spreads throughout the nation's population. Hopefully, the results of this research will aid in policy decisions regarding national security.

1.2 Motivation

A 2008 Institute of Medicine (IOM) and National Research Council (NRC) workshop report makes the case for increasing foreign animal and zoonotic disease risk arising in today’s world. The report shows us how several factors influence vulnerability to a foreign animal or zoonotic disease outbreak such as:

- population growth
- changing patterns of human–animal contact
- increased demand for animal protein
- increased wealth and mobility
- environmental changes
- human encroachment on farm land and previously undisturbed wildlife habitat

All of the above factors are interrelated and have implications for US vulnerability to disease outbreaks.

1.2.1 Population Growth

Population growth has created, and will continue to create, significant struggles in sustaining the world food supply. The world human population was less than 3.5 billion in 1950 and reached approximately 6.5 billion in 2005; it is projected to pass 11 billion by 2100. Population growth is accompanied by an increase in demand for food; in particular, as developing nations gain wealth and participate in international trade, demand for animal protein and products increases. Figure 1 shows the increase in meat consumption in the developed and developing parts of the world since 1983. This increase in demand is projected to double by 2020, which will also increase the risk regarding global health (IOM and NRC 2008).

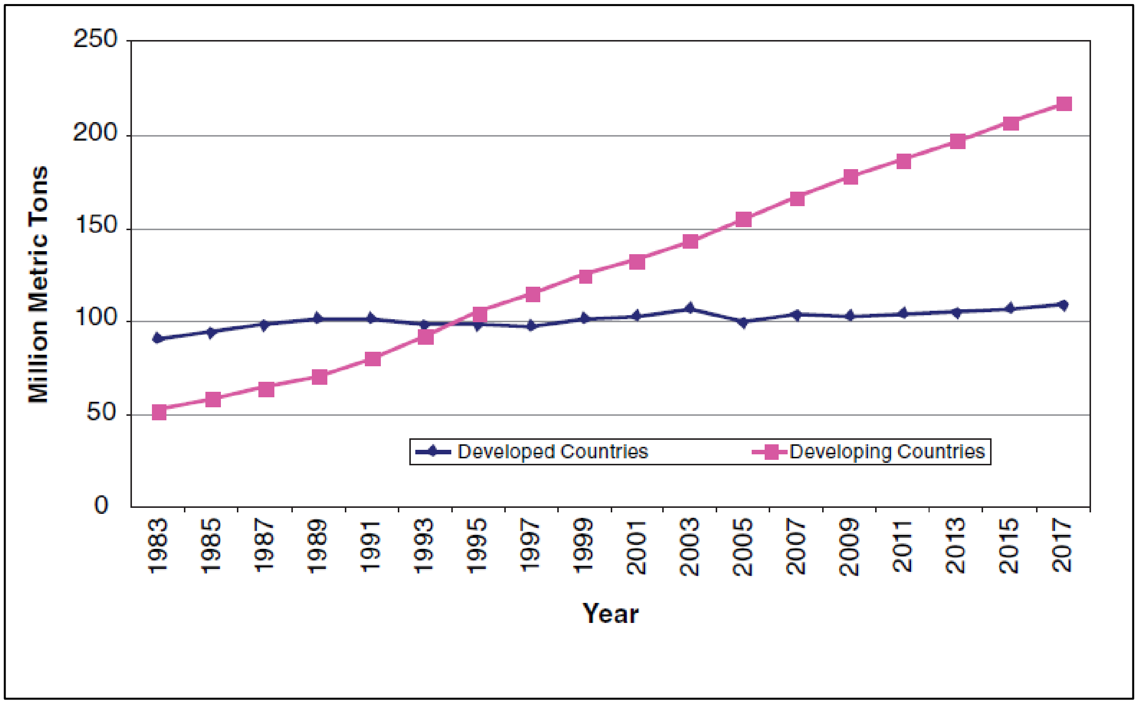

Figure 1. World Meat Consumption Projections from 1983-2017 Adapted from IOM and NRC 2008

1.2.2 Human-Animal Contact and Changing Demands

To satisfy an increase in demand, production must also increase. Global meat production has nearly tripled since 1960 and is expected to keep growing (Speedy, 2003). Production practices have aimed at gaining efficiency in livestock production to satisfy this demand. How this efficiency gain is realized varies by country and by the species of livestock produced. Historically in developed countries such as the U.S., this increase in production has been accomplished by increases in producing and finishing animals in concentrated animal production (or feeding) operations, often referred to as CAFOs. This is particularly true of poultry and swine production. Although cattle are not as intensely produced, there has been an increase in the number of both beef and dairy cattle in CAFO operations, especially dairy. Since the late 1980s, there has been a tripling of dairy cows in CAFOs (Keeney 2010). These operations tend to use selective breeding which produces more homogeneity in animal products and carcass size. The characteristics of these concentrated animal production operations along with the decrease in genetic variability contribute to an increase in vulnerability to disease. As Gilchrist et al. (2007) state,

> The industrialization of livestock production and the widespread use of non-therapeutic antimicrobial growth promotants have intensified the risk for the emergence of new, more virulent, or more resistant microorganisms. These have reduced the effectiveness of several classes of antibiotics for treating infections in humans and livestock. Recent outbreaks of virulent strains of influenza have arisen from swine and poultry raised in close proximity.

Also, there are over 800 million livestock owners around the world who depend on their livestock for their living. In lesser developed countries such as Asia and Africa; these are typically resource scarce farmers who have little money and/or land which results in raising an increased number of livestock on constrained land, while at the same time not having the resources to vaccinate or protect the livestock from disease (IOM and NRC 2008).

1.2.3 Increase in Wealth and Mobility

Furthermore, an increase in population along with an increase in technology has led to increased travel and trade, which have a strong influence on disease incidence (Cossar 2006). This increase in mobility means animals and pathogens can travel faster and further than before. As the IOM and NRC report states, one billion persons cross international borders every year (25 persons per second), some of who may be transporting goods such as meat and other foods. In addition, the largest portion of population growth is taking place in the least developed countries where a larger portion of the population live in poverty, a higher population density occurs and contact with domestic and wild animals is high compared to developed countries. This creates a prime condition for the transmission and emergence of zoonotic disease. People travelling from developed countries such as the U.S. to developing countries create risk of bringing the disease to their home country, or spreading the disease to their next travel destination. A prime example of this is the H1N1 (swine flu) pandemic of 2009, which originated in Mexico and had infected people in over 60 countries by 2010 (WHO 2010). Figure 2 is a graphical representation of the number of passengers who arrived to cities flying from Mexico between March 1 and April 20, 2009 (NEJM 2009).

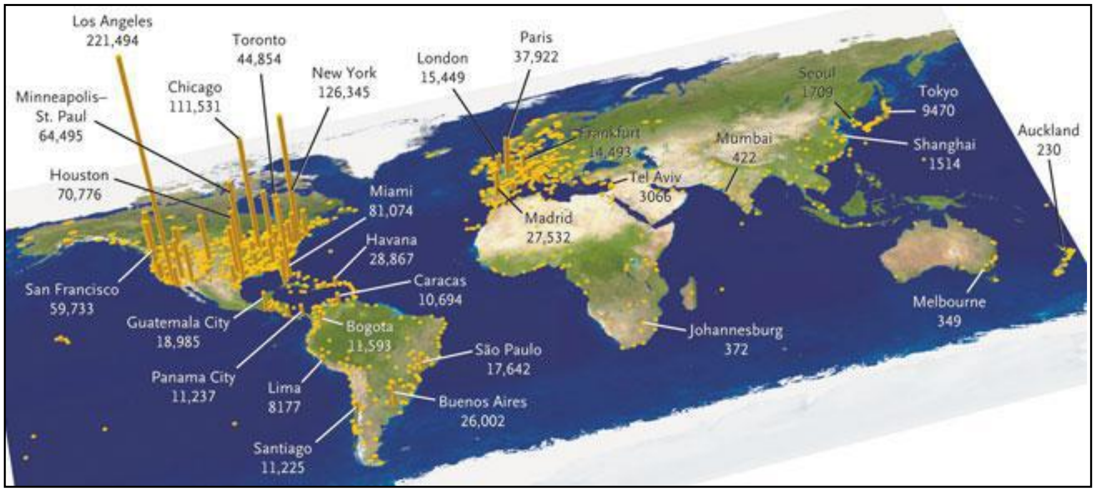

Figure 2. Graphical Representation of Flights from Mexico to the Corresponding Cities between March 1 and April 20, 2009. Source (NEJM 2009)

1.2.4 Environmental Factors and Human Encroachment

Increase in demand and use for natural resources has led to great environmental changes. These include changes in weather and humidity patterns, and increases in drought and desertification. In turn, these have created changes in the geographical ranges of pathogens and other species. These changes also affect the prevalence, competency, distribution, and movements of human and animal pathogens and associated vectors. Also, this increase in demand for natural resources has led humans and animals to encroach on wild lands and new environments exposing them to new pathogens (IOM and NRC 2008).

2. RVF: BACKGROUND

2.1 Basics of the Disease

Rift Valley Fever is a vector-borne zoonotic disease caused by the Rift Valley Fever virus, a member of the genus *Phlebovirus* (Family *Bunyaviridae*). The disease was first identified in the Rift Valley of Kenya in 1931. It is currently confined to the African continent and the Arabian Peninsula. RVF mainly affects humans, sheep, cattle and goats, although other domestic and wild ruminants can also be infected. In infected livestock, the main symptoms are abortion of pregnant females and mortality in young animals. The two main vectors that carry RVF are the mosquitoes in the genus *Aedes* and *Culex*, although other genera of mosquito as well as biting insects can act as transmitters of the disease (Martin et al. 2008).

Outbreaks of RVF in Africa are strongly correlated with heavy rain fall. This is most likely related to the fact that the disease is vertically transmitted in the *Aedes* mosquito. Vertical transmission occurs when the female mosquito has the ability to pass the virus along through her eggs. The *Aedes* mosquitoes are often referred to as "Floodwater" mosquitoes, they have drought resistant eggs which may survive several years without hatching and require one or more floodings to trigger their further development (Peters and Linthicum 1994).

This vertical transmission may also be an indicator as to why the virus has become endemic in many countries, and a strong reason to believe that an outbreak in a disease-free country may result in a high probability of the disease becoming endemic. For this reason, as well as many others, RVF is viewed as a major threat to the United States.

West Nile Virus (WNV) is also a mosquito-borne virus. WNV did not reach the U.S. until 1999, and since then there have been 29,569 human cases and 1,159 human fatalities (CDC 2010). RVF is deadlier to humans than the WNV. Hence, the potential socio-economic impact of RVF in the U.S. could be detrimental. As the WHO states, "the vast majority of [RVF] human infections result from direct or indirect contact with the blood or organs of infected animals. The virus can be transmitted to humans through the handling of animal tissue during slaughtering or butchering, assisting with animal births, conducting veterinary procedures, or from the disposal of infected carcasses or aborted foetuses. Certain occupational groups such as herders, farmers, slaughterhouse workers and veterinarians are therefore at higher risk of infection. There is some evidence that humans may also become infected with RVF by ingesting the unpasteurized or uncooked milk of infected animals. Human infections have also resulted from the bites of infected mosquitoes and biting flies. Those infected either experience no detectable symptoms or develop a mild form of the disease characterized by a feverish syndrome with sudden onset of flu-like fever, muscle pain, joint pain and headache. While most cases are relatively mild, a small percentage (less than 1%) develops a much more severe form of the disease such as ocular disease, meningoencephalitis or haemorrhagic fever" (WHO 2010).

RVF could be introduced to regions where it is not currently present by movement of infected vectors or through importation of infected domestic or wild ruminants, although this could only happen if importation took place within the short incubation period for the disease. Adoption of the recommended guidelines of the OIE International Animal Health Code for such importations would prevent this. Another possible mechanism is to transport RVF-infected mosquitoes or people through international flights. They can be moved from RVF endemic countries within a matter of hours (UNFAO 2003).

2.2 Disease Control Strategies for Livestock

For the reasons previously stated, RVF is a serious threat to the US, and therefore, alternative disease management strategies in livestock need to be valued. Governments and international organizations such as the FAO have RVF contingency plans (UNFAO Animal Health Manual, No. 15 and Rift Valley Fever Contingency Plan for the Netherlands, 2003). Although the U.S. has no specific RVF contingency plan, there are guidelines for emergency management of mosquito-borne disease outbreaks (ASTHO 2008). The following section will discuss alternative disease management strategies suggested by the FAO and found in UNFAO Animal Health Manual, No. 15 and UNFAO Animal Health Manual, No. 17 (2003).

2.2.1 Vaccination for Livestock

The FAO states that preventive vaccination is the most effective means to control RVF. Currently there are two vaccines available for veterinary use, the live Smithburn vaccine and the inactivated vaccine. The live vaccine is highly immunogenic[1] and relatively inexpensive to produce, but has the drawbacks that it may cause pregnant females to abort or cause fetal abnormalities. Successive vaccinations may be needed every 3-5 years. Since this vaccine may cause pregnant females to abort, a value judgement would have to be made whether to include pregnant females even though some abortions and fetal abnormalities may occur.

The inactivated vaccine is quite safe for all animals, but has shown signs of being poorly immunogenic. It is recommended that after the first dose is given, a booster dose would be needed three to four months later, followed by an annual vaccine thereafter. Not only is the inactivated vaccine not as successful at producing the needed immunity in the animals as the live vaccine, it is also fairly expensive to produce (UNFAO Animal Health Manual, No. 15, 2003).

Currently efforts are underway to produce new and improved RVF vaccines, both for humans and animals. Some of these vaccines would contain “markers”, which make it possible to know through testing whether the animal has antibodies to a vaccine or 'wild-type' strain (UNFAO Animal Health Manual, No. 17). Hagerman (2009) in her study of Foot and Mouth disease (FMD) showed how the vaccines with bio-markers may

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[1] Having the ability to elicit a response in the immune system.

reduce welfare slaughter due to the fact that if vaccinated animals were distinguishable from unvaccinated animals, the value of bringing feed into a quarantined zone at a higher cost may beneficial. The rationale for this is the possibility of encountering higher costs from an increased number of slaughtered animals and disposal if feed were not able to be brought in. The same may be true for Rift Valley Fever. However, vaccination in outbreak areas is not recommended at this time, when there is evidence of high levels of RVF transmission by mosquitoes. Apart from vaccinating too late when the animals may already be infectious, needle propagation of the virus is a real danger. (UNFAO Animal Health Manual, No. 17 and UNFAO Animal Health Manual, No. 15).

2.2.2 Vector Control

Both FAO Health Manual No. 15 and No. 17 state that, at present, the options for vector control of RVF are limited. The best vector control strategy is larvicide treatment of potential mosquito breeding sites, however this process is still at the experimental stage. The most practical way of application is through burying larvicides in the mud of pans before flooding occurs[2]. Toxins derived from the bacterias *Bacillus thurigiensis* and *sphericus* as well as larval growth inhibitors, such as Methoprene, have been used experimentally and given excellent results. Methoprene is not as widely used as it once was, and presently Altocide is being used in replacement of Methoprene. Larvicide treatment is applicable where well-defined, discrete areas are expected to flood and where the likely floodwater area can be estimated (UNFAO 2003).

Mass insecticide spraying to control adults may be impractical and too costly, as well as environmentally unacceptable. Experts in Africa claim that this approach has not proven to be effective in controlling RVF outbreaks (OIE Regional Seminar Report, 2009). Also, when compared with larvicides, insecticides tend to be roughly ten times as expensive.

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[2] Pan is a term used in Africa to refer to dry lake beds.

One vector control strategy that has proven to be quite effective are "pour-ons". These are insect repellents that usually come in the form of a liquid, which is then applied directly to the animal. These can range in prices, but the low cost pour-ons have given favourable outcomes, showing this to be a cost-effective approach to preventing the spread of the disease. One downside to pour-on is the need for regular reapplication, which may or may not be practical depending on the production practices of the specified region. Other vector control strategies stated by the FAO include controlled burning and smoke (OIE Regional Seminar Report 2009).

2.2.3 Livestock Movement Control

Livestock movement control is another disease management strategy for RVF recommended by the FAO. It would restrict livestock movement into/out of the high-risk epizootic areas during periods of greatest virus activity, but might allow movement to an area where no potential vector species exists, such as high altitudes.

2.2.4 Sentinel Herd Monitoring

UNFAO Animal Health Manual, No. 17 states that sentinel herds are small herds located in high risk areas, such as near rivers, swamps, or damns when referring to RVF. Monitoring of these herds has been used in different parts of Africa as a disease control strategy to monitor viral circulation in susceptible populations. This strategy could be enhanced by the additional monitoring of climatic parameters and utilization of an early warning system (see section 2.2.5). When using this approach, no preventative measures should be taken among sentinel animals as this could affect the exposure of the animals to potential vectors. The manual also notes that in some cases, incentives can be put in place to encourage participation. An example is free anti-parasite drugs for human use.

2.2.5 Early Warning Systems

As stated by the WHO (2010) and as discussed in the section 2.2.4, early warning systems are comprised of timely surveillance systems that collect information and data on environmental and other conditions related to diseases associated with forecasts that conditions are favourable that they may become epidemic in order to trigger prompt public health interventions. According to the UNFAO (2003), taking advantage of early warning systems might be the most accurate and least costly mechanism to controlling RVF. Currently there are models that have proven to be effective in practice at predicting RVF virus activity up to five months in advance (Anyamba et al. 2009). These models usually combine remote sensing satellite data (RSSD) with surface sea temperatures (SST) and are readily available on a country and regional basis. Utilizing these systems would allow for ample time for preventative measure to take place in anticipation of an outbreak, such as preventative vaccination and mosquito larval control.

2.2.6 Veterinary Certificates

Veterinary certificates are a control strategy option for countries who import from regions where the disease is present[3], aiding to the regionalization[4] concept. Importing countries should require the presentation of these health certificates from the exporting country. Currently, the OIE is working on improving the quality of national veterinary services so that these certificates may become more reliable. Not all importing countries trust the certificates, perhaps because they are issued exclusively by veterinary services and under full responsibility of the exporting countries government. These certificates may also stand to benefit the exporting countries during times of disease

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[3] Veterinary certificates are certificates issued by a veterinarian relating to matters within the scope of veterinary medicine. These certificates are usually of soundness, freedom of products from diseased tissue, vaccination or surgical alteration.

[4] Regionalization allows consideration for importation of animals and animal products from specific areas or zones with in a country.

outbreak if the importing country recognizes and allows importation of animals with the presentation of the certificate (OIE Regional Seminar Report 2009).

2.3 A Brief Review of Relevant Disease Analyses

Here I review the literature regarding economic and select epidemic studies of RVF as well as other diseases. Although not much economic work has been published on RVF, there have been a few studies which look at the economic impact of a RVF outbreak. Studies on other diseases, such as FMD and WNV allow us to explore different techniques and methods to quantify the economic damages related to such outbreaks.

2.4 RVF Related Studies

While the literature on the economic impact of RVF is limited, there have been a few studies on the economic effects of RVF outbreaks in parts of Africa and the Arabian Peninsula. USAID conducted a study in which they examined the economic implications of the ban on livestock imports from Somaliland imposed in mid-September 2000 by the Kingdom of Saudi Arabia (KSA) and other states in the Arabian Peninsula. Their study found that Somaliland's traditional dependency on a single-sector and market has proven to have many adverse effects. Prior to the import ban, Somaliland's exported about 2.8 million head of livestock valued at $120 million. After the export ban (between September 2000 and November 2002) less than 0.5 million head were exported. The Somaliland shilling experienced a dramatic depreciation and local currency of imported commodities inflated. Decline in livestock prices and closing of markets was another outcome of the ban which resulted in millions of dollars in lost income (Holleman 2002).

The International Livestock Research Institute (ILRI) evaluated the costs of the 1998 and 2000 export ban by Saudi Arabia and other Gulf countries on livestock products from Ethiopia. Evaluation of a proposed program of live animal certification from a RVF non-free zone is also conducted using benefit-cost analysis. Results of the study find that the export ban had substantial damages to the Somali region of Ethiopia, with GDP being reduced by $91 million (roughly a 25% reduction in comparison to a normal year). In the short-run, the ban caused a sharp reduction of livestock prices, deteriorating pastoralist's input/output price ratio. The total loss in value added in the region was $132 million, or 42% of total value added produces in a normal year. Results also indicate that implementation of animal health programs is feasible and justifiable in the region, with an increase in taxes on livestock sales offering the best way to implement the health certification plan given that it has the proper redistribution effects.

Further ILRI studies were conducted on the 2006/2007 RVF outbreak in the Greater Horn of Africa specifically in Tanzania and Kenya. These studies attempted to assess the market and economic impacts of the outbreak and subsequent control measures on the livestock value chain, the local and national response capacity, costs and socio-economic impact in livestock, public health and private sectors (ILRI 2008). The study estimated that total loss of value due to death of animals was estimated to be kSh 45,566,030 in Garissa and KSh 154,918,459 in Ijala district (565,019 and 1.9 million US$ respectively) . Total domestic supply falls by 0.09% or Ksh 2.1 billion (26 million US$), with the bulk of the impacts felt in the livestock sector in terms of highest percentage change. The value of other crops fell by over 0.5%, possibly due to a lower demand for feed crops. Shocks to the tourism sector were relatively small on a percentage basis (less than 0.1%) but Ksh 28 million (347,200 US$) in absolute value terms. Value of poultry rose by 5%. Slaughterhouses and butchers value loss was estimated to be KSh 1,440,000 and 125,000 respectively (17,856 and 1,550 US$). The study also notes that the outbreak resulted in an increase in public awareness about the disease due to the extensive media campaigns put forth by the government, development agencies, and the media.

The potential for vectors of RVF in other areas of the world have been examined. Two such studies are those conducted by Turell et.al (2008) and Moutailer et. al. (2008)

The Turell et.al (2008) study observes the potential for North American mosquitoes to transmit RVF while the Moutailer et. al. (2008) focuses on the potential for mosquitoes collected in southern France and Tunisia to transmit RVF in the Mediterranean region. Both studies found that the vectors studied could transmit the virus.

The fate of mosquito borne diseases often comes into question when considering climate change. Many have speculated that higher global temperatures will enhance their transmission rates and extend their geographic ranges (Bourgarel et al. 2010). Reiter (2001) found, through studying the history of three such diseases; malaria, yellow fever, and dengue, that climate has rarely been the principal determinant of their prevalence or range. Rather, human activities and their impact on local ecology have been more significant factors.

2.4.1 Studies on Other Diseases

Although the literature on the economics of disease outbreaks is expanding, these studies tend to focus on diseases other than RVF, such as Bovine Spongiform Encephalopathy (BSE also known as Mad Cow disease) or Foot-and-Mouth disease (FMD). Review of these studies is used to help understand the mathematical procedures and economic approaches that have been used to model animal disease outbreaks and alternative disease management strategies. However, each animal disease is unique from the other; therefore, the epidemiological processes and models may be quite different. This section will cover a brief review of such studies, for a more general review, see Jin et al. (2009) and Hagerman et al. (2009).

Hagerman et al. (2009) conducted a study in which they simulated an FMD outbreak in the California dairy industry using the Davis Animal Disease Simulation model and the Agricultural Sector Model (ASM). A number of management alternatives were simulated and analyzed such as: early detection, late detection, vaccination, no vaccination, and welfare slaughter. The results found that early detection was always preferred to late detection, with early detection at 7 days showing median losses of $2.3

billion and late detection at 22 days showing median losses of $68.9 billion. Vaccination was shown to reduce the median number of animals slaughtered and put under movement restrictions; however, it also caused an increase in median losses to producers in the infected region. The study found that producers in some other, non-infected regions experienced gains as a result of national price changes.

Another study by Elbakidze et al. (2009) simulated an FMD outbreak in the Texas High Plains using the same method of integrated epidemic-economic modeling, but a different epidemic model. The AusSpread epidemic model was used along with the same ASM used in the California study, but did not include an international trade ban. Similar disease management strategies were simulated and analyzed as in the California FMD simulations. The study found on average, an outbreak might cost $500 million without trade losses. Early detection was most effective at reducing the length of the epidemic and number of heads slaughtered, but results in higher national welfare loss. The study found that enhanced surveillance may reduce the length of an epidemic and national welfare losses. Vaccination was shown to not be a cost effective mitigation option when trying to lower average cost, but may reduce risk of extreme outcomes.

The OECD conducted a study on the impacts of animal disease outbreaks. The objective of their study was to quantify costs related to trade bans on the beef and pork markets. Outbreaks were simulated for the United States, Canada, and the Netherlands. No epidemic model was used in the study and both the length and the duration of the waiting period (period between last outbreak and reclamation of disease free status) was based on historical evidence. Four disease management scenarios were examined: stamping out, vaccination to live, stamping out with regionalization, vaccination to live with regionalization. The duration of the epidemic was assumed to be 2 months, while the waiting periods were assumed to be 4.5 months and 7.5 months with stamping out and vaccination to live, respectively. Control strategies were assumed to not affect the duration of the epidemic and no assumptions were made on losses in production as a consequence of the disease itself or veterinary intervention. All quantities that would be exported under normal conditions were assumed to be diverted to the domestic market.

This OECD study used the Aglink-Cosimo model, an agricultural sector model which combines a partial equilibrium economic model of developed countries and a partial equilibrium model of developing countries. Aglink is a partial equilibrium sector model developed by the OECD which represents OECD countries (developed countries). The Cosimo model is also a partial equilibrium sector model developed by the FAO which represents a number of developing countries. A Global Trade Analysis Project (GTAP) general equilibrium model was also used to analyze global economic implications.

The quantities affected were calculated using the following equation:

$$q_1 = q_0(1 - t^*r^*\mu)$$

Here, q_1 represents the quantity of exports in the year of the outbreak, q_0 represents the initial quantity of exports, t is the time declared as infected expressed in percent of the year, r is equal to the share of the infected region in national meat exports and μ represents the share of the affected commodity in GTAP, which is equal to 1 in all Aglink-Cosimo simulations. Annual data is used to translate the trade ban into shares of one year, assuming trade flows are equally distributed over the year.

They chose the outbreak to occur in the state of Iowa under the rationale that in the year of their data, Iowa was the state with the largest share in export value of live animals and meat. The results indicate that no matter which strategy was chosen, the impacts on the pork market were always greater. This can be rationalized by the fact that pork has a greater export share than that of beef in the U.S. The vaccination to live strategy resulted in the highest amount of loss, which can be related to the assumption that the trade ban under this alternative is three months longer. The stamping out with regionalization resulted in the lowest loss. This can be explained by the assumption that under the regionalization strategies, the infected zone was assumed to be only that of Iowa with the rest of the U.S. declared free from FMD along with the assumption that trading partners accept the regionalization. This would imply that only 4% of beef exports and 28% of pork exports would be affected by the ban (OECD 2009).

2.5 Incorporating Human Damages

When estimating a country's human vulnerabilities to an epizootic disease outbreak, several items must be taken into account. Since RVF can infect humans, the economic consequences of the outbreak should reflect this. This could be done using one of the following methods:

- Cost of Illness (COI)
- Willingness-to-pay (WTP)
- Human Capital (HK)
- Daily Average Life Year (DALY)

The COI approach attempts to measure the sum of medical expenses, forgone earnings of affected individuals, and productivity losses to employers of affected individuals on paid sick leave. In an August 1996 report, the U.S. Department of Agriculture estimated the medical costs and productivity losses of six bacterial foodborne diseases using the COI approach. They estimated the annual cost-of-illness for these six foodborne illnesses at $2.9 billion to $6.7 billion.

The WTP method aims to estimate the value that individuals place on reductions in risk to identify the value to society of publicly provided risk reduction. As Viscuci (1993) demonstrates, one dominant approach to obtain estimates of this risk-dollar tradeoff is by using a hedonic wage equation with labor market data on worker wages for risky jobs to infer attitudes toward risk. This wage premium is the result of the interaction of labor demand by firms and labor supply decisions by workers. Providing greater workplace safety is costly to the firm; therefore, to maintain the same level of profits along some isoprofit curve, the firm must pay a lower wage rate to offset the cost of providing a safer work environment. The econometric task of the hedonic wage equation is to estimate the locus of these wage-risk tradeoffs for the entire market.

In the standard HK approach, it is assumed that the value to society of an individual's life is measured by future production potential, usually calculated as the present discounted value of expected labor earnings. Landefeld and Seskin (1982) provide an adjusted WTP/HK approach in which they produce adjusted HK estimates based on a WTP criterion. With this adjusted WTP/HK method, they find the value for males aged 40-44 to be $660,193 and females aged 40-44 to be $414,562.

Taken from the definition given by the WHO, Daily Adjusted Life Years (DALY) is a summary measure of population health to express epidemiological burden of diseases. One DALY can be thought of as one lost year of "healthy" life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability. DALYs for disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Year Lost due to Disability (YLD) for incident cases of the health condition. A study by Krishnamoorthy et al. (2009) estimated the burden due to suspected chikungunya, a vector-borne disease, in India during the 2006 epidemic using DALYs. Their study found that the national burden was estimated to be 25,588 DALYs lost, with an overall burden of 45.26 DALYs per million.

The Emerging Infectious Diseases Department of the CDC (EIDD-CDC) estimated the impacts of the 2002 West Nile Virus epidemic in Louisiana. Estimated total cost of the outbreak was calculated as the sum of 1) medical costs (inpatient and outpatient); 2) non medical costs (productivity loses, premature deaths, costs of transportation, childcare expenses); and 3) costs incurred by public health or government agencies for epidemic control. Medical costs were calculated using information received from Louisiana hospitals while non medical costs were calculated from information gathered by interviews using a questionnaire administered by telephone. The cost due to productivity losses attributable to illness and death were calculated using the human-capital (HK) method. Information obtain from the Louisiana Office of Public Health on costs incurred for laboratory support, epidemiologic aid, administrative and clerical activities, and communication services was used to calculate the cost for total epidemic control. The study found that the estimated total costs of the 2002 epidemic were $20.1 million (Zohrabian et al. 2004).

Prior to assessing the economic consequences of the disease outbreak on humans, we must have an idea of what the magnitude of infection to humans could possibly be. Since surveillance of RVF is not well documented, this study will utilize the data available from the 1999 outbreak of West Nile Virus infection in the U.S. By doing so, we assume that the two diseases have similar disease infection and spread rates.

3. BIOSECURITY AS AN ECONOMICS PROBLEM

When analyzing the potential economic impacts of a biosecurity threat such as RVF, several factors could potentially play a role in affecting the welfare of both producers and consumers, and therefore need to be considered in the analysis. Another term which is used interchangeably with welfare is surplus. A graphical representation of surplus can be seen in Figure 3. Consumer surplus is the area below the demand schedule and above the price line, and is depicted as CS. Producer surplus is the area above the supply schedule and below the price line, depicted as PS. As one can visualize, these areas are dependent on the supply and demand schedules. Shifts or rotations in these schedules can either increase or decrease the areas which represent the consumer and producer surplus. Examples of possible situations which may alter these values will be discussed further in the following sections.

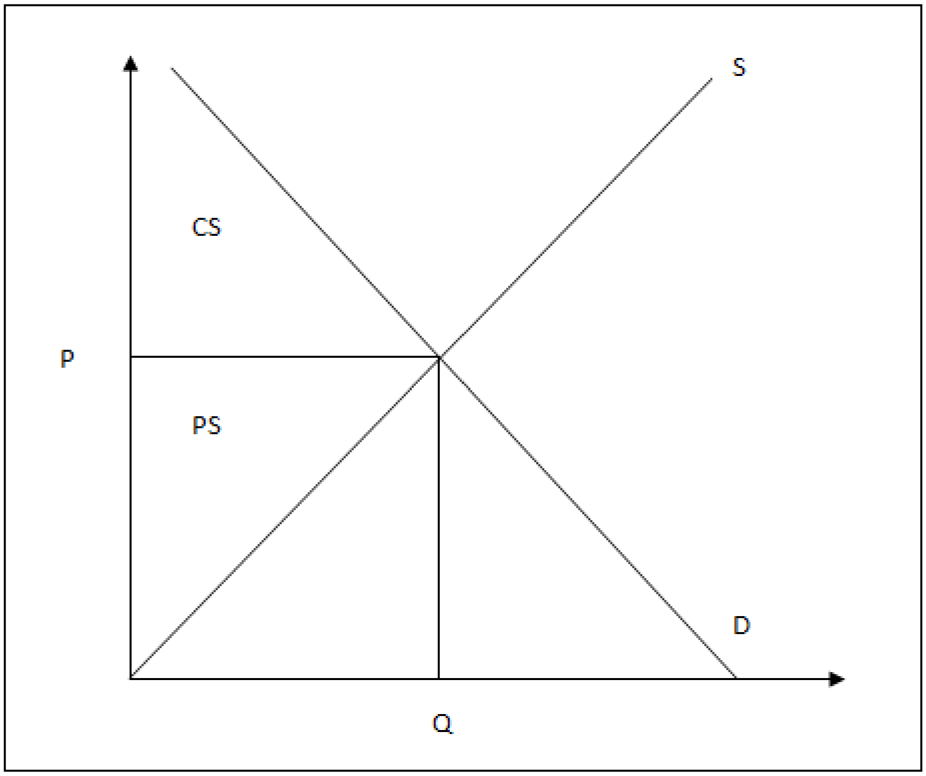

Figure 3. Graphical Display of Consumer and Producer Surplus

3.1 Market Damages

Market damages occur through a decrease in demand, altered supply, or through price changes. In the event of an animal disease outbreak, consumer confidence may be altered. This may result in a decrease in demand for the product directly affected by the disease as well as an increase in demand for substitutes of the product. Such evidence of events can be seen in Leeming and Turner (2004). The likelihood of consumer demand and confidence to alter in the event of a RVF is most likely to be high due to the vulnerability of infection when handling raw meat.

The supply chain could also be greatly impacted in the incidence of a disease outbreak, particularly when the supply alteration is large. Depending on the production loss, this could have a noticeable impact on the market supply. If supply is decreased enough to have an effect, this could cause an increase in prices. If demand is simultaneously decreased, then depending on the elasticities and magnitudes of the shifts, prices could increase, decrease, or stay the same. In the long run, domestic supply may be increased due to trade bans and inability to export, creating pressure and decreasing prices. Prices could also experience different changes along the supply chain, which may increase or decrease price margins.

3.2 Loss of Breeding Value

Farmers may invest their money in preserving the genetics of their livestock, which may reach back for several generations. The value of this loss in blood line may be very hard to estimate, but nevertheless should be considered.

3.3 Trade

Trade impacts tend to have significant impacts to economies when it comes to animal disease outbreaks. Import/export bans are usually put into place, which may vary in length depending on what actions were taken during disease management, such as vaccination. If regionalization was put into place, some regions may gain in welfare while others may lose welfare. Similarly, producers and consumers may be affected differently.

Hong (2009) found that trade related welfare losses in the beef markets due to animal disease outbreak is reduced by up to 40%. Attavanich et al. (2010) examined the effect that the initial swine flu label for H1N1 and associated press coverage had on US meat demand and found that domestic and international pork markets suffered. Results from the study show a drop in lean hog futures price which lasted around 3 months, causing a loss of $167.3 million.

3.4 Compensation

Farmers may receive indemnity payments in the case of a disease outbreak when animals are slaughtered due to disease control or for welfare reasons. Calculation of the value that the farmers should receive can be complicated. The price should be low enough to prevent individual farmers from over-reporting, transporting animals from areas from outside event zone, or manufacturing diseased animals. However, it should be high enough to prevent under-reporting or hiding potentially sick animals.

3.5 Related Markets, Local Economies, and Tourism

Markets such as tourism could face potential loss in the event of disease outbreaks. A prime example of this is the UK FMD outbreak in 2001 in which it was estimated that a large amount was lost due to tourism and other non farming communities (Bennett el al. 2002).

Another example of this is the case of swine flu outbreak in Mexico and its impacts on their economy (BBC 2010). Other related markets such as those that produce feed may also be affected due to a decrease in demand due to massive slaughter, causing an oversupply of feed.

Figure 4 was adapted from Hagerman (2009) and used a partial equilibrium model to show an example of possible outcomes from an animal disease outbreak on the cattle and meat markets. The U.S. is a net exporter of fed beef and a net importer of live cattle. Supply is shown to be inelastic to indicate the short run analysis. As depicted in the graphical model, a reduction in the short run supply of live cattle in the infected region reduces the national aggregate short run supply. This reduction from $S_{C\text{-}US}$ to $S'_{C\text{-}US}$ changes the excess demand from $ED_{C\text{-}W}$ to $ED'_{C\text{-}W}$, which in turn increases the price on the world market from p to p’ as can be seen in the bottom right panel.

Producers in the infected region will be affected both by a shift in the supply and shift in price. If the shift in price (T+U) is greater than the decrease in supply (U+W) they could gain. This is most likely not the case, price increase is usually not large enough to offset the supply reduction for producers in the infected region, and large producer surplus losses tend to occur. Producers in other regions, such as those depicted in the bottom left panel, face no shift in supply but do have an increase in prices, and therefore a gain in producer surplus.

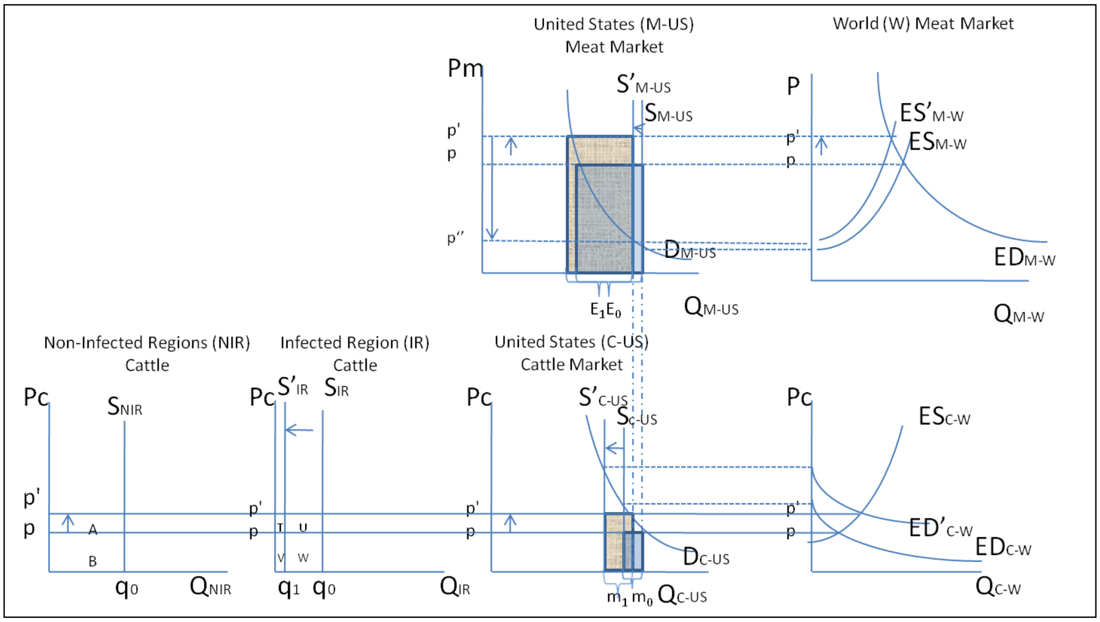

Figure 4. Regional Effects of a Disease Outbreak

If a trade ban were put into place and exports for fed beef must go to zero, the effect can be seen in the top left panel of Figure 4. Now the price is set by the domestic market and falls to p'', increasing consumer surplus, while producer surplus is decreased. If no trade ban is put in place, a decrease would still occur in the world markets excess supply from ES_{M-W} to ES'_{M-W}, increasing the price on the world market from p to p'.

A loss in market share is also possible in the event of a disease outbreak. Importing countries may look to other disease free countries to import from in an event of an outbreak in an exporting country. Market share could be temporarily and sometimes permanently lost in such cases if the importing country continues to import from the previously disease free country even after eradication and reclamation of disease free status.

In the case of RVF, it is a notifiable disease to the OIE and has consequent trade implications for those commodities of which could be affected by the disease. This study did not incorporate trade impacts into the model. For a more in depth overview of the impact to the trade in commodities, see OIE (2009). With trade implications not taken into account, a RVF outbreak would most likely mean an increase in imports of live cattle. Since RVF causes such a high abortion rate, the number of replacement cows needed would increase. In order to meet this increase in demand for replacement cows, other regions outside of the infected area in the US will either have to increase production, or it could be met with an increase in imports. Exports of fed beef would most likely decrease, unless there were also an increase in production in other areas which could meet the same pre-event demand levels.

4. METHODOLOGY

This study will employ a two part methodology to separately estimate livestock implications and human implications. A livestock related epidemic/economic analysis method will be used to analyze RVF vulnerability and the value of control strategies in the context of the U.S. agriculture sector. The human analysis method attempts to estimate the potential economic impact due to human illness and death.

4.1 Integrated Epidemic-Economic Modelling

Since we do not have data on actual outbreaks in the U.S., we must rely on models that simulate hypothetical outbreaks and then value the effects with an economic model. The specific models being used are a RVF epidemic model developed at Georgetown University (Gaff et al. 2007) and the Agricultural Sector Model (ASM) economic model developed at Texas A&M University (Adams et al. 2005). The epidemic model is a Monte Carlo simulation model for two populations of mosquito species, those that can transmit vertically and those that cannot, and for one livestock population. The ASM is a partial equilibrium agricultural sector model that endogenizes market prices as documented in Adams et al. 2005.

The epidemic model is used to simulate the spread of the animal disease under no intervention and certain control strategies, in this case larvicides and vaccination. The economic model then uses the simulated epidemic model outcomes to develop a distribution of disease impact. Partial equilibrium models, like ASM, utilize sets of supply and demand relationships which recognize interdependencies between markets in the U.S. Through this model, there is ability to assess the direct and secondary effects of an animal disease outbreak by including not only initial prices and quantities, but price shifts as demand varies. This study will not directly vary the demand curves. However, there may be a shift in quantity demanded as the price adjusts in response to the supply shift.

4.1.1 Epidemic Model

When using integrated modelling to assess the potential impacts of a disease outbreak, the epidemic model must be carefully chosen. There are a vast range of characteristics that an outbreak may hold which depend on several elements such as the disease, the environment, and the host. Since RVF is a vector borne disease that is sensitive to rainfall, the spread of the disease will differ from those diseases which are not vector borne, such as FMD, and the epidemic model should be able to reflect this.

The specific epidemic model used in this study is a compartmental ordinary differential equation model of RVF transmission developed by Gaff et al. (2007). The model considers two populations of mosquitoes and a population of livestock animals with disease-dependent mortality.

The two population of mosquitoes considered are the *Aedes* mosquitoes, which can be infected through either vertically or via a blood meal form and infectious host, and the *Culex* mosquito which is able to transmit the virus to hosts but not to their offspring. Once infectious, mosquito vectors remain infectious for the remainder of their lifespan. Hosts, which in this case represent various livestock animals and populations, can become infected when fed upon by infectious vectors. The livestock may then die or recover, having lifelong immunity to reinfection.

The host population can belong to one out of four stages: (1) a susceptible stage (S_i), where they are vulnerable to infection; (2) an incubating stage (E_i), where they are infected but are showing no signs of infection and are not yet infectious; (3) an infectious stage (I_i), where they are showing signs of infection and are able to spread the infection; and (4) a removed or recovered stage (R_2), where they are either removed due to death or slaughter, or they recover with an immunity to reinfection.

To reflect the vertical transmission in the *Aedes* species, compartments for uninfected (P_1) and infected (Q_1) eggs are included. The *Culex* species only includes uninfected (P_3) eggs. The adult mosquito population is $N_i = S_i + E_i + I_i$, for $i = 1$ and 3. The livestock population size is $N_2 = S_2 + E_2 + I_2 + R_2$.

The following equations are taken from Gaff et al. (2007) and represent the corresponding populations. Although this particular model is not used, the parameters are based off of the Gaff et al. (2007) model, except a Monte Carlo approach is used in order to get the stochasticity:

Aedes mosquito vectors

$$\frac{dP1}{dt} = b_1\,(N_1 - q_1I_1) - \theta_1P_1$$

$$\frac{dQ1}{dt} = b_1q_1I_1 - \theta_1Q_1$$

$$\frac{dS1}{dt} = \theta_1P_1 - d_1S_1 - \frac{\beta 21S1I2}{N2}$$

$$\frac{dE1}{dt} = -d_1E_1 + \frac{\beta 21S1I2}{N2} - \varepsilon_1E_1$$

$$\frac{dI1}{dt} = \theta_1Q_1 - d_1I_1 + \varepsilon_1E_1$$

$$\frac{dN1}{dt} = (b_1 - d_1)N_1$$

Livestock hosts

$$\frac{dS2}{dt} = b_1N_1 - \frac{d2S2N2}{K2} - \frac{\beta 12S2I2}{N1} - \frac{\beta 32S2I3}{N3}$$

$$\frac{dE2}{dt} = -\frac{d2E2N2}{K2} + \frac{\beta 12S2I1}{N1} - \frac{\beta 32S2I3}{N3} - \varepsilon_2E_2$$

$$\frac{dI2}{dt} = -\frac{d2I2N2}{K2} + \varepsilon_2E_2 - \gamma_2I_2 - \mu_2I_2$$

$$\frac{dR2}{dt} = -\frac{d2R2N2}{K2} + \gamma_2I_2$$

$$\frac{dN2}{dt} = N_2(b_2 - \frac{d2N2}{K2}) - \mu_2I_2$$

Culex mosquito vectors

$$\frac{dP3}{dt} = b_3N_3 - \theta_3P_3$$

$$\frac{dS3}{dt} = \theta_3P_3 - d_3S_3 - \frac{\beta 23S3I2}{N2}$$

$$\frac{dE3}{dt} = - d_3S_3 + \frac{\beta 23S3I2}{N2} - \varepsilon_3E_3$$

$$\frac{dI3}{dt} = - d_3I_3 + \varepsilon_3E_3$$

$$\frac{dN3}{dt} = (b_3 - d_3)N_3,$$

where:

β_{12} = adequate contact rate: *Aedes* to livestock

β_{21} = adequate contact rate: livestock to *Aedes*

β_{23} = adequate contact rate: livestock to *Culex*

β_{32} = adequate contact rate: *Culex* to livestock

$1/d_1$ = lifespan of *Aedes* mosquitoes

$1/d_2$ = lifespan of livestock animals

$1/d_3$ = lifespan of *Culex* mosquitoes

b_1 = number of *Aedes* eggs laid per day

b_2 = daily birth rate in livestock

$b3$ = number of *Culex* eggs laid per day

K_2 = carrying capacity of livestock

$1/\varepsilon_1$ = incubation period in *Aedes*

$1/\varepsilon_2$ = incubation period in livestock

$1/\varepsilon_3$ = incubation period in *Culex*

$1/\gamma_2$ = infectiousness period in livestock

μ_2 = RVF mortality rate in livestock

q_1 = transovarial transmission rate in *Aedes*

$1/\theta_1$ = development time of *Aedes*

$1/\theta_3$ = development time of *Culex.*

4.1.2 Economic Model

This study builds on a previous RVF study done by Hartley et al. (2009). The economic model used in this study is the ASM component of the Forest and Agricultural Sector Optimization Model (FASOM) which is a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States, originally developed to evaluate the welfare and market impacts of alternative policies and documented in Adams et al. (2005). The model depicts the allocation of land, over time, to competing activities in both the forest and agricultural sectors and is also designed to aid in the appraisal of a wider range of forest and agricultural sector policies. The modeling system of FASOM is designed to work on the forest and/or agricultural sectors either independently or simultaneously allowing for evaluation of independent sector issues, or across both sectors. This study examines only that of the agricultural sector.

The FASOM model is based on a joint, price-endogenous, market structure. Prices are endogenously determined given demand functions and supply processes. It simulates 36 primary crop and livestock commodities and 39 secondary commodities that compete for land, labor, and irrigation water at the regional level. Competition allows for simultaneous price determination in both sectors. Land use is capable of changing over time, and constraints on production possibilities can be relaxed, which is a valuable aspect when analyzing animal disease outbreaks which may become endemic.

Maximization of net present value of the sum of consumers' and producers' surplus for each sector allows the model to provide estimates of total welfare, as well as the distribution of welfare between producers and consumers.

The Agricultural Sector Model (ASM) of FASOM contains budgets for beef, dairy, hogs, sheep, broilers, turkeys, egg layers and horses, along with a number of intermediate budgets such as calves, milk, eggs, wool, and culled livestock.

ASM runs over 11 regions and 66 sub-regions. Results can be reported on either a sub-region or aggregated regional basis. The 66 sub-regions consist of one sub-region for each U.S. state except for California, Illinois, Indiana, Iowa, Ohio, Oregon, Oklahoma, Texas, and Washington. These states have sub-state production regions based on differences in production conditions.

FASOM also allows for trade with 37 international regions. Animal products which are imported to the U.S. are eggs, wool, non-fed beef, fed beef, pork, secondary dairy products, and some live cattle. The exports are eggs, fed beef, wool, pork, secondary dairy products, chicken, and turkey.

The market structure includes both explicit and implicit demand and supply curves in a five-year period which are solved such that the affected agricultural markets are in equilibrium. When conducting a comparative analysis with different control strategies for animal disease outbreaks, land is not allowed to shift to reach equilibrium. Supply changes in response to the slaughter will cause the shifts in prices. Such 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 export demand
- Regional or national import supply
- Regional feed supply and demand

- International transport perfectly elastic supply
- Country-specific excess demand and supply of rice, sorghum, corn, soybeans and the 5 types of wheat

This study analyzes the economic impacts of a disease outbreak of RVF in south and east Texas by adjusting the corresponding agricultural budgets. The limitation of the outbreak is confined to Texas, but state, regional, and national impacts will be evaluated.

5. CASE STUDY: RFV OUTBREAK IN SOUTHEAST TEXAS

This particular study simulates an outbreak of RVF in South and East Texas. The breakdown of the regions can be seen in Figure 5. This study uses data collected only from those counties in the Central Black Land, East Texas, South Texas and Coastal Bend regions to adjust the corresponding livestock and feed budgets as a result to disease outbreak.

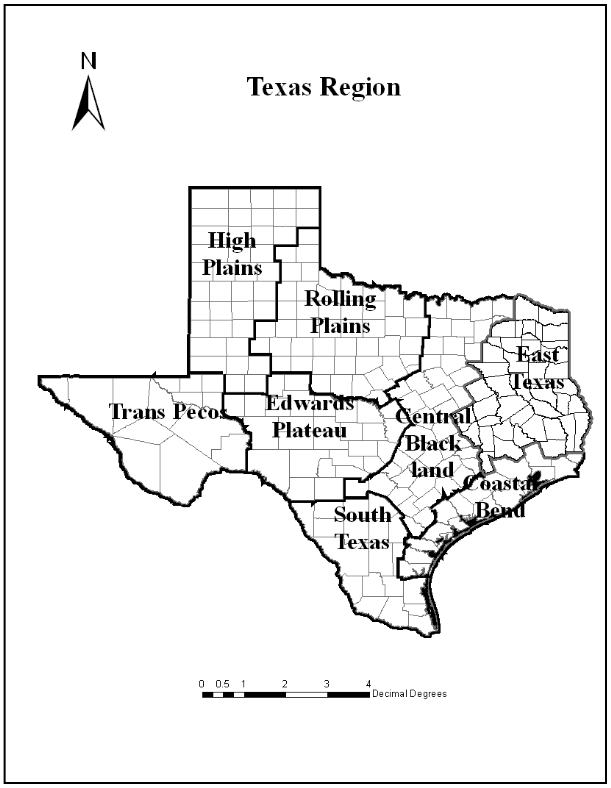

Figure 5. Breakdown of Texas Regions

When developing epidemic models, it is imperative to understand the environment in which an epidemic develops as well as the complex interrelationships of the relevant variables and their resulting behaviour (Ritchie-Dunham 1999). This particular region was chosen under the assumption that it is viewed as a highly vulnerable region to a RVF outbreak. This is due to several factors: 1) Environment of the region, 2) High livestock population along with high human population such as in the city of Houston, 3) High vector (mosquito) population.

Another decision that needs to be made is whether you want to model a onetime outbreak of the disease or model a disease outbreak that becomes endemic since model structure between the two different assumptions is very different. If the outbreak under consideration is assumed to be a onetime outbreak, sometimes referred to epizootic outbreak, then it is assumed that the outbreak occurs once and then is eradicated. If the disease is assumed to be endemic, meaning the outbreak occurs in time T and then another outbreak occurs in time T+1, and so on, then the economic results of investing in certain control strategies is very different. For example, some might argue that if the U.S. were to have taken certain measures to implement control strategies of West Nile Virus when it first broke out, then perhaps we would have been able to eradicate the disease, which is now endemic to the U.S. This study assumes a onetime outbreak of RVF.

Data for the number of cattle and herd size in Texas counties East of interstate highway 35 and South of interstate highway 10 was taken from the National Agricultural Statistics Service (NASS 2010). Data was taken from this area only as opposed to the whole state based on the assumption that if an outbreak were to occur in Texas, this area is more vulnerable. This is due to two reasons. First, the breeding sites of the vectors and vector population is increased in this area due to the geographic nature, such as the swampy areas of Houston and Beaumont, and the close proximity to the ocean and it's ports of entry. Second, this area has a high number of cow/calf and beef operations. This along with the prime conditions not only for the vector to live and propagate, but also to be introduced through one of the ports along the Texas coastline, puts this area at high risk of infection and spread of the disease. Each set of state data was plotted as a histogram and the resulting figure was used to fit (using maximum likelihood estimation) to a lognormal PDF[5]. For the number of counties possessing non-zero cattle inventory, random numbers were generated based on the fitted PDF to yield a simulated county cattle population. We assume the virus was introduced into randomly selected Texas counties. Furthermore, we model scenarios of different control strategies, in particular, we modeled the effect of no intervention, vaccination, larvicide, and vaccination and larvicide together.

The data from the epidemic model are then used to make a distribution of herd size which is randomly drawn from to obtain herd numbers used for the susceptible populations. In other words, we do not start the outbreak at a single point in real geographic space, but rather create a Texas-like region where the outbreak occurs. The random draws are done 10,000 times. From these 10,000 data points, a random sample of 1,000 is taken and then fed into the ASM.

A simple static estimation model is applied to the Texas-like region rather than using a spatially-explicit, dynamic mathematical epidemiology model for several reasons. First, since Rift Valley Fever is seen as a national security threat to the U.S., complications can arise when simulating an outbreak that may show the exact points of high vulnerability to the disease. Second, there are currently no validated dynamic models specific for RVF in the U.S. There are models that are in the process of being adapted to the U.S., however the only completed dynamic models for RVF are those that are specific for Africa, which cannot be geographically compared to the U.S. Finally, by creating a Texas-like region, the model is able to be generalized and therefore can be utilized and applied to a wider range of situations than if the model were to be built with a more specific geographical specification.

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[5] The lognormal was chosen arbitrarily. However, the basic properties of the lognormal function reflect the characteristics of the cattle inventory data, namely that a few counties have zero or very few cattle while some counties have extremely high populations of cattle.

5.1 Scenarios

This study analyzes the effects of a RVF under alternate control strategies. The following control strategies comprise of the four scenarios which were considered in the study:

- No intervention. We simulate the disease and let it run its course with no interruption.
- Vaccination of the herds. Specifically, 43.87% of the herd is vaccinated resulting in a 33% reduction in infection, death and abortion.
- Larvicide applied to the vector population. Specifically, we assume a 5% reduction in mosquito population in the populations.
- Vaccination and larvicide used together.

Adulticide was initially considered, and no simulations were performed due to the supporting evidence found in the literature indicating that adulticide is unlikely to be efficient and that it is an expensive method of vector control, most of the time only serving as a measure that provides piece of mind for the public (OIE, Boyce et al. 2007, Newton and Reiter 1992, and Speigal et al. 2005).

Only the larvicide reduction of the 5% scenario was run through the economic model. The reason for not using a higher percentage in reduction comes from evidence in the literature that a 50-70% or higher reduction in disease incidence is nearly unattainable. As Gu and Novak (2005) point out, to achieve this amount of effective larval intervention would call for implementation of targeted control efforts towards productive habitats. However, for targeted larval interventions, aquatic habitats need to be mapped and surveyed to estimate adult productivity along with quantification of habitat productivity based on sample data, e.g. larval density and surface size of habitats. In the event of a Rift Valley Fever outbreak, resources and systems such as these would have to already be in place, of which they are currently lacking in the US. Most larval control in the U.S. is untargeted, of which result in the 5% reduction (Gu and Novak 2005).

5.2 Interfacing the Models

To evaluate the economic costs of a potential outbreak and the use of alternative control strategies, output from the epidemic model will be used to feed into an economic model, in this case the ASM portion of the FASOM model. The epidemic model will give results of the simulated outbreak in terms of number of animals in each state (e.g. infected, dead, aborted) as well as number of animals receiving any intervention (e.g. vaccination). In order to make the output from the epidemic model be the input for the economic model, certain conversions of the data will need to be made in order to make appropriate adjustments. In the ASM model, the focus will be on reducing the production of outputs and increasing other costs. This action allows for an imitation of a disease shock in the region. Since budgets in the ASM are normalized to a one animal basis, the epidemic data in terms of head slaughtered, vaccinated, infected, etc., must also be normalized. This causes the impact of the outbreak to be spread evenly across the entire region such that the average productivity per animal in the region is reduced and the average cost of production per animal is increased. This increase in cost is associated with the costs of disease management such as vaccination, carcass disposal, and culling. This study also incorporates a decrease in feed requirement in the infected region as a result of loss of animals due to the outbreak. For a more in depth review of interfacing epidemic models with economic models, see Hagerman (2009).

5.3 Herd Inventory

The epidemic model focuses on the spread of the disease throughout the region. As stated in the previous section 5.2, the output will give a number of animals in each state, which is called the herd inventory. The herd inventory data are then used to adjust the corresponding livestock budgets in the ASM. The particular herd inventories given by the epidemic model in this study are categorized below:

- Young_Susceptible

- Adult_susceptible
- Pregnant_susceptile
- Young_Infected
- Young_dead
- Pregnant_Infected
- Pregnant_dead
- Abortions
- Adult_infected
- Adult_dead
- Young_vaccinated
- Pregnant_vaccinated
- Adult_vaccinated

These categories are aggregated in the ASM model as: (1) cow/calf and (2) dairy. The susceptible populations are those that are vulnerable to infection and death, this number is reduced under vaccination scenarios. Under vaccination we assume that 43.87% (arbitrarily chosen in the epidemic model from a range of 25%-75%) of each susceptible population is vaccinated resulting in a 33% reduction in infection, abortions and death.

5.4 Cost and Other Assumptions

The direct cost incurred as a result of an RVF outbreak is captured in our disease management cost estimates. Disease management cost is the number of animals infected times the cost per head of disease management. The disease management cost component consists of costs to clean and disinfect the premises plus the cost of surveillance. These costs are incurred under all scenarios. The vaccination scenario also incurs the cost to vaccinate. The larvicide scenario includes the costs of the larvicides. The costs are based on a schedule that varies by the size of the herd, and are adapted from Galli's (2009) cost estimates, adjusted for herd size specific to the regions in Texas for this study. All cost assumptions include cost of personnel, supplies, and equipment. The affected animals in the ASM were limited to cow/calf beef operations and dairy operations. Affected calves were limited to calves for slaughter, dairy calves, steer calves, and heifer calves.

- The cost of disposal for beef and dairy cattle were assumed to be a fixed cost of $50 each head.
- The cost of cleaning and disinfecting for beef and dairy cattle was assumed to be $37 and $23 per head, respectively.
- Vaccination costs for beef and dairy cattle were assumed to be $32 and $10 per head, respectively.
- Cost of surveillance the beef and dairy cattle were assumed to be $113 and $34 per head, respectively.
- Cost to apply larvicide at the 5% reduction rate was assumed to be $187 per head infected. We assumed a constant square mile coverage between 25-30 sq mi. To get this into a per-head cost we divided the total cost to treat this square mileage by the number of infected cattle under no intervention. Spreading the costs out over the number of all animals would not be justifiable and would understate the true cost.

Further assumptions were made regarding disposal and culling of infected animals. It was assumed that 100% of dead animals will be disposed of, while 50% of adult and pregnant infected animals will be disposed and 50% will be culled for disease management purposes. Seventy-five percent of young infected animals will be disposed of for disease management purposes. In beef operations, we assume the following: replacement heifers will be at weaning weight. The population of potential replacement heifers is reduced by abortions, young deaths and pregnant cow deaths as well as those young cattle that are culled or disposed of due to infection. Outside of the reduced replacements, cow/calf budgets also need to be reduced directly by adult deaths, young deaths, abortions, pregnant deaths, and infected animals that are culled or disposed of.

Dairy cattle are treated similarly. There will also be a reduced milk supply by abortions, young deaths, pregnant cow deaths as well as young cattle culled or disposed due to infection. Only those animals culled due to abortion are assumed to increase meat sale. Labor requirements are also decreased by .04 times the number of infected animals to better simulate the conditions under an outbreak. With less animals due to abortions, death and culling of infected animals, less labor hours would be needed due to smaller herd numbers.

All feed budgets will be decreased by the number of dead animals and infected animals that are culled or disposed of for disease management purposes, as previously discussed in section 5.2. The reason for this being simply that the demand for feed will be reduced due to a decrease in number of livestock; fewer animals will need to be fed and therefore less feed will be bought. This decrease in demand of feed in the infected region will result in an increase in the overall national supply of feed, which could lead to a change in price for the related feeds. The following list reflects all feed items that are directly adjusted in the ASM model:

- Silage - Fermented feed made from corn or sorghum plants for ruminants.
- Hay - Cut, baled and stored grass for livestock feeding.
- Soybean Meal - A soybean processing by-product used in animal feeding.
- DairyCon0 – A blend of grain concentrates for dairy operations.
- CowGrain0 – A blend of grains for cow calf operations.
- CowHighPro0 – Protein feed for cow calf operations.
- SaltMiner - Salt mineral supplements used in animal feeding.
- StockPro0 – A protein feed for stockers.
- WheatPastu - Wheat pasture used for grazing.
- CatGrain0 – A blend of grains for finishing cattle.
- HighProtCa – A protein feed for finishing cattle.

5.5 Human Valuation

To analyze the effect of a RVF outbreak on public health, we need to develop assumptions on the extent of the outbreak. However RVF has yet to be introduced into the U.S. and is currently confined to Africa and the Arabian Peninsula (AAP). Past surveillance and historical data on RVF is very limited. The way humans interact with climate and animals is different in the U.S. from that of the Arabian Peninsula and Africa. Livestock production in Africa and the Arabian Peninsula involves much more human-animal interaction than in the U.S. There exist nomadic farmers who migrate alongside their herds creating a very close interaction with the livestock. This provides greater exposure to mosquito vectors as well as direct contact. Slaughterhouse processes vary greatly between the countries as well. Slaughterhouses in the U.S. utilize a largely automated system and wear protective clothing including gloves and masks, minimizing direct human contact with the meat and blood. Carcass processing in Africa is still largely done wholly by human hands without the use of protective clothing, masks and gloves, which means more contact with animal products and blood. Recall, RVF transmission can occur from contact with the raw meat, blood, and organs of an infected animal. Another risk factor is aerosolization of virus from body fluids leading to infection. This creates different degrees of potential disease exposure. Therefore, using data from human illness in Africa and applying to U.S. may give improper estimates.

Given these diverse environmental, animal rearing and slaughtering aspects, and the unlikely event of RVF being introduced into the U.S. other than by mosquito-borne vectors, this study uses data from studies on the initial outbreak of 1999 West Nile Virus(WNV) to estimate the number of potential human infections. Infection rates from these studies along with initial land area coverage of the outbreak are then utilized to estimate the disease impact and distribution within the human population. Data from the CDC on costs of illness, deaths, and hospitalizations are then applied to the distribution in order to assess the economic costs. Specifically mapping data made available by nationalatlas.gov will be employed from 1999 along with the rate of infection for WNV given in Nash et al. 2001. The same distribution of outbreak numbers among the human population previously obtained from the WNV data is then used to estimate numbers of DALYs lost due to the outbreak. Then the calculation of the number of Disability Adjusted Life Years (DALYs) utilizes the cost figures given in Meltzer et al. (1999) to calculate a cost of illness. We assess these numbers for multiple stages of the outbreak, as the disease would progress and spread throughout the human population.

As stated by Melzter (2010), using a cost of illness metric to estimate potential impact of a disease outbreak is strongly recommended. Melzter also states that DALYs as a whole are not a particular good measure of impact of rare occurrences such as RVF, but rather that particular components that make up the DALY are typically of high importance to public health officials. This will be further explained in section 5.5.3.

5.5.1 Employing West Nile Virus Spread Data

WNV first originated in the U.S. in Queens county in 1999 and had spread to a total of 10 adjacent counties by 2000. We will apply this geographic spread rate to construct a possible initial outbreak of RVF. The outbreak is chosen to start in the Texas county of Brazoria. This area has the highest cattle population along the coastal region of Texas, which is viewed to be a high risk area for mosquito borne diseases such as RVF.

To construct this outbreak we followed 3 basic steps:

Step 1. We assembled the infection rates from Nash et al. (2001) which can be seen in Table 1 below.

Table 1. Infection Rate of WNV Per Million Population Adapted from Nash et al. 2001

Age	Rate of Infection per million pop
0-17	0.9
18-79	3.425
60+	30.8

Step 2. We assembled data on the population in 5 Texas coastal counties from the U.S. census bureau data and it can be seen in Table 2 below.

Table 2. U.S. Census Bureau Data on Human Population in Corresponding Texas Counties

	Age group 0-17		Age group 19-64		Age group 65+	
County	**Percent**	**Total**	**Percent**	**Total**	**Percent**	**Total**
Brazoria	36%	108,677	55%	164,671	9%	27,696
Galveston	33%	95,695	56%	161,702	11%	30,842
Matagorda	33%	12,633	52%	19,378	14%	5,254
Harris	37%	1,494,131	55%	2,175,455	8%	314,764
Fort Bend	35%	186,249	58%	310,770	7%	35,121
Wharton	34%	14,073	52%	21,007	14%	5,711

Step 3. We applied the infection rates to the population yielding the infected population of 24.4, which can be seen below in Table 3.

Table 3. Number of Estimated Infected Persons in Corresponding Texas Counties

	Age group 0-17	Age group 18-65	Age group 65+	Total
Brazoria	0.10	0.85	0.56	1.51
Galveston	0.09	0.95	0.55	1.58
Matagorda	0.01	0.16	0.07	0.23
Harris	1.34	9.69	7.45	18.49
Fort Bend	0.17	1.08	1.06	2.31
Wharton	0.01	0.18	0.07	0.26
Total	1.72	12.92	9.77	24.4

5.5.2 Cost of Illness

Disease outbreaks which infect both animals and humans can result in high economic damages. Meltzer et al. (1999) estimated what the economic impact would be for the U.S. if an influenza pandemic were to occur and found costs ranging from US$71.3 to $166.5 billion, excluding disruptions to commerce and society. Attavanich et al. (2010) looked at the effects of the 2009 H1N1 outbreak and its media coverage on consumer demand and agriculture markets and found that roughly $156.5 million was lost in market revenue for lean hogs alone.

Therefore, in order to grasp the full economic impact of a zoonotic disease such as RVF, efforts must be made to value the impacts to both animals and humans. In an attempt to do so, this study estimates a cost of illness to the U.S. if humans were to become infected with RVF.

To calculate the total cost of illness for the first year of a hypothetical outbreak, the number of hospitalized cases was rounded up to 25. The assumptions shown in Table 4 that were drawn from Meltzer et al. 1999, gives a breakdown of costs by disease outcomes and age groups for 1995 U.S.$ were then used. This study was chosen because it gives cost estimates for illness related to influenza, which is supposed to resemble the common side effects of RVF infection in humans (WHO 2010). The categorization of outcomes was as follows:

- Death
- Hospitalized
- Outpatient Visits
- Ill, no medical care sought

For this study, we use the rates of underreporting given by the CDC for influenza to better estimate total human vulnerability. Each reported hospitalized case represents 2.7 unreported hospitalized cases of which one percent results in death. Each case of infection also represents a certain number of illnesses that go unreported. Estimates were made under four different levels of underreporting of infection (non-hospitalized) cases:

- Each reported case represented 10 unreported cases.
- Each reported case represented 20 unreported cases.
- Each reported case represented 50 unreported cases.
- Each reported case represented 80 unreported cases.

The dollar cost for each case is finally achieved by using the estimated cost per case for each category and each age group which can be seen in Table 4 below.

Table 4. Values Used to Calculate Cost of Illness 2010 US$ Adapted from Meltzer 1999

		Age group	
	0-19	20-64	65+
Deaths			
avg. age	9	35	74
PV lost earning($)	1,016,101	1,037,673	65,837
hosp. cost($)	3,435+2,632	7,605+3,888	8,309+3,692
subtotal($)	1,019,536	1,045,278	74,146
Hospitalizations			
hosp. cost($)	2,936+2,099	6,016+2,086	6,856+3,200
net pay for outpatient visit($)	74±40	94±70	102±60
avg. copayment for outpatient($)	5	4	4
net payment for drug claims($)	26±9	42±30	41±10
days lost	5±2.7	8±4.8	10±5.4
value of 1 day lost($)	65	100	or
subtotal($)	3,366	6,842	7,653
Outpatient visits			
avg. no. visits	1.52	1.52	1.52
net payment per visit($)	49±13	38±12	50±16
avg. copayment for outpatient visit($)	5	4	4
net payment per prescription($)	25±18	36±27	36±22
avg. prescriptions per visit	0.9	1.8	1.4
avg. copayment per prescription($)	3	3	3
days lost	3	2	5
value 1 day lost($)	65	100	65
subtotal($)	300	330	458
Ill, no medical care sought			
Days lost	3	2	5
Value 1 day lost($)	65	100	65
over-the-counter drugs($)	2	2	2
subtotal($)	197	202	327

Costs are estimated for the following assumed reported hospitalized cases in Table 5:

Table 5. Reported and Unreported Hospitalized Cases

Reported	Unreported	Total
25	43	68
625	1,063	1,688
2,000	3,400	5,400
6,000	10,200	16,200

The reason these different scenarios are considered is due to the nature of vector born disease spread, and to shed light on the cost of future years if the disease were to become endemic. WNV reached a total of 9,862 reported cases in 2003, RVF is said to be more contagious than WNV and more deadly (CDC). However, it is still uncertain how species in the U.S. would react to infection and therefore this study calculates estimates for a range of severity rather than choosing one level.

5.5.3 Disability Adjusted Life Years (DALYs)

DALY is global measure of disease burden. One DALY can be thought of as one lost year of healthy life. It is calculated as the number of Years of Life Lost (YLL) plus the number of Years of Life lost due to Disability (YLD) as defined by WHO (2010). As previously stated, DALYs as a whole are not a particular good metric to use for estimating impacts of rare diseases such as RVF, rather the specific component of the YLL are typically of high importance to public health officials. Public health officials are generally concerned about "how many" and "who". In other words, they want to know how many deaths and what age group are most at stake.

$$\text{DALY} = \text{YLL} + \text{YLD}$$

where

YLL = N x L

N = Number of deaths

L = Life expectancy at age of death

YLD = I x DW x L

I = Number of incident cases

DW = Disability weight

L = Average duration of case until remission or death in years

Average life expectancy was taken from the data provided by the Internal Revenue Service (IRS). The average number of deaths and number of incidence cases were taken from our previous calculations used to estimate cost of illness. DALYs were calculated for the same number of different estimated cases as the cost of illness (25, 625, 2000, 3000, and 6,000). Since RVF does not have a unique disability weight, the disability weight for dengue fever and dengue hemorrhagic fever are used which are 0.197 and 0.545 respectively. Since the average duration of illness under RVF is 3-7 days (WHO) we used 5 days and divided by 365 to get on a scale of years.

6. RESULTS

This section will present the results. Detailed results for the integrated epidemic and economic modelling will first be presented. The cost of illness and DALY results will comprise the last part of this section.

6.1 Epidemic Model Results

The epidemic model yields results on animal losses by animal category and control scenario, which are used as input into the economic model. Summary statistics for the corresponding herd category under each scenario can be seen in Tables 6 through 9 below. Figure 6 gives a graphical demonstration of these results across the scenarios. The control scenario with the most infections, deaths, and abortions is the no intervention case, followed by the larvicide case. Using vaccination along with larvicide gives the smallest animal loss result, having less infection, abortions and death among the herd population. This would be expected under these scenarios as with no intervention there are no measures being taken to prevent or stop the disease from spreading. With vaccination and larvicide together, you would expect to have the least number of dead, infected, and aborted animals because you have both the vaccination of the animals and the larvicide acting to kill the vector of the disease, which should result in a decrease in the extent of animal damages.

Table 6. Summary Statistics for Number of Head Infected, Dead, or Aborted, for RVF Outbreak with No Intervention

	Mean	StDev	Min	Median	Max
young_infected	4061	3973	0	2711	23549
young_dead	2042	2406	0	1161	19802
abortions	26095	16257	1918	22770	123901
pregnant_dead	4121	2661	266	3538	20247
pregnant_infected	34753	20306	3317	31075	131316
adult_infected	38291	20108	4664	34732	132219
adult_dead	4210	2652	299	3637	20252

Table 7. Summary Statistics for Number of Head Infected, Dead, or Aborted, for RVF Outbreak with Vaccination

	Mean	StDev	Min	Median	Max
young_infected	2735	2676	0	1826	15859
young_dead	1375	1620	0	782	13336
abortions	17574	10948	1292	15335	83442
pregnant_dead	2775	1792	179	2383	13635
pregnant_infected	23404	13675	2234	20928	88436
adult_infected	25787	13542	3141	23390	89044
adult_dead	2835	1786	201	2449	13639

Table 8. Summary Statistics for Number of Head Infected, Dead, or Aborted, for RVF Outbreak with Larvicide

	Mean	StDev	Min	Median	Max
young_infected	3940	3855	0	2633	22487
young_dead	1981	2334	0	1128	19142
abortions	25314	15767	1837	22106	118808
pregnant_dead	3997	2581	254	3432	19379
pregnant_infected	33711	19693	3242	30178	127695
adult_infected	37144	19502	4559	33729	128574
adult_dead	4083	2572	287	3521	19384

Table 9. Summary Statistics for Number of Head Infected, Dead, or Aborted, for RVF Outbreak with Vaccination & Larvicide

	Mean	StDev	Min	Median	Max
young_infected	2653	2596	0	1774	15144
young_dead	1334	1572	0	760	12891
abortions	17048	10618	1237	14888	80012
pregnant_dead	2692	1738	171	2311	13051
pregnant_infected	22703	13262	2183	20324	85997
adult_infected	25015	13134	3070	22715	86589
adult_dead	2750	1732	193	2371	13054

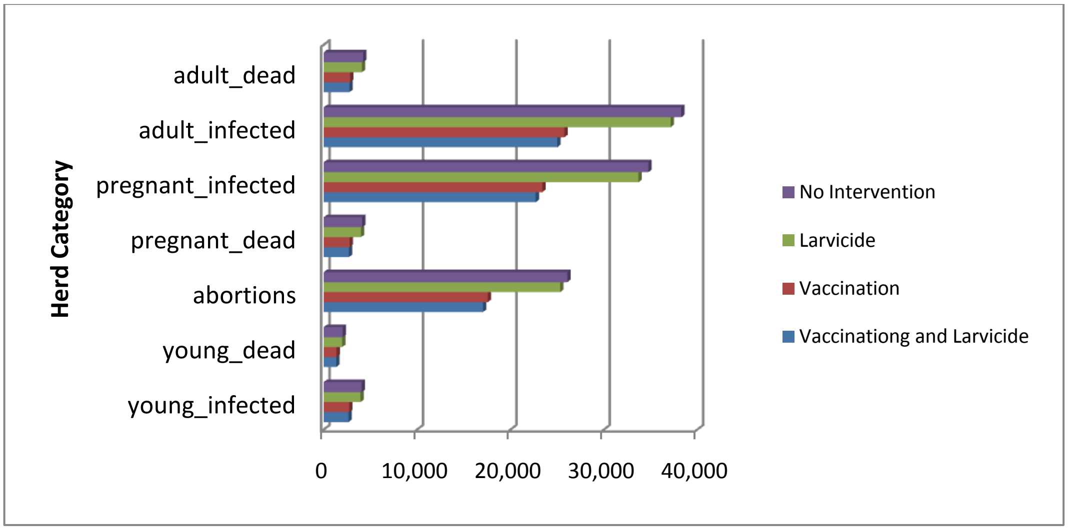

Figure 6. Epidemic Results

6.2 Economic Model Results

The epidemic model results were used to adjust the corresponding budgets in the ASM as previously discussed in section 5.2. This study restricts the outbreak to that of the South West and South Central region. Since this region contributes to the national supply of livestock, the effects of the outbreak could be felt throughout the nation. This section will display the results of national welfare loss, price changes, as well as total livestock producer welfare and regional producer welfare effects of a RVF outbreak.

6.2.1 Total Welfare Loss Under Alternative Control Strategies

The total welfare loss is a measure of societal loss due to the event on a national level. These results are presented in millions of 2004$ and can be seen in Table 10. The highest loss occurs under the larvicide scenario, however, the highest median loss occurs under the vaccination scenario, which also has a higher standard deviation than the other scenarios. Although the vaccination and larvicide scenario gives the least amount of infections, abortions, and deaths, it can be an expensive and risky control strategy. As the results indicate, there is a chance to experience a large gain in welfare under this scenario and the vaccination scenario, but there is also potential to experience large losses. The least economic damage occurs under the no intervention scenario. This shows the cost of the control strategies outweigh the benefit in terms of the value of reduced animal losses. Under the larvicide scenario, the increase in disease management cost per head of livestock is far greater than under the vaccination scenario, and therefore results show a much higher loss relative to the vaccination scenario.

Table 10. Total National Welfare Loss

	Million 2004 US$			
	No Intervention	Vaccination	Larvicide (5%)	Vaccination and Larvicide
Mean	-5.61	-9.42	-26.76	-16.23
StDev	17.00	19.94	5.06	16.82
Min	-37.40	-102.30	-46.30	-44.60
Median	-14.60	-11.75	-25.10	-23.70
Max	18.00	16.40	-15.80	25.80

6.2.2 Price Impacts

Price impacts have the potential to occur due to reduced supply as discussed in 3. This section will present the price effects of select commodities. Although Texas does not contribute much to the national supply of dairy cattle with roughly 4% of national dairy cattle inventory in 2007, it makes a noticeable contribution in terms of beef and cow/calf operations. Texas held around 14% of national inventory and 17% of the sales by cow/calf operations in 2007. Furthermore, it held roughly 20% share of both inventory and sales for beef cows in 2007 (USDA 2009). Any major decrease in this supply could impact national prices.

Table 11 shows the price changes for live cattle under the alternative scenarios. All prices are in constant 2004$ per unit. Most of the costs incurred from the disease outbreak are going to be attributed to disease management, such as vaccination and larvicide costs, as well as disposal cost which will also be felt under no intervention. This increase in cost for the producers is partially transferred to consumers by an increase in commodity price.

Since all culled animals were assumed to go into non-fed beef, the increased number of cull cows due to disease management did not have an effect on fed beef. The decrease in the number of beef calves and dairy calves due to death from disease, culling for disease management, and the decrease flow from heifer calves due to an increase in replacement needs, can cause these prices to increase.

Although the number of heifer calves and stocked heifer calves decreased in the infected region, there was an overall national increase in these numbers as well as an increased need for replacement heifers due to mature animal losses, which may contribute to the decrease in the prices. This increase may have been in response to the increase in replacement cows needed in the infected region to replace those livestock who either died, got infected, or were culled due to disease management.

Table 11. Mean Prices of Live Cattle Under Alternative Scenarios in $ Per Unit

Mean	Nonfed Slaughter	Feedlot Beef Slaughter	CullBeef Cow	CullDairy Cow	Steer Calve	Heifer Calves
Base	59.132	83.454	58.629	54.869	125.734	133.446
No Intervention	59.217	83.454	58.719	54.965	126.575	133.216
Vaccination	59.217	83.454	58.719	54.965	126.430	133.240
Larvicide (5%)	59.218	83.454	58.719	54.965	126.575	133.232
Vaccination and Larvicide	59.217	83.454	58.719	54.965	126.572	133.231
Mean	**Stocked HCalf**	**Stocked SCalf**	**Dairy Calves**	**Stocked Yearling**	**StockedH Yearl**	**StockedS Yearl**
Base	110.076	103.568	117.226	91.113	96.753	96.171
No Intervention	108.093	103.648	119.051	93.965	95.956	96.257
Vaccination	109.982	103.705	118.666	95.281	95.923	96.257
Larvicide (5%)	110.509	103.687	118.803	95.630	94.254	96.257
Vaccination and Larvicide	112.038	103.695	118.968	95.858	96.834	96.257

As previously stated, pork and poultry are seen as substitutes for beef. Therefore, changes in beef could impact these commodities. Production for eggs and broilers did not increase, however the price of some inputs fell, which can explain the slight decrease in price for eggs and broilers. The result for price impacts for eggs and live poultry can be seen in Table 12, while those for beef, pork, and poultry can be seen in Table 13 below.

Table 12. Price Impacts for Eggs and Live Poultry

	Eggs	Broilers	Turkeys
Base	0.893	50.780	45.535
No Intervention	0.875	50.440	45.505
Vaccination	0.875	50.514	45.433
Larvicide (5%)	0.875	50.439	45.450
Vaccination and Larvicide	0.875	50.514	45.520

Table 13. Price Impacts for Beef, Pork, and Poultry

	FedBeef	NonFedBeef	Pork	Chicken	Turkey
Base	113.079	72.813	67.442	69.202	68.307
No Intervention	113.079	72.950	67.662	68.777	68.263
Vaccination	113.079	72.950	67.326	68.869	68.162
Larvicide (5%)	113.079	72.950	67.318	68.776	68.186
Vaccination and Larvicide	113.079	72.950	67.346	68.869	68.285

Dairy prices could also be affected due to any price impacts that may occur to dairy cows. The infected region however does not have a significant contribution to the dairy sector, and therefore may not have a significant impact on the prices. Results for price impacts on dairy products can be seen in Table 14.

Table 14. Price Impacts for Dairy Products

	NonFatDry Milk	Butter	AmCheese	OtCheese	Cottage Cheese	IceCream
Base	1.475	2.026	2.208	1.989	1.583	1.721
No Intervention	1.475	2.026	2.208	1.989	1.583	1.721
Vaccination	1.475	2.024	2.207	1.988	1.583	1.720
Larvicide (5%)	1.476	2.017	2.204	1.986	1.582	1.714
Vaccination and Larvicide	1.476	2.013	2.203	1.985	1.582	1.711
	Milk	FluidMilk whole	FluidMilk LowFat	Skim Milk	Cream	EvapCondMilk
Base	15.636	0.377	0.246	0.167	0.737	0.332
No Intervention	15.637	0.377	0.246	0.167	0.737	0.332
Vaccination	15.631	0.377	0.246	0.167	0.737	0.332
Larvicide (5%)	15.606	0.376	0.245	0.167	0.734	0.331
Vaccination and Larvicide	15.595	0.376	0.245	0.167	0.732	0.331

Since there is a decrease in the feed requirement in the infected region due to a decrease in number of animals needing to be fed, prices of feed could be impacted. Since less feed is needed, this would cause an oversupply of feed and hence a decrease in its price. However, if feed production is also reduced, and livestock production in other regions increased to take advantage of higher livestock prices, this could cause the feed price to increase. This could happen when the dairy calf production increase is not more than offsetting the death loss. Price impacts for feed and feed grains can be seen in Table 15 below.

Table 15. Price Impacts for Feed and Feed Grain

	Soybean Meal	Silage	Hay	Dairy Con0	Cow Grain0
Base	200.417	24.981	108.419	10.777	6.200
No Intervention	200.417	24.983	108.426	10.865	6.200
Vaccination	200.417	24.982	108.427	10.862	6.200
Larvicide (5%)	200.417	24.980	108.421	10.844	6.200
Vaccination and Larvicide	200.417	24.983	108.429	10.865	6.200
	CowHiPro0	**StockPro0**	**CatGrain0**	**HighProt Ca**	
Base	11.819	11.355	6.343	12.310	
No Intervention	11.817	11.674	6.344	12.309	
Vaccination	11.817	11.689	6.343	12.309	
Larvicide (5%)	11.812	11.654	6.343	12.306	
Vaccination and Larvicide	11.790	11.634	6.344	12.292	

6.2.3 Total Regional Livestock Producer Surplus Impacts

The economic model also breaks down the U.S. into 10 different regions, which can be seen in Figure 7 below. With the U.S. livestock industry being concentrated in certain regions, such as the dairy region in California, impacts of an animal disease outbreak will most likely have stronger impacts on some regions rather than others. This section will display impacts specific to the livestock producers for each region. All results are in millions of 2004$.

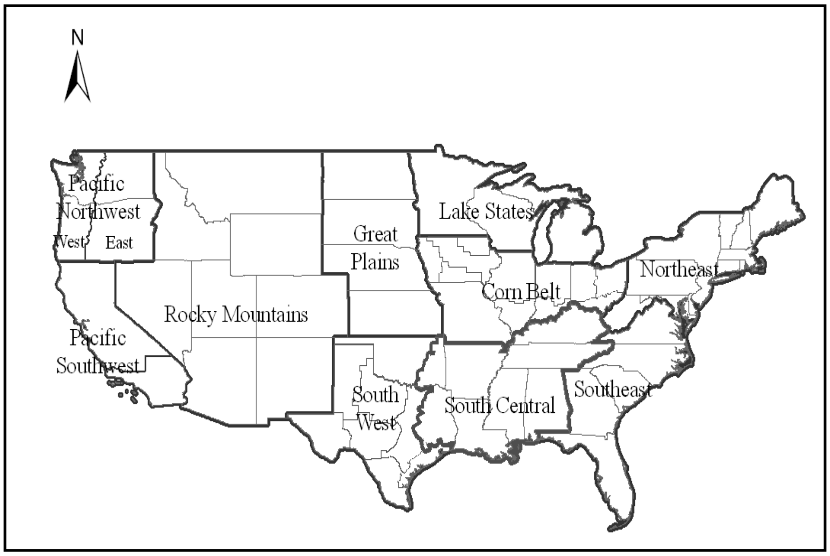

Figure 7. Regions in ASM Model

Total national livestock producer surplus impacts under the alternative interventions can be seen in Table 16 below. The lowest impact for livestock producers is under the no intervention scenario, which can be attributed to the same reason as those discussed under section 6.2.1. Again, it should be noted that there is a higher median loss as well as variation in loss when using vaccination and larvicide together.

Table 16. Total National Livestock Producer Surplus Impact under Alternative Scenarios

Million 2004 US$				
	No Intervention	Vaccination	Larvicide	Vaccination and Larvicide
Mean	-171	-210.584	-302.77	-251.64
StDev	75.74	90.79	58.21	126.55
Min	-321.27	-391	-406.83	-366.77
Median	-142.01	-223.59	-256.12	-268.18
Max	-96.34	124.96	-138.58	171.85

6.2.4 Regional Producer Surplus Impacts

While there is an overall loss in welfare with each scenario, results indicate that under some conditions, producers in regions outside of the outbreak can stand to gain from due to price increases. Results for regional producer (both crop and livestock producers) surplus impacts under no intervention can be seen in Table 17 below. As would be expected, the two regions with the higher damages are South Central (SC) and South West (SW), where the outbreak occurred. The South East (SE) region experiences high losses as well. This region is high in the production of broilers and other meat-type chickens, which experienced a decrease in price which would cause the welfare of the producers in this region to fall. Other regions such as the Great Plains (GP), Rocky Mountains (RM) and Pacific South West (PSW) gain. This could be attributed to the increase in prices along with these regions, especially GP, having the highest production in cow/calf and beef calves. With the inputs to these animals not increasing much if at all while the output price increases, along with these regions not having to undergo the costs of disease management related to the outbreak, allows for a large increase in producer surplus. Other regions that lose are the Corn Belt (CB) and the Lake States (LS). This loss can be attributed to the fact that these are dairy producing regions and the prices of inputs (feed and dairy calves) are going up while the output price (milk) is going down, causing a loss. Regional price impacts under vaccination, larvicide and vaccination and larvicide together can be seen in Tables 18 through 20, respectively.

Table 17. Regional Producer Surplus Impact Under No Intervention

Million 2004 US$

	CB	GP	LS	NE	RM
Mean	-11.619	24.720	-11.314	2.062	-3.476
StDev	23.203	19.023	16.882	4.230	3.709
Min	-54.429	-7.082	-45.204	-6.992	-8.921
Median	0.308	36.910	-0.848	0.222	-2.452
Max	9.188	40.757	1.494	8.085	7.724
	PSW	**PNWE**	**SC**	**SE**	**SW**
Mean	0.748	-4.187	-96.039	-45.649	-23.317
StDev	0.825	1.136	6.389	9.770	2.437
Min	-1.729	-6.165	-110.211	-65.508	-27.174
Median	0.537	-3.996	-93.927	-40.862	-22.147
Max	1.850	-2.691	-89.309	-37.635	-18.884

CB stands for Corn Belt, GP stands for Great Plains, LS stands for Lake States, NE stands for Northeast, RM stands for Rocky Mountains, PSW stands for Pacific Southwest, PNWE stands for Pacific Northwest West East, SC stands for South Central, SE stands for Southeast, and SW stands for South West.

Table 18. Regional Producer Surplus Impact Under Vaccination

Million 2004 US$

	CB	GP	LS	NE	RM
Mean	-34.777	8.187	-27.510	-0.056	3.941
StDev	7.364	6.169	17.878	4.429	6.615
Min	-54.682	-12.379	-83.497	-19.753	-14.745
Median	-34.605	9.836	-21.541	-1.654	3.581
Max	8.683	40.006	-2.779	6.694	12.241
	PSW	**PNWE**	**SC**	**SE**	**SW**
Mean	0.728	-3.907	-84.643	-50.891	-19.412
StDev	1.198	1.977	51.518	17.287	4.873
Min	-3.815	-10.128	-112.493	-66.851	-32.913
Median	0.111	-3.453	-101.015	-55.665	-21.518
Max	2.686	-1.309	74.832	11.907	-9.495

CB stands for Corn Belt, GP stands for Great Plains, LS stands for Lake States, NE stands for Northeast, RM stands for Rocky Mountains, PSW stands for Pacific Southwest, PNWE stands for Pacific Northwest West East, SC stands for South Central, SE stands for Southeast, and SW stands for South West.

Table 19. Regional Producer Surplus Impacts Under Larvicide

Million 2004 US$					
	CB	GP	LS	NE	RM
Mean	-41.459	0.192	-52.212	-3.995	-10.741
StDev	6.972	6.877	26.988	1.655	6.496
Min	-57.903	-13.478	-83.627	-9.460	-19.379
Median	-39.097	0.273	-56.197	-4.070	-12.292
Max	-3.181	37.074	-2.327	-1.241	3.229
	PSW	PNWE	SC	SE	SW
Mean	-0.342	-7.633	-104.916	-59.192	-26.990
StDev	0.484	2.439	3.350	5.144	1.858
Min	-1.872	-11.164	-112.974	-68.452	-31.193
Median	-0.202	-8.740	-104.311	-57.272	-27.182
Max	0.432	-3.602	-95.788	-41.520	-22.051

CB stands for Corn Belt, GP stands for Great Plains, LS stands for Lake States, NE stands for Northeast, RM stands for Rocky Mountains, PSW stands for Pacific Southwest, PNWE stands for Pacific Northwest West East, SC stands for South Central, SE stands for Southeast, and SW stands for South West.

Table 20. Regional Producer Surplus Impacts Under Vaccination and Larvicide

Million 2004 US$					
	CB	GP	LS	NE	RM
Mean	-36.633	7.193	-51.027	-1.949	-4.367
StDev	6.765	4.218	28.135	2.282	7.077
Min	-46.433	-1.680	-78.672	-13.294	-17.897
Median	-38.473	6.690	-68.758	-1.752	-6.229
Max	13.610	46.820	23.435	1.587	6.792
	PSW	PNWE	SC	SE	SW
Mean	0.587	-6.581	-81.001	-51.406	-22.405
StDev	1.014	2.546	59.388	22.863	5.539
Min	-2.998	-10.640	-109.469	-64.183	-31.193
Median	0.177	-7.791	-102.172	-61.473	-23.001
Max	2.143	-1.704	81.946	20.532	-7.859

CB stands for Corn Belt, GP stands for Great Plains, LS stands for Lake States, NE stands for Northeast, RM stands for Rocky Mountains, PSW stands for Pacific Southwest, PNWE stands for Pacific Northwest West East, SC stands for South Central, SE stands for Southeast, and SW stands for South West.

Figure 8 below shows a graphical representation of the total national welfare loss (as seen in Table 10) in billions of 2004$ under each control strategy that the study analyzed. As can be seen, not much difference resides between the two scenarios with the most damages, vaccination and vaccination and larvicide together. The least damages occur the no intervention scenario, showing that the cost of investing in vaccination and larvicide for exceeds the benefit of reducing the number of infections and deaths in the livestock.

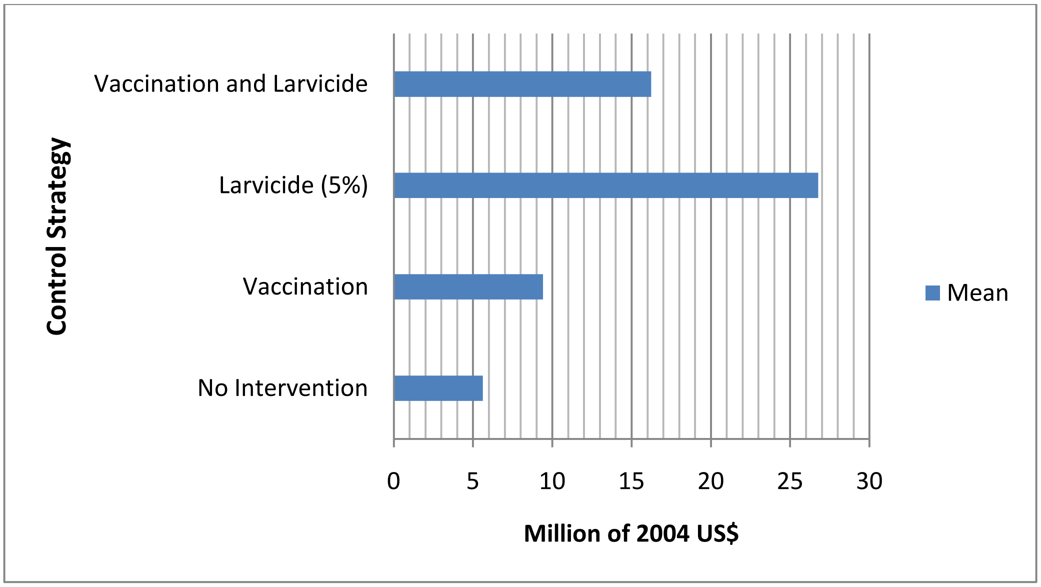

Figure 8. Graphical Representation of Total National Welfare Loss

6.3 Cost of Illness Results

In year one, with 25 reported cases, the costs of illness accounting for underreporting where one reported case equals either, 10, 20, 50, or 80 unreported cases can be seen in Table 21 and graphically in Figure 9 below.

Table 21. Cost of Illness for Year One of Outbreak

Reported cases to unreported cases	Dollars
1 to 10	$ 4.47
1 to 20	$ 5.14
1 to 50	$ 7.15
1 to 80	$ 9.16

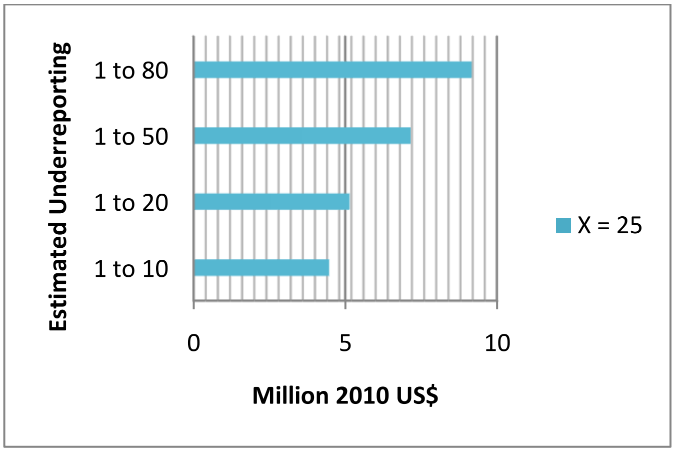

Figure 9. Cost of Illness for Year One

This study also calculated the cost of illness as the disease would progress among the human population and have a number of reported cases equal to either 625, 2000, 3000, or 6000 cases. The results can be seen in Table 22 and Figure 10 below.

Table 22. Cost of Illness as Disease Progresses in Million $

	Cases			
	625	**2000**	**3000**	**6000**
1 to 10	$ 114.50	$ 366.41	$ 549.62	$ 1,099.23
1 to 20	$ 131.66	$ 421.31	$ 631.96	$ 1,263.92
1 to 50	$ 183.12	$ 409.79	$ 878.99	$ 1,757.99
1 to 80	$ 234.59	$ 750.69	$ 1,126.03	$ 2,252.06

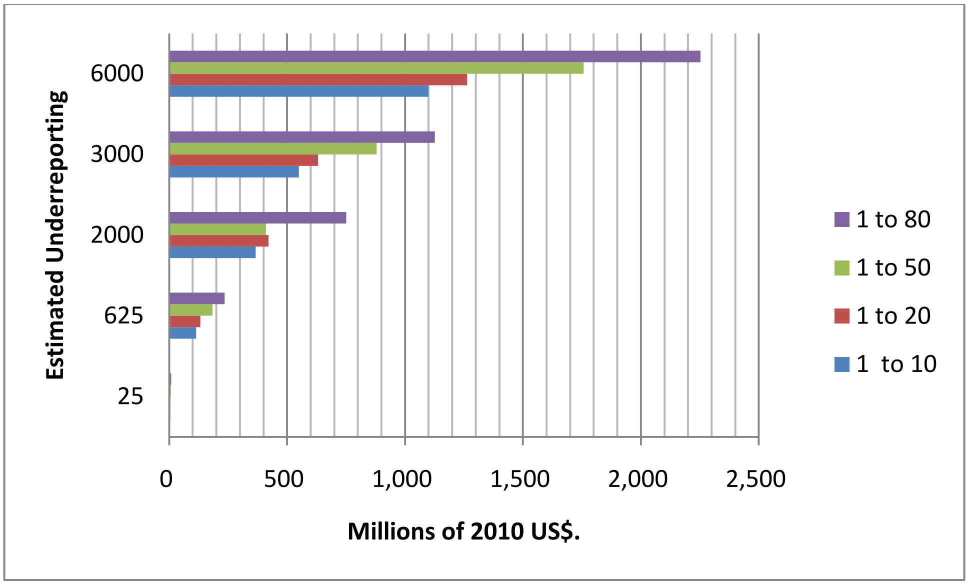

Figure 10. Cost of Illness as Disease Spreads

If RVF were to be introduced into the U.S. and follow the path of WNV, which reached over 9,000 reported cases in 2003, economic damages can be expected to be in the billions. As can be seen from the tables above, with either a low estimate of cases (1 reported case representing 10 unreported) or a high estimate of cases (1 reported case representing 80 unreported cases), damages will be in the billions. The results for the reported cases of 6,000 with a low estimate of total cases shows a total cost of $1.1 billion while the high estimate shows a total cost of $2.3 billion.

6.4 Disability Adjusted Life Years Results

The results from the Disability Adjusted Life Years (DALYs) can be seen in Table 23 and Figure 11 below. As would be expected, the DALYs increase as number of cases increase. With a number of reported cases equal to 25, the total number of DALYs lost is 297. As this number increases, or as the virus spreads throughout the country to a number of reported cases equal to 6000, the total number of DALYs lost is equal to 71,216.

Table 23. DALY Results

Number of Cases	DALY
25	297
625	7418
2000	23739
6000	71216

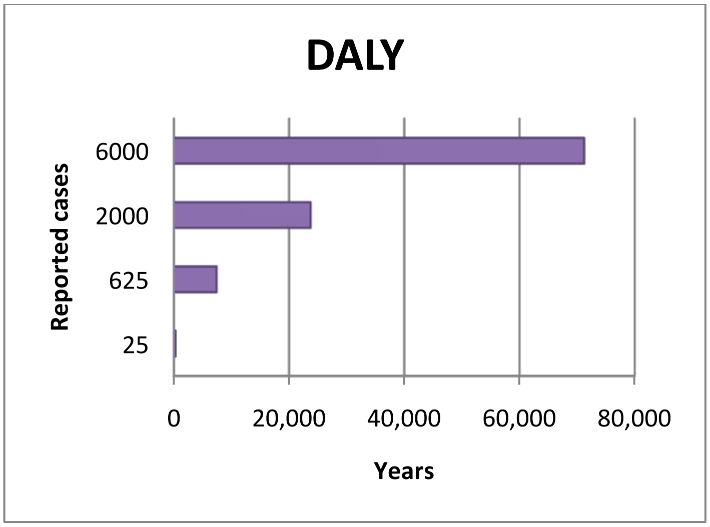

Figure 11. Disability Adjusted Life Years (DALYs)

As stated by Meltzer (2010), one of the more important components of a DALY is the YLL value, the value that shows how many deaths and to which age group they belong. Another important factor when dealing with public health issues and disease outbreak is who is going to get sick and how many. Seeing as how this is so, Table 24 gives a breakdown of the number of hospitalizations, sick, dead, YLL, and YLD for the given three age groups (under 18, between 18 and 65, and 65+). As the table shows, those aged between 18 and 65 have the most cases of hospitalization, sickness, and deaths. The most YLL occurs for those under age 18, seeing as how the younger population would have a greater number of life expectancy, with more to lose in this parameter.

Table 24. Breakdown of Case Severity and YLL by Age Group

Number of Cases = 25	Hospitalized	Sick	Dead	YLD	YLL
under 18	24	6,305	0.876	17	129
18< x <65	37	9,819	1.364	27	115
above 65	7	1,876	0.261	5	4
Number of Cases = 625					
under 18	591	157,635	22	427	3231
18< x <65	921	245,475	34	666	2863
above 65	176	46,890	7	127	105
Number of Cases = 2000					
under 18	1,892	504,432	70	1368	10338
18< x <65	2,946	785,520	109	2130	9160
above 65	563	150,048	21	407	336
Number of Cases = 6000					
under 18	5,675	1,513,296	210	4103	31014
18< x <65	8,837	2,356,560	327	6389	27481
above 65	1,688	450,144	63	1220	1009

7. CONCLUDING COMMENTS

Zoonotic disease outbreaks can cause economic losses. This study developed information on the potential livestock and human vulnerability to RVF by assessing economic consequences. In addition, the economic implications of using a number of control strategies for RVF are examined, which have the potential for reducing the magnitude of impact on livestock populations. The results provide information relevant to decisions regarding the prevention or response to a RVF epidemic.

As the results show, the number of infected, aborted, and dead animals is best controlled by coupling vaccination along with larvicide, but results in the second highest median national welfare loss. Therefore, depending on what the goals are for policy makers, careful decisions must be made as to what actions should be taken. If the ultimate goal is to reduce infections, abortions and deaths in the livestock population, then vaccination along with larvicide is the best answer. However, if the goal is to reduce economic impact, then the best answer is to let the disease proceed without significant intervention.

Total national producer welfare is reduced with each scenario, and is more severe than the total national welfare loss (producer, consumer, and processor together). Consumer welfare is increased with each scenario due to a drop in prices of some commodities, and in some instances, an increase in supply as well. The majority of the national welfare loss can be attributed to the producers' and processors' loss in welfare. The highest damages are seen in the regions of the outbreak such as the South Central (SC). Other regions such as the Corn Belt, Lake States, and South East regions also see high damages due to price changes. The outbreak did not have substantial price effect on dairy products, but did have noticeable price changes for live cattle such as heifer calves, stocked yearling, and dairy calves. Prices for substitutes such as pork, chicken, and turkey experienced a price reduction, which can also be a factor resulting in consumer welfare gains.

It must be noted that these control strategies did not incorporate effects on human illness and death. Further research could be done on estimating the human infection implications with each of these control strategies, which would most likely change the cost-benefit analysis.

This study does however shed light on the potential impact to the public health sector as humans may become infected if an outbreak of RVF were to occur in the U.S. This cost along with the economic loss of the agriculture sector suggests substantial potential losses to the U.S. if this hypothetical situation were to become reality. Combining total loss estimates from the cost of illness and ASM models, potential damage of a RVF outbreak could range from 121 million to 2.3 billion US 2010$. The results of this study show the economic damages of an outbreak in the livestock population being much greater relative to the outbreak in the human population (roughly 16 times greater). It should be pointed out that both cost estimates are most likely under estimated. The animal outbreak is not incorporating all susceptible livestock (e.g. hogs and goats), and the human illness is not incorporating other damages to society (e.g. damages due to loss of tourism).

Results indicate that the age group most affected by an outbreak would be those aged 18-65. Again, this is based on the infection rates from a WNV outbreak in a human population with high density and applied to an area with roughly half the population density, but with a higher livestock population, and therefore further research could also be done with a more accurate infection rate corresponding to each age group for RVF and for the accurate geographic area.

With potential costs above $2 billion for human illness, and with this number not accounting for loss or damages to other sectors of the economy, it can be highly probable that investing in a human vaccination campaign can be cost-effective and possibly cost-reducing. Needless-to-say, this study would ideally be done with an integrated epidemic/economic model that includes both livestock and human targets, all livestock populations which are susceptible not just cattle, as well as control strategies for both public health and agriculture sectors. This research was limited due to a lack of completely accurate data on what the disease would actually do and how both livestock and human population would respond to a RVF outbreak in the U.S.

Future follow up research could incorporate international trade issues. Trade bans which are put into place under disease outbreaks can have a major impact and should be taken into account. Furthermore, this study could also be enriched by incorporating changes in demand for particular commodities as a result of an outbreak. Other livestock which are targets, such as hogs and goats, could also be incorporated. Other disease management strategies could be incorporated as well, such as surveillance, animal disease tracking, human vaccination, and other vector control measures such as repellants.

This study could also be extended to other regions. This study simulated a RVF outbreak in the southeast region of Texas. It has been shown that RVF has competent vectors across the entire nation of the U.S., and therefore this research could be expanded to include a wider geography of a potential outbreak. The state of California along with the U.S. southeast are potentially highly vulnerable, and also have high livestock populations. An outbreak in these regions, as well as other regions in the U.S., could cause substantial economic losses.

Impacts of animal disease outbreaks may either be elevated or alleviated depending on what disease control actions policy and decision makers take. This study uses careful economic assessment of RVF vulnerability and the value of prevention and control strategies along with assessment of damages to public health in order to support decision making. We find that there is a need for yet further development of control strategies as the ones examined herein did not have a large impact and were generally worse than letting the disease run its course.

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