

EVALUATING DISTRIBUTIONS OF ECONOMIC IMPACTS OF FMD EMERGENCY
STRATEGIES IN THE UNITED STATES

by

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Abstract

The livestock industry is susceptible to several diseases, of which Foot and Mouth Disease (FMD) is one. FMD is neither a fatal nor zoonotic animal disease, but most animals less than one year of age are killed in about 80% of cases. FMD also causes reductions in yield and milk production. FMD is recognized as an economic disease because any outbreak will lead to a drastic reduction in the export market. This study is centered on livestock production in mid-western United States. The study incorporated the result from an epidemiology model into an equilibrium displacement model; this is used to determine the economic impact of the FMD outbreak on both consumers and producers. Three vaccination-to-die scenarios were simulated. Each scenario had 200 disease spread simulation runs. The economic impact results were presented with normal distribution curves in order to see how the economic impacts were distributed across the 200 runs in each scenario. Scenario 14 with 50 and 80 herds vaccination capacity at 22 and 40 days respectively, coupled with 50 km vaccination zone has the lowest negative impact on both consumer and producers. The diseases lasted for shorter period of time in scenario 14 than scenarios 2 and 12. Scenario 14 also has least number of animals killed. It can be concluded from the equilibrium displacement outcomes that the best mitigation strategy for the control of FMD is to have a large vaccination zone area, and increment in the vaccination capacity will also curb the disease on time.

Keywords: FMD, economic impact, distribution

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Dedication

This work is dedicated to Almighty God, the alpha and omega, for giving me wonderful family, and for all his wonderful works in my in my life.

Chapter 1 - Introduction

1.1 Background on Foot and Mouth Disease

Foot and Mouth Disease (FMD) is an animal disease that can have a great impact on livestock markets all over the world. The livestock industry is susceptible to several diseases, of which FMD is one of utmost concern. Even though FMD is not zoonotic (affects both animal and man), great importance is still placed on FMD because of its potential economic impact on infected regions. The negative effect that can arise from any disease outbreak is greater than the impact just on the country where the disease originated from but can also have great impact on international markets, since the food supply chain has become increasingly global (Park *et al.*, 2008). Many countries like Japan and Korea are more highly dependent on imported meats for their source of animal protein, at the same time; these countries put strict measures on the importation of meats like beef, pork, and lamb that are prone to diseases.

In about 80% of cases, most animals under one year of age are often killed by the disease (Rich *et al.*, 2005), the mortality rate is less than 6 percent in adult animals and FMD can cause reduced milk yield and loss of weight (Mahul and Gohin, 1999). An outbreak of FMD can cause substantial economic stress for countries where the livestock sector makes a significant contribution to the economy. Such a disease outbreak can also adversely affect other aspects of the economy in addition to the livestock industry. For instance, the 2001 FMD epidemic in United Kingdom confirmed at an abattoir near Brentwood in Essex, England (Wilson and Kinsella, 2004). As reported by British press (Sunday times) it cost UK around 9 billion Pounds starlings of which 60 percent were losses from the tourism and leisure industry due to restrictions in movement in the countryside (Burrell and Mangen, 2001).

A single animal disease outbreak incident can lead to large losses in the livestock industry that can persist for numerous years. Putting major efforts and regulatory interventions to control the outbreak/spread of animal diseases can yield great economic benefits to countries/regions with large livestock sectors (Rich *et al.*, 2005). Disease-free status is an important element of the trading strategy of livestock exporting countries (Burrell and Mangen, 2001). Better understanding through studies of the different aspects of FMD and FMD virus may improve future, national, regional and global control, even eradication plans for the disease (Garebed *et al.*, 2008). Eradicating FMD in any country also involves more than simply vaccination or killing of all infected animals. Many disease control measures are also important including the political status and the educational level of the society. People in the area have to understand the potential effect of the disease and the significant losses they can incur from an outbreak. For example, vaccination in regions where susceptible populations reside often can be hindered because of political instability, corruption, economic hardship, or inaccessibility due to poor infrastructure (Mohiddin and Johnston, 2006; Rennie and Behets, 2006; Heymann, 2004; Aylward *et al.*, 2003; Henao-Restrepo *et al.*, 2003; Cutts *et al.*, 1999; Hull *et al.*, 1998; Garabed *et al.*, 2008).

FMD is trans-boundary in nature, because of this, it is important for the policy makers in North American countries to understand the potential impacts of an FMD outbreak and the consequence of the different mitigation policies (Nogueria *et al.*, 2011). For instance, the Mexican cattle industry's main exports consist of male and female calves to the United States. Also, approximately 15% of the weaned calves are exported to the United States (Nogueria *et al.*, 2011).

A lot of researchers have worked on FMD prevention and control, and studied the economic impact of outbreaks. The research also explored best practices to follow in order to reduce economic losses and to minimize outbreak severity. This study will use an equilibrium displacement model (EDM) model to estimate economic impacts across industry sectors of a hypothetical FMD outbreak in the United States. The EDM comprises retailer, wholesale, and producer sectors focused on the livestock sector of the United States (Schroeder and Tonsor, 2011). The FMD outbreak epidemiology is simulated using the North American Animal Disease Spread Model (NAADSM). The epidemiology of a hypothetical FMD outbreak is stochastic and NAADSM simulates alternative disease spread probability distributions. As a result, any outbreak can have numerous alternative possible impacts. We will explore in detail the distributions of these simulated disease spreads to determine how the economic impacts (welfare) are distributed across each sector of the market under alternative animal disease mitigation strategies.

This study builds upon a recent study of Schroeder *et al.*, (2012) that explores economic impacts of alternative FMD emergency vaccination strategies in the United States. The unique aspects of the current study relative to Schroeder *et al.*, 2012 include: 1) the Economic Displacement Model is used here to explicitly estimate the entire distribution of potential losses with each sector of the livestock industry in the event of FMD (Schroeder *et al.*, (2012) estimate only median and 10th and 90th percentile impacts). 2) A graphical representation will be presented that makes it easy to read and compare how the losses were being distributed. Exploring the entire distribution of potential economic impacts can prove very insightful. In an FMD outbreak, the disease containment can vary substantially based on numerous factors that may or may not facilitate disease spread and disease duration. There is a lot of uncertainty

associated with potential disease spread for any given introduction of the disease because the disease can be easily spread through numerous vectors including wind, feed, humans, clothing, wildlife, and vehicle tires in addition to direct animal contact. Understanding the probability distribution of possible outbreaks is important. Short-lived, rapidly contained, FMD outbreaks likely have much smaller economic impacts than a longer-lasting wider outbreak. Consideration of just median or average economic impacts masks the potentially very important distributional aspects of an FMD outbreak. This study is the first we know of to estimate the distribution of economic impacts from simulated FMD outbreaks in the United States.

1.2 Objectives of study

The main goal of this study is to find the best way to reduce the economic losses to Foot and Mouth Disease by evaluating the entire distribution of potential economic outcomes. A graphical representation of the equilibrium displacement model output is used here to readily illustrate how alternative control strategies affect the economic impacts.

The objectives can be categorized into the following three

- 1) To estimate the economic impacts from simulated FMD outbreaks in the United States using an equilibrium displacement model.
- 2) Present the distribution of losses/gains incurred by the producers and consumers due to an FMD outbreak with graphical representation to make it easy to read and compare across different mitigation strategies.
- 3) Ranking the practices to follow in order to reduce economic losses and minimize FMD outbreak severity among the three Scenarios considered in this study.

Epidemiological models can simulate the distribution of the size and duration of the disease outbreak, and the outcomes of these models can be integrated with economic models. In this

study, the epidemiological model result is integrated into economic estimates (Niemi and Lehtonen, 2010)

1.3 Organization of Thesis

This study will be organized into five chapters. This first chapter is an introduction and it gives the overview of this study. Chapter 2 is the review of literatures, this will give more detail into the past works and findings on the FMD outbreak. The literature review will also include the impacts of FMD outbreaks on the global livestock market. The next chapter (3) will give the description of data used in this study; it will also describe the methodology involved in the economic analyses conducted. Chapter 3 will also explain how the objectives stated in chapter 1 are achieved. The result is presented in chapter 4 with graphical representation of the outcomes. Chapter 5 includes the conclusion, recommendation, and limitation of this study.

Chapter 2 - Review of Literature

2.1 Introduction

A Foot and Mouth Disease outbreak could be very detrimental to the United States economy and to the world in general. This importance has motivated a body of past literature exploring economic impacts of a potential FMD outbreak. Here I provide a review of FMD research broadly discussed in three categories that comprise: 1) “understanding of FMD” , 2) exploring the economic importance of an FMD outbreak in the United States and other developed economies of the world, and 3) discussing two methods of control of FMD- whether to vaccinate or not to vaccinate.

2.2 Understanding Foot-and-Mouth Disease

FMD originates from a virus that affects all cloven-hoofed ruminants and is highly contagious (APHIS, 2010). FMD can be spread by direct or indirect contact; it can also travel through air up to 60 km over land (Burrell and Mangen, 2001). Disease signs can appear within two to three days after exposure and can last for seven to ten days (Grubman and Baxt, 2004). Some of the symptoms of FMD are: fever, blister-like lesions, and erosions on the tongue, lips, mouth, teats, and hooves (APHIS, 2007). FMD affects all stages in the cattle productions: breeding, feeding, and marketing (Nogueria *et al.*, 2011)

Decision makers have always been faced with many difficult choices in designing the right policy for Foot and Mouth Disease (FMD) control policy in the United States (Hagerman, *et al.*, 2012). In the past decade, large FMD events have occurred in Taiwan, the Netherlands, Japan, The Republic of Korea and the United Kingdom (Hagerman *et al.*, 2012). FMD is a type of disease that has the ability to spread very rapid in a susceptible population (Barnett *et al.*, 2002) without proper control measures to stop the spread. FMD is highly contagious and can move

rapidly through many means like contact, livestock movement, airborne spread, and infected wildlife (Rich and Winter-Nelson, 2007). The last outbreak of FMD reported in the United States was in 1929 (Schroeder *et al.*, 2012). There have been frequent outbreaks of FMD around the world in recent years which has made the disease a global concern even in long standing FMD-free countries (Grubman and Baxt, 2004, Schroeder *et al.*, 2012). The effects of FMD can be very bad to a country, it can also threaten food supplies, security and safety (FAO, 2006).

2.3 Economic importance of FMD

Evaluating the economic welfare impact of an FMD outbreak involves more than the vaccination process, the demand and supply impacts are also very important. Introduction of demand and supply shocks enables studying the economic impacts. Each time there is a disease outbreak, there is likely a drop in demand for the livestock product in the affected region, the supply is also affected due stamped out animals. Outbreaks of animal diseases mostly impact the supply and demand of the livestock. The effect of the disease outbreak on demand and supply can last beyond the period of the disease outbreak. There are some specific characteristics for countries such as dependence on exports or imports, disease control policies, consumer demographics, value of livestock, make it difficult to get the accurate impact of FMD from one country to another (Nogueria *et al.*, 2011). Devadoss *et al.*, (2006) presented a general equilibrium analysis on foreign and domestic demand of a disease outbreak in the United States. They stated that United States exports 10% of its beef, trade ban by about 50 countries on its beef will lead to about a 90% decline in US beef exports. FMD is considered a major threat to the United States due to herd destruction, trade restrictions, disease eradication costs, and market disruptions (Doel 2003; APHIS 2010, Hagerman *et al.*, 2011).

As a result of the restrictions imposed on the beef imports from FMD-endemic countries, a significant price gap (as large as 50-60% for manufacturing beef) existed between the FMD-endemic and FMD-free markets. The avoidance of large production losses that can be up to 10% of annual output was the main incentive for eradication. In beef exporting countries, there was an added incentive of accessing more profitable markets. (Ekboir *et al.*, 2002)

Using the incidence of FMD in United Kingdom (2001), Paarlberg *et al.*, (2003) estimated the potential revenue impact of an outbreak of Foot and Mouth Disease in United States. The greatest impact was the lost international market access and reduction in domestic market demand due to fear from local consumers on the effect of the disease on them. They determined that an FMD outbreak could cost the United States up to \$14 billion in gross revenue which amounts to about 9.5% of the total agricultural sector income.

A single disease outbreak in a country can lead to the ban on exports of meat for an extended period of time from countries that normally import meats from the affected country. *Bovine spongiform encephalopathy* (BSE) that occurred in Washington state in 2003 lead to stoppage in US beef exports and the United States lost \$3-5 billion yearly because of the of the single reported incident (Coffey *et al.*, 2005, Zishun *et al.*, 2006). And another impact of FMD outbreak is the changes in the way finished livestock products were marketed (Wilson and Kinsella, 2004). Korea banned beef imports from the United States (the largest country exporting beef to Korea which accounted for 68% of total beef import in Korea) immediately after the confirmation of the *Bovine Spongiform Encephalopathy* (BSE) in 2003, and it lasted till 2007 when they allowed the importation boneless beef from United States. Likewise, due to the largest outbreak of FMD in Korea confirmed in March 25, 2000 Japan banned the importation of pork from Korea (Park *et al.*, 2008).

An FMD outbreak in the United Kingdom in 2001 cost the country between \$3.6 and \$11.6 billion (Mathews and Buzby, 2001; Nogueira *et al.*, 2010). The risk study for the newly proposed National Bio Agro-Defense Facility (NBAF) study of 2010 estimated that the economic welfare loss from simulated FMD outbreaks in Kansas range from \$2.8 to \$50 Billion depending on the scenario (NBAF, 2010).

Nogueira *et al.*, (2010) in their study of Foot and Mouth Disease on the Mexican cattle industry reported that changes in the economic surplus due to FMD range from positive \$0.89 to \$1.6 billion to a net loss of about \$67 billion depending on the outbreak scenario and specific mitigation strategy.

FMD clearance processes involve some steps that must be followed before an infected country can regain a lost export market. The process starts with eradication and vaccination, followed by a period of FMD-free status, certification by an international agency and finally clearance by individual importing countries. Any country labeled as disease-free will be able to have high demand for its livestock products and will also command high prices relative to those not enjoying this status. Due to the high cost of maintaining FMD Free status, countries designated as FMD Free by World Organization for Animal Health (OIE) restrict the importation of meat and livestock from the countries that are not designated as FMD-Free (Rich and Winter-Nelson, 2007). The trade restriction placed on the FMD countries serve as an incentive to eliminate FMD in the countries that have high potential for exportation of meat to other countries (Rich and Winter-Nelson, 2007).

2.4 Vaccination Vs Non-Vaccination

Different forms of studies on Vaccination types had been reported in the literature. For example, Vaccination-to-die versus vaccination-to-live, some studies also included other constraints like the different sizes of emergency vaccination, vaccination capacity and more. Barnett *et al.*, (2002) illustrated the difference between the two confusing words “emergency vaccination” which include ring vaccination or barrier vaccination (this may applied to a country or region at risk, the non-infected country try to create barrier against movement of products from the infected country), suppressive or Dampening down vaccination, and “emergency FMD vaccine” which is vaccine ideally formulated to contain higher levels of antigen than conventional. Barnett *et al.*, (2002) indicated that within the last 20 years, great advances have been made in safety, quality and efficacy of the available FMD antigens and even the conventional FMD vaccines from appropriate licensed manufacturers. The availability of reliable and dependable vaccines tends to develop more support for vaccination before or when there is an FMD outbreak.

The major issue with vaccination is that it has to be done in routines once FMD is present. If routine vaccination is discontinued, the disease often reappears, which can sometimes be in interval of many years or sometimes a matter of months (Barnett *et al.*, 2002).

FMD vaccination is controversial for the following reasons: (a) risk of virus introduction via the vaccine and vaccination team; (b) potential delays in the re-opening of international markets; (c) potential of higher culling due to vaccinate-to-die policies or lack of differentiation between animals that have been vaccinated and those that are sub-clinically infected or recovered (i.e., the vaccine not being a Differentiate Infected from Vaccinated Animals, or DIVA, vaccine); and (d) the costs of implementation, plus the limited availability of key resources such as personnel, and necessary vaccination equipment. The fact that vaccinated animals are culled along with non-vaccinated animals may seem counter-intuitive (Hagerman *et al.*, 2011).

This study is focused on Vaccination-to-die scenarios to complement the report by Schroeder *et al.*, (2012) on the Economic Impact of Alternative FMD Emergency Vaccination Strategies in the United States. A major issue in FMD control is the argument on whether to vaccinate or not to vaccinate. Elbakidze *et al.*, (2009), and Hagerman *et al.*, (2012) found that the economic losses under vaccination exceed losses under no vaccination, and detection delay also increase losses. Another problem faced during vaccination is choice of which vaccine to apply because the strain of the FMD Virus responsible in the outbreak may not be quickly determined, and the disease spreads so fast that before the right vaccination is applied, it may have gone out of control. Part of the factor to be considered when applying vaccination includes the number of livestock to be protected, the species and location of these livestock, the introduction and spread of the disease, and the cost-benefit studies (Barnett *et al.*, 2002)

Different countries have different ways they control an FMD outbreak. Some countries control FMD through vaccination while some control through killing of the infected animals. In southern cone of America, vaccination was used to eradicate the disease outbreak in the 1990s (Rich and Winter-Nelson, 2007). Generally, FMD-free status is restored three months after the last infected case, or the last vaccinated herd has been slaughtered (Burrell and Mangen, 2001). Argentina and Uruguay eradicated foot and mouth disease in 2000 and 1995 respectively, and they gained greater access to FMD-free markets after (Javier *et al.*, 2002). According to the EuroChoices publication by Burrell and Mangen, (2001), the European Union followed a policy of non-vaccination since 1991. The European Union (EU) has a special policy on control of FMD which involves culling of all susceptible livestock in the affected area, animal restriction, and compensation of livestock producers for their losses (European commission, 2003). In United States, the North America Guidelines for FMD Vaccine Use indicate that if FMD can be

eradicated through culling alone, no vaccination should be employed (Hagerman *et al.*, 2012). However, Animal and Plant Health Inspection Services of United States Department of Agriculture (APHIS) may determine where vaccination is necessary to contain the disease after putting into consideration different factors such as suspected origin of infection, estimated date of introduction, and possible spread of the disease (APHIS, 2010; Hagerman *et al.*, 2012). Another example is Zimbabwe in southern Africa, to maintain freedom from FMD. A zonation system is implemented with fencing and movement controls have been used to protect a central export zone where most of the large scale commercial farming is concentrated (Randolph *et al.*, 2012). Even with stringent trade restrictions and border control, some countries that were initially FMD-free have not been able to maintain the FMD-free status (Scudamore and Harris, 2002; Pluimers *et al.*, 2002; Chmitellin and Moutou, 2002; Costelloe *et al.*, 2002; Bruckner *et al.*, 2002; Sakamoto and Yoshida, 2002; Garabed *et al.*, 2007).

2.5 Economic models and FMD

Even though there is much economic importance attached to Foot and Mouth Disease outbreak, only few researches has combined the epidemiological models with up-to-date economic analysis. Rich and Winter-Nelson, (2007) developed an integrated epidemiological-economic model of animal disease control that is both dynamic and spatial. Rich and Winter-Nelson, (2007) used epidemiological model to simulate an FMD outbreak in Paraguay and its consequent spread to other countries. The most common measures of welfare are consumer and producer surplus (Ekboir *et al.*, 2002). The relationship between domestic supply and domestic demand determines the trade and welfare effects of changes in international markets. The welfare effect

will be larger for countries that export a large share of their production or import a large share of their consumption (Ekboir *et al.*, 2002).

Equilibrium Displacement Model (EDM) is used to analyze the impact of the simulated disease outbreak on each sector of the market in United States including both Domestic and International market. In livestock industry market analyses, lots of researchers have used EDMs to conduct welfare analysis on the livestock industry with the introduction of disease outbreaks or applications of new technology. Zhao *et al.*, (2000) developed an Equilibrium Displacement Model for the Australian Beef industry, and their main study' objective was to thoroughly document the model and the procedures followed in defining the price, quantity and market parameters (supply, demand and substitution elasticities). Schroeder and Tonsor, (2011) also applied an Equilibrium Displacement Model to determine the economic impact of adoption of newly approved technology in cattle feeding.

Epidemiological and economic modeling of livestock disease outbreak involves knowing different types of factors involved which include size, location, and operational type of each livestock facilities in United States (Melius *et al.*, 2006). Three types of mitigation was adopted in Karl and Alex, (2007) study; stamping out, vaccination and preventative vaccination. Generally, researchers use cost-benefit in animal health economics to evaluate alternative strategies for contagious disease control, and the evaluation is based on expected values of gain and losses (Mahul and Gohin, 1997). Rich *et al.*, (2005) addressed the problem of modeling space in a regulatory environment through the example of efforts to control Foot Mouth Disease (FMD) in the southern cone of South America. Their result showed that from a policy perspective, the regulatory controls will be more effective if private incentives are made more uniform over space. This can be achieved through subsidies or transfer and regional

developments. They also found that improving markets and incentives in lagging countries may be an important part of an international effort to control FMD in more developed, exporting regions.

Randolph *et al.*, 2012 evaluated the equity of animal disease control in Zimbabwe. In their study, they disaggregated costs and benefits into sub-sectors which comprise of five major sub-populations: communal area households, lower-and upper income households on large commercial farms, and lower and upper-income urban households. Improving FMD control had a significant contribution to the economic growth of the country but the magnitude of the benefit is very small for the poor relative to the greater share captured by the higher income group. But every group benefits from FMD control improvement.

A study conducted by Pendell *et al.*, (2012) determined the economic implications of a hypothetical FMD outbreak in a specific local region southwest Kansas under three different disease introduction scenarios. This study follows the same format of having three vaccination-to-die scenarios that is differentiated by vaccination capacity, feedlot size, and trigger size. This study added another form of reporting the economic losses by illustrating how the losses to each sector surpluses are distributed across different scenarios. Niemi and Lehtonen, (2010) used a stochastic dynamic programming model to simulate the market implications of alternative foot and mouth disease scenarios in the pig sector.

Elbakidze *et al.*, (2009) investigated the economic impact of FMD with the help of epidemiologic-economic modeling framework associated with time-to-disease detection, slaughter capacity of infected herds, and availability of FMD vaccines. The study area involved only eight counties in high plains of Texas. Their economic analysis shows that early detection of the outbreak is the most economically effective control option. The study used simulations like the epidemiology model used in this study. Their simulation suggested that the epidemic might cost up to \$1 billion within the local cattle industry. This result was in line with the

Hagerman et al., (2012) report which suggested that standard culling of animals from early disease detection have smaller animal and economic welfare losses compared to emergency vaccination. Wilson and Kinsella, (2004) also looked into the impact of FMD on the price of beef. They found out that changes to livestock supply chains and market methods had a more direct effect on beef industry.

Chapter 3 - Data and Methodology

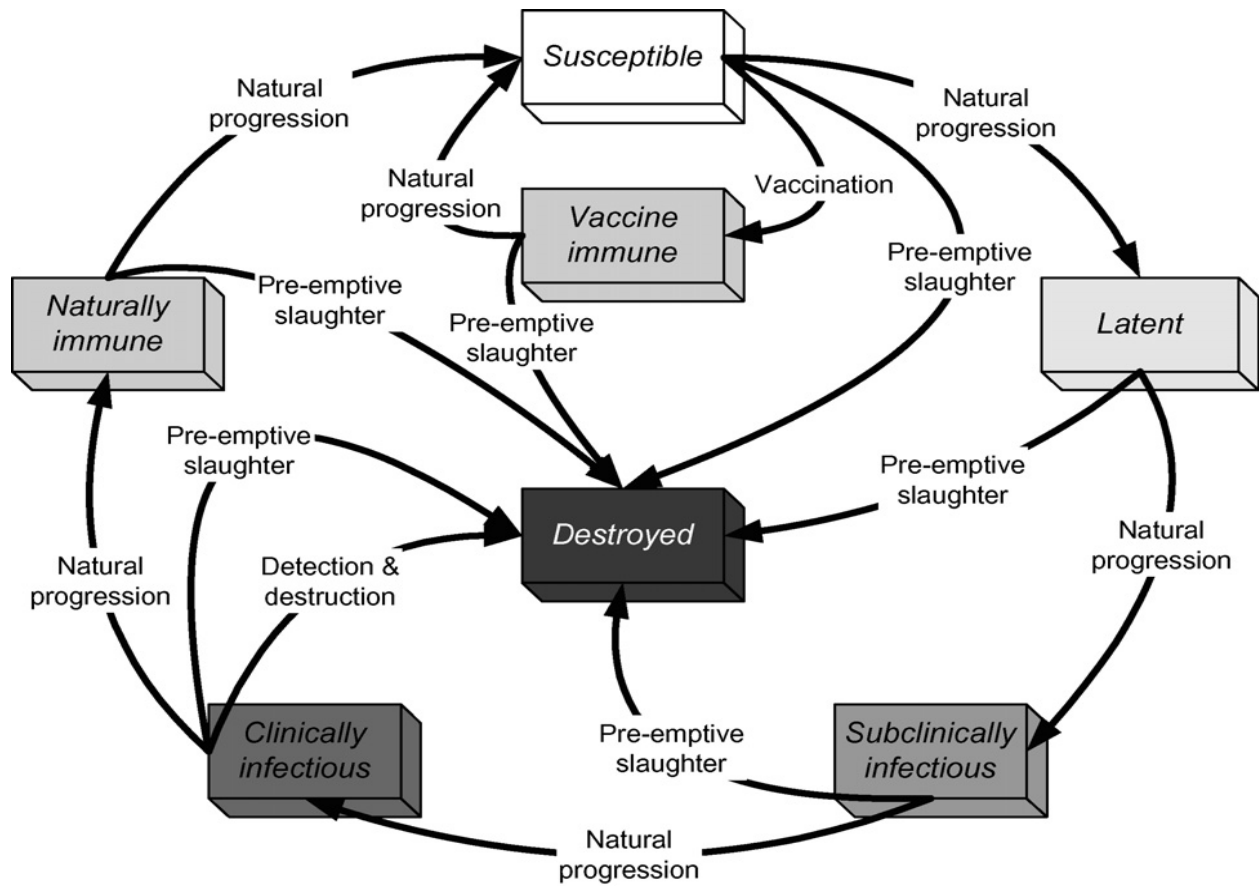
3.1 – Introduction

The data used in this study is from the result of running an epidemiological disease spread model, the North American Animal Disease–Spread Model (NAADSM). NAADSM is a stochastic, spatially explicit, state-transition simulation model designed to simulate the spread of highly contagious animal disease (Schroeder *et al.*, 2012; Harvey, N. et al., 2007). NAADSM originated from the efforts within (Harvey, N. et al., 2007) to designed models for animal disease spread and controls. NAADSM is intended to be used as a research and planning tool in advance of an incursion of a highly contagious disease (Harvey, N. et al., 2007). The model also serves as a means of preparedness for any unforeseen disease outbreak. Modeling of a disease spread can reveal the best control measure to be adopted in order to reduce loss that may occurred due to the disease outbreak.

Under NAADSM, Foot and Mouth Disease can be spread in four different ways including: 1) Direct contact; 2) Indirect contact; 3) Local Area Spread; and 4) Airborne. FMD can be spread through direct contact when a susceptible animal has body contact with an already infected animal. Indirect contact can occur through movement of people or materials from an infected region to an uninfected region. The local area spread is one that cannot be fully determined how it is spread but recognizes the fact that the disease has occurred in the nearby area. The disease virus can also be carried by air from infected animals to uninfected ones. FMD goes through different states in livestock. When a susceptible animal is infected, the virus will first undergo latent states, the animal will remain in the latent state for a while, unless any disease control activity is performed, the animal will move from the latent state to the subclinical infectious

state. At this state, the animal will not have any visible sign of sickness. If the disease is detected at this stage, the infected animal can undergo pre-emptive slaughter. But if the disease is not detected at the subclinical state and any disease control was not performed on the animal, it will move to clinically infectious state, this is the main state of the sickness with all symptoms of infection appearing. At clinically infectious state, the infected animal can undergo destruction if detected or pre-emptive slaughter. If not detected, it will follow natural progression to naturally immune state. At this state, the animal has survived the disease and developed immunity against the virus. But with time, the infected animal will become susceptible again (Figure 3.1).

Figure 3-1 States and Transitions simulated by NAADSM



Source: Harvey, N. et al., 2007.

In this study, the NAADSM simulated data is similar to that used in Schroeder *et al.*, (2012). In that study the model was developed for 15 different scenarios of Foot-and-Mouth disease outbreaks varying by animal health management strategies employed during the simulated outbreaks. This study focuses on three specific scenarios among the 15 scenarios in Schroeder *et al.*, (2012). The scenarios selected here were Scenarios 2, 12, and 14. The three scenarios were selected in order to compare the economic impacts as a result of varying conditions under which the disease might be controlled. The three scenarios were all vaccinate-to-die scenarios. Vaccinate-to-die is chosen because in the livestock global market, killing infected animals allows

the country to regain its entry into international trade more rapidly than a vaccinate-to-live condition.

3.2 NAADSM – The Model

The North American Disease Spread Model (NAADSM) is a computer program that simulates spread of highly contagious animal diseases. NAADSM provides researchers, policy makers and animal health emergency responders to devise a way to combat or control any unsuspected animal disease outbreak like Foot and Mouth Disease and other serious livestock diseases. The results from the model can also be used to demonstrate to policy makers the economic impacts of an outbreak in a certain region. NAADSM is a stochastic model because there is no specific output expected if the model is run several time without changing any factor in the model. This occurs as a result of random variables involved in the model, which include the spread of animal disease through environment. The movement of animals can also be a factor that cannot remain constant in the modeling.

In setting up the disease model, many factors were pre-determined before running the model. These factors include; Scenarios, vaccination strategy, vaccination capacity, vaccination trigger, size of Vaccination Zone.

3.2.1 – Scenarios

In the NAADSM set up, three different scenarios were simulated for use in this study. Each scenario represents a certain condition under which an FMD outbreak can occur and the type of control performed during the outbreak. Each scenario has 200 runs of NAADSM (replicates).

All the runs in each scenario contain the same specified condition, each specified each time the model is run on the scenario and output recorded. Since NAADSM is a stochastic model, each run output is different from the others. The number of animals culled each day was recorded under each run. In this model, the basis of simulation is “unit” which is represented by a group of animals. Each unit is determined by other factors like production type, number of animals, point location, and a transition state. NAADSM allows the production type to be a single type of livestock or mixed species. Single production types can comprise beef cattle only or model simulated based on sheep only. Meanwhile, the mixed production type in NAADSM simulation can be mixtures of different kinds of livestock. In this study, mixed production types were included used in the simulations. The production types included are 1) mixed beef-swine, 2) cow-calf, 3) large and small feedlot, 4) dairy, 5) large and small swine, and 6) small ruminant (sheep and goats). The number of animals in each unit is assumed to be static i.e., there is less movement of animals from one area to another. Though in the model simulation, the animal movement is restricted to 30% of pre-outbreak level. The simulation also proceeds in time-step of one day.

There were 151,620 herds defined by point locations (expressed in latitude and longitude), production type and herd size (as shown in Table 3-2). This study, like the NBAF (2012), was based on 8 states (Colorado, Kansas, Nebraska, Northern New Mexico, Northern Oklahoma, South Dakota, Panhandle of Texas, and Wyoming) that are similar in geographic region (Figure 3.2). The simulated population was generated based on the data from U.S Department of Agriculture National Agriculture Statistic Services -NASS (Schroeder *et al.*, 2012).

Figure 3-2 An 8-state outlined region of central U.S. selected for modeling the potential of a foot and mouth disease outbreak initiated in a large feedlot in Northeast Colorado



Source: Sara McReynolds (Veterinary College, Kansas State University), 2013

The scenarios simulated for various FMD vaccination protocols varied by the following factors:

- 1) **Vaccinated to live or die:** In the NAADSM model, the scenarios were either vaccinated-to-live or emergency vaccinated-to-die. This study focused on 3 vaccinated-to-die scenarios. The difference between the two strategies is that in Vaccinated-to-live, the animals were not killed; the infected animals were culled while the whole herd was vaccinated and allowed to live. In the vaccinated-to-die situation, the infected herds and the surrounding herds yet to be infected were killed after being vaccinated. All animals vaccinated to die were depopulated the quarter they were vaccinated. The number of

animals depopulated is taken from the NAADSM simulation of an FMD outbreak initiated in a Northeast Colorado feedlot.

- 2) **Vaccination capacity:** The vaccination capacity refers to the number of herds that can be vaccinated per day at 22 days and 40 days after the first disease detection. In this study, scenarios 12 and 14 have the same vaccination capacity which is 50 herds at the first 22 days and 80 herds at 40 days. But scenario two has 5 herds at 22 days and 10 herds at 40 days. The vaccination capacity is predetermined in the model.
- 3) **Vaccination trigger:** vaccination trigger means the number of herds that are infected before an emergency vaccination program is implemented (Schroeder *et al.*, 2012). The vaccination trigger used in this study is 10 and 100 herds. It means that in a scenario when 10 herds are infected that the emergency vaccination will start while in the other scenario it has to reach 100 herds before any emergency vaccination can be implemented. The three scenarios in this study have vaccination trigger of 10 herds.
- 4) **The size of vaccination zone:** this is the diameter of the vaccinated region around the infected herd measured in kilometers. The vaccination zones were grouped into two, either 10 km or 50 km. In a 10km vaccination zone, only the herds in the 10 km zone are vaccinated and others beyond the diameter were not touched. The same goes for the 50km vaccination zone. Scenario 2 and 12 were both have 10km vaccination zones while scenario 14 was has a 50km vaccination zone.

The day of the first detention of the disease was randomly selected by NAADSM. The depopulation capacity was set at 8 herds per day by day 10 and 16 herds per day by day 30 after disease detection.

The three scenarios focused on in this study are summarized below. They are all vaccinated to die scenarios, and all the same vaccination trigger, meaning that the number of herds infected has to reach 10 before a vaccination strategy can be implemented. Scenarios 12 and 14 have the same vaccination capacity: at 22 days of outbreak, 50 herds were vaccinated and 80 herds vaccinated at 40 days after disease outbreak. Unlike Scenarios 12 and 14, in scenario 2, only 5 herds were vaccinated at 22 days and 10 herds at 40 days. Size of vaccination zone is also different in scenario 14 with 50km vaccination zone while scenarios 2 and 12 have 10km vaccination zone. From the table 3-1 below summarizing the scenario characteristics, it can be deduced that only vaccination capacity and size of vaccination zone create differences among the scenarios.

Table 3-1 Summary of FMD Outbreak Scenarios

Scenario	Vaccine Strategy ¹	Vaccination Capacity (herds, day 22, day 40) ²	Vaccination Trigger (herds) ³	Size of Vaccination Zone (Km) ⁴
2	V2D	5,10	10	10
12	V2D	50,80	10	10
14	V2D	50,80	10	50

3.3 - Data Summaries

In the animal disease simulation, there were 39.4 million animals grouped into 151,620 herds. Table 3-2 shows the production type and the numbers of animals in each type including the herd sizes used in the epidemiology modeling. The production type in this study includes cow-calf, feedlot, swine, and sheep.

¹ Vaccine Strategy - vaccinate to die is denoted as V2D - all animals vaccinated are subsequently destroyed

² Vaccination Capacity – number of herds vaccinated per day at 22 days and 40 days after first disease detection

³ Vaccination Trigger – number of herds infected before the vaccination strategy is implemented

⁴ Size of Vaccination zone – diameter of vaccination zone in kilometers around infected herds.

Table 3-2 Summary of Population of Animals and Herds used in NAADSM by Production Type

Production Type	Animals	Herds
Cow-calf	9,698,630	86,655
Feedlot-Large ($\geq 3,000$ head)	9,147,279	979
Feedlot-Small ($< 3,000$ head)	7,377,698	25,096
Dairy	1,062,276	3,232
Swine-Large ($\geq 1,000$ head)	9,227,569	1,071
Swine-Small ($< 1,000$ head)	663,465	6,463
Beef-swine mix	520,283	5,159
Sheep	1,716,028	22,965
Total	39,413,228	151,620

Note: In the economic modeling, large and small feedlots were grouped into a single category of feedlots; cow-calf and half of mixed swine and beef operations were also grouped into cow-calf; and large and small swine and half of mixed swine and beef grouped into swine.

Source: Schroeder *et al.*, 2012

Scenario 2 has most of the runs ending within six to nine quarters following the outbreak. Approximately 30 of the 200 runs also end in the first quarter. Likewise, Scenario 12 also has a long duration with some of the runs lasting for 11 quarters. Most of Scenario 12 outbreaks lasted 5 to 9 quarters. Scenario 14 is different because the majority of the runs lasted only 2 quarters and averagely between 2 to 3 quarters.

The epidemiology model simulation of the outbreak of foot and mouth disease was repeated 200 times to have data distribution of potential number of animals killed under each scenario, and also the duration of the disease. Figures 3-3, 3-4, and 3-5 describe how long the

foot and mouth disease lasted under scenarios 2, 12, and 14 respectively. Scenario 2 like other two scenarios has 200 runs. Under scenario 2 (figure 3-3), the disease lasted 6 to 10 quarters in over 80% of the runs simulated. Most runs lasted for 7 quarters. The disease stopped in first quarter about 13% of the runs. A quarter is comprised of 90 days, and a year has 4 quarters. Also in scenario 12 (figure 3-4), foot and mouth disease lasted between 5 and 10 quarters in majority of the runs simulated. Close to 12% of the runs have the disease contained in the first quarter. But in some, very small percentage (less than 3%) of the simulated runs, the disease lasted longer, extending to the 11th quarter. Figure 3-5 shows that scenario 14 has less duration for which the foot and mouth disease was active. In over 70% of the simulated runs, the disease was eradicated before the 5th quarter. The longest duration is 7 quarters, and is in about 2% of the simulated runs. Figure 3-6 put the three scenarios together on the same chart for easy comparison

Figure 3-3The distribution of disease duration in quarters across runs in scenario 2

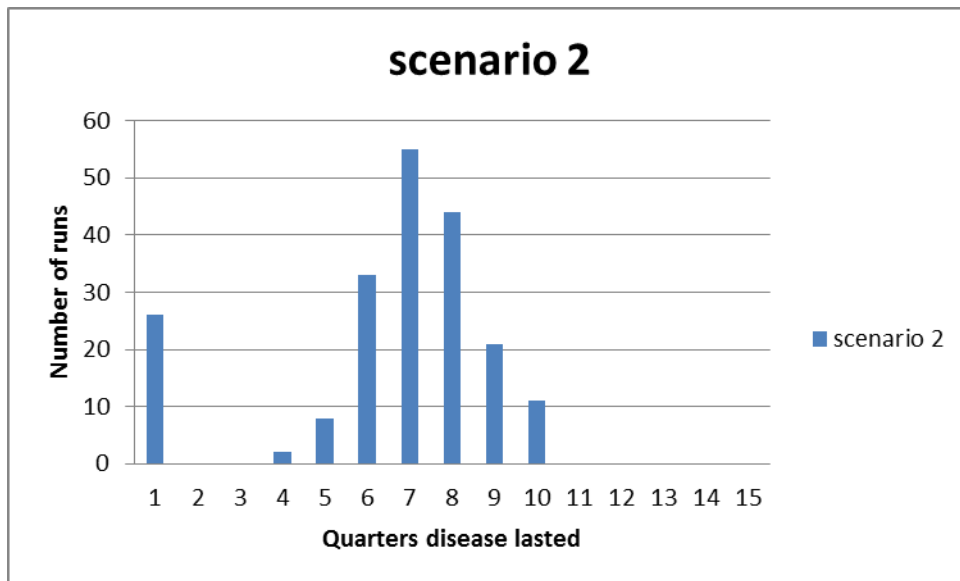


Figure 3-4 The distribution of disease duration in quarters across runs in scenario 12

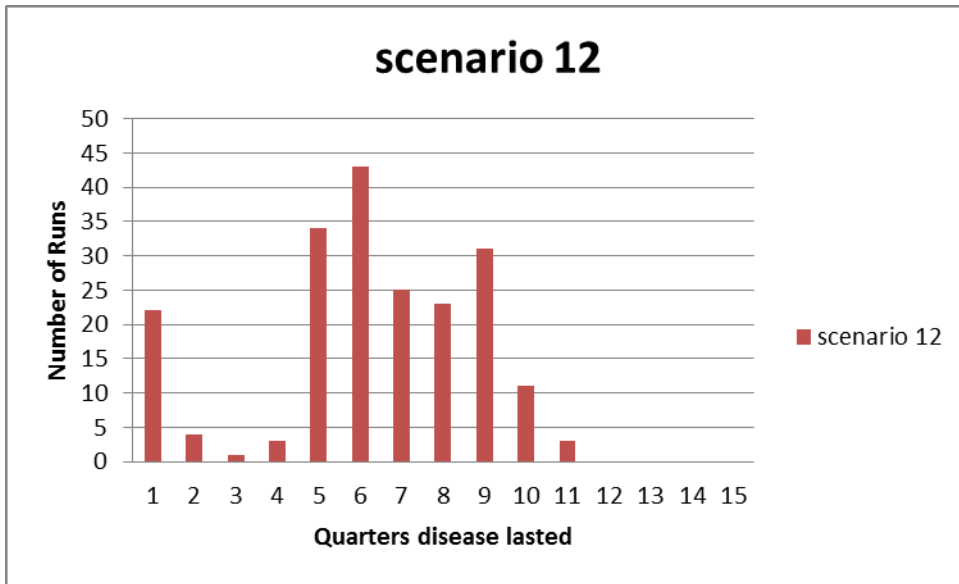


Figure 3-5 The distribution of disease duration in quarters across runs in scenario 14

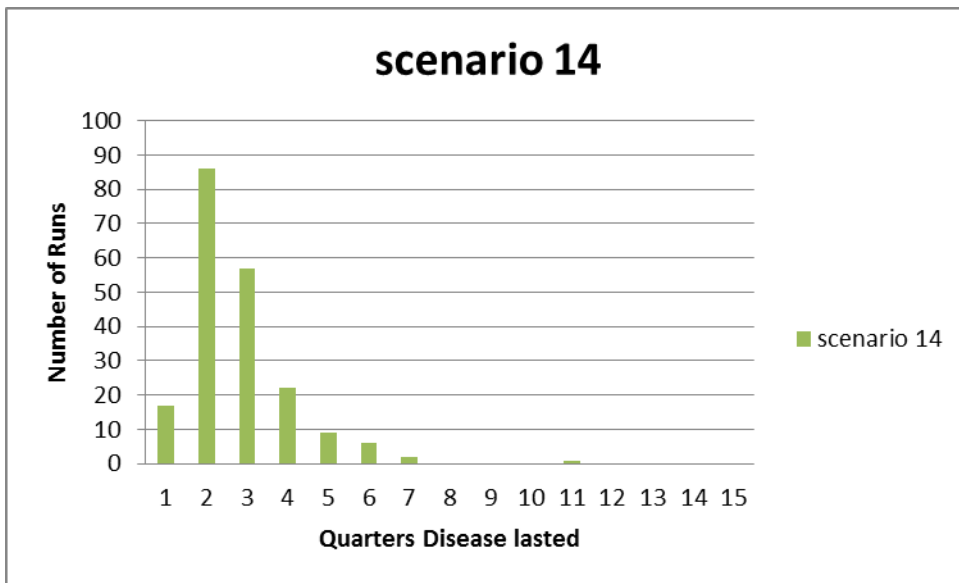
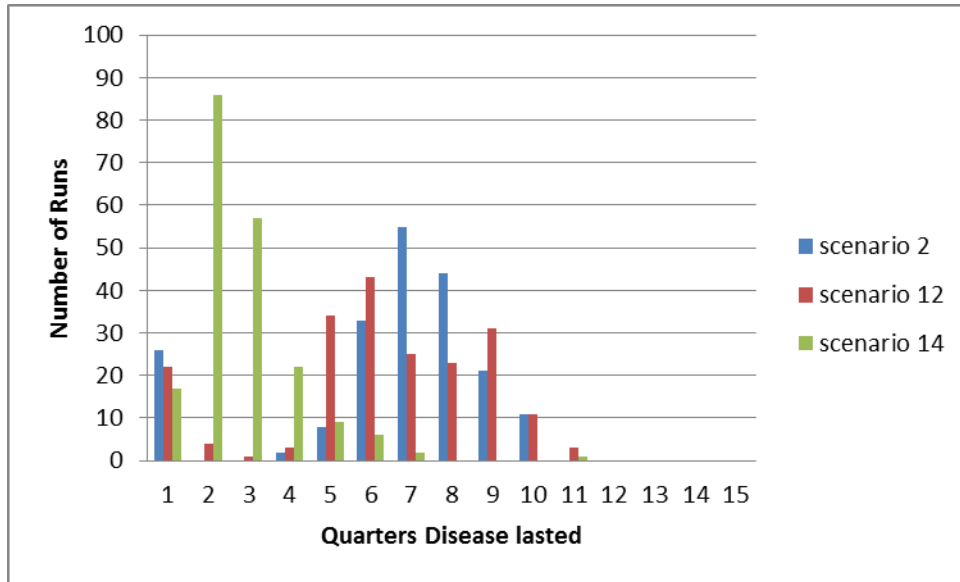


Figure 3-6 The distribution of disease duration in quarters across runs in scenario 2,12,and 14 combined



Fewer animals (about 2 million heads at 90th percentile) were depopulated in scenario 14 relative to the other two scenarios, 12 and 14. Scenario 12 had the highest number of animals depopulated, about 24 million head (90th percentile) while scenario 2 had approximately 10 million animals depopulated. Feedlots had the highest animal depopulations in all the three scenarios except scenario 12 where swine had the greatest number of animals depopulated at the 90th percentile. Sheep also underwent the smallest number of animals depopulated. In the other three animal groups, cow-calf, dairy, and swine, there were differences in relative sizes of animals depopulated across the three scenarios. In scenario two, at the 90th percentile, approximately 46,000, 306,000, and 1 million animals were depopulated in cow-calf, dairy, and swine sections, respectively. Approximately 3 million, 1 million, and 11 million animals were depopulated in cow-calf, dairy, and swine sections respectively under scenario 12. In scenario 14, about 8,000, 60,000, and 42,000 were depopulated in cow-calf, dairy, and swine sections respectively.

Figures 3-7, 3-8, and 3-9 pictured the distribution of numbers of animals killed in each runs under scenario 2, 12, and 14 respectively. In scenario 2 (figure 3-7), most of the runs (over 70%) lost 8 to 10 million animals. About 25% of the runs have less than 2 million animals

vaccinated and killed. Scenario 12 (figure 3-8) had most lost across the runs, the majority of the runs lost between 16 million and 30 million animals but close to 10% lost less than 2 million animals. The number of animals lost is very low in scenario 14 (figure 3-9) compared to the other two scenarios. About 90% of the runs lost below 2 million animals. Only one run lost above 4 million animals in scenario 14. Like figure 3-6, figure 3-10 combined the three scenarios on a chart for easy comparison among the scenarios.

Figure 3-7 The distribution of number of animals killed across runs in scenario 2

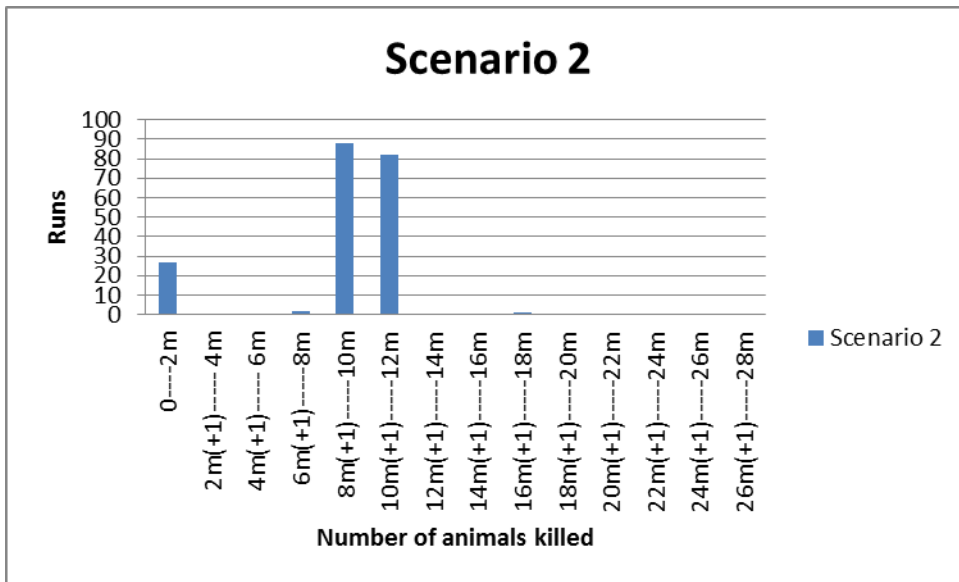


Figure 3-8 The distribution of number of animals killed across runs in scenario 12

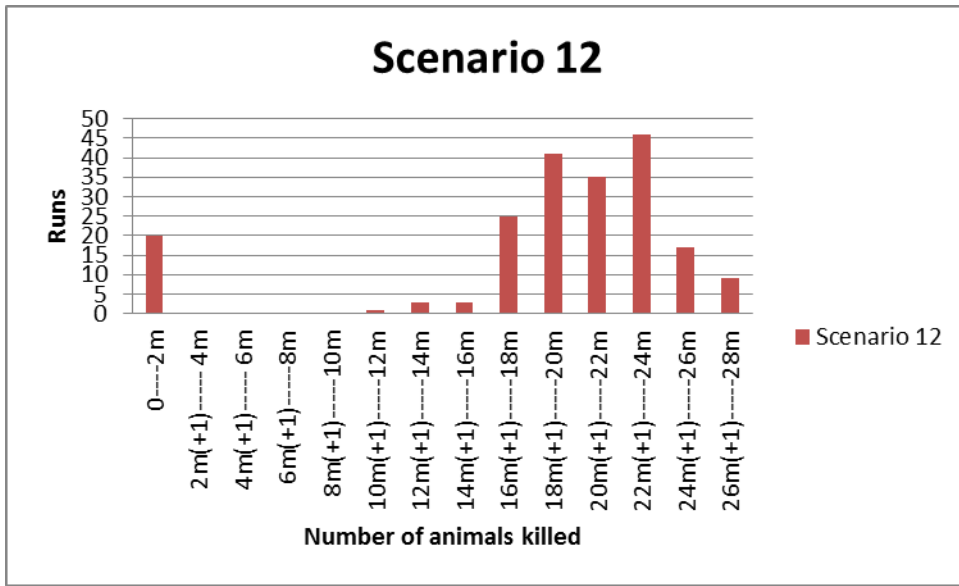


Figure 3-9 The distribution of number of animals killed across runs in scenario 14

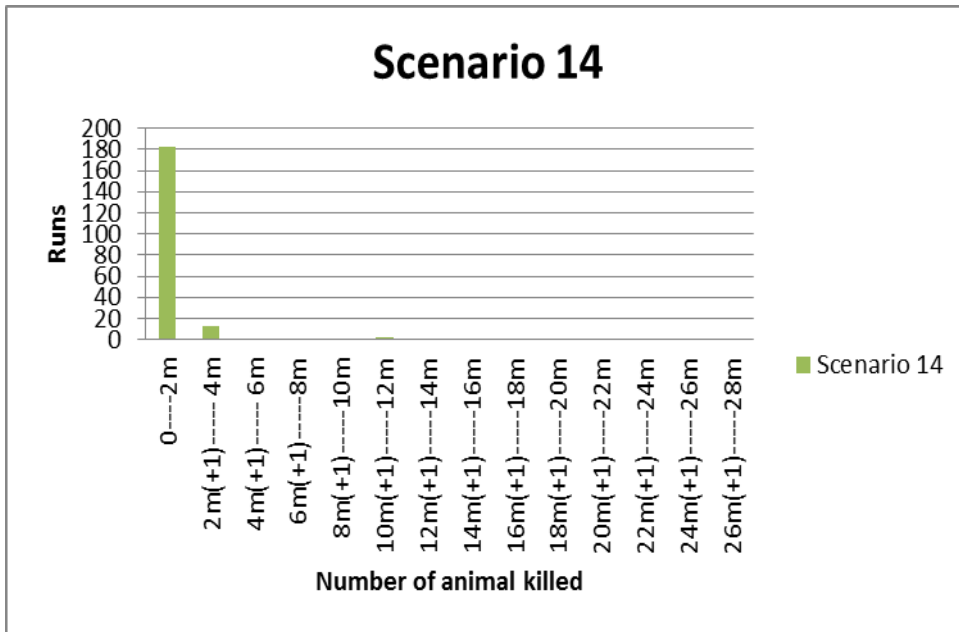
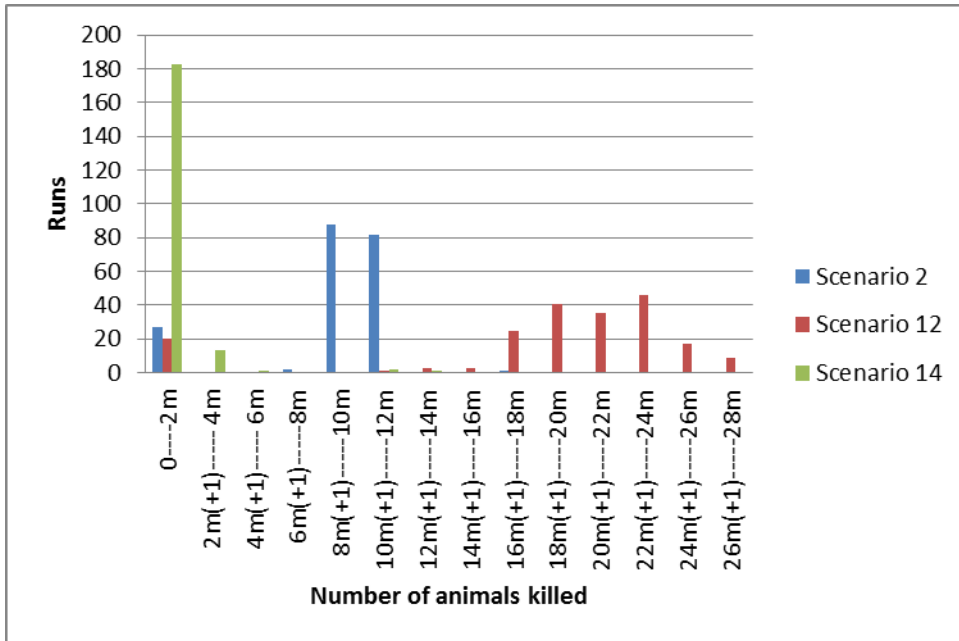


Figure 3-10 The distribution of number of animals killed across runs in in scenario 2, 3, and 14 combined



Figures 3-11, 3-12, and 3-13 show numbers of animals killed using scatter plots across scenarios 2, 12, and 14 respectively. It is shown in figure 3-11 that most of the runs fall on average of 10 million as number of animals killed. Same occurred in scenario 12 (figure 3-12) and scenario 14 (figure 3-13) where the runs are concentrated in a region

Figure 3-11 Scatter plot of number of animals killed across runs in scenario 2

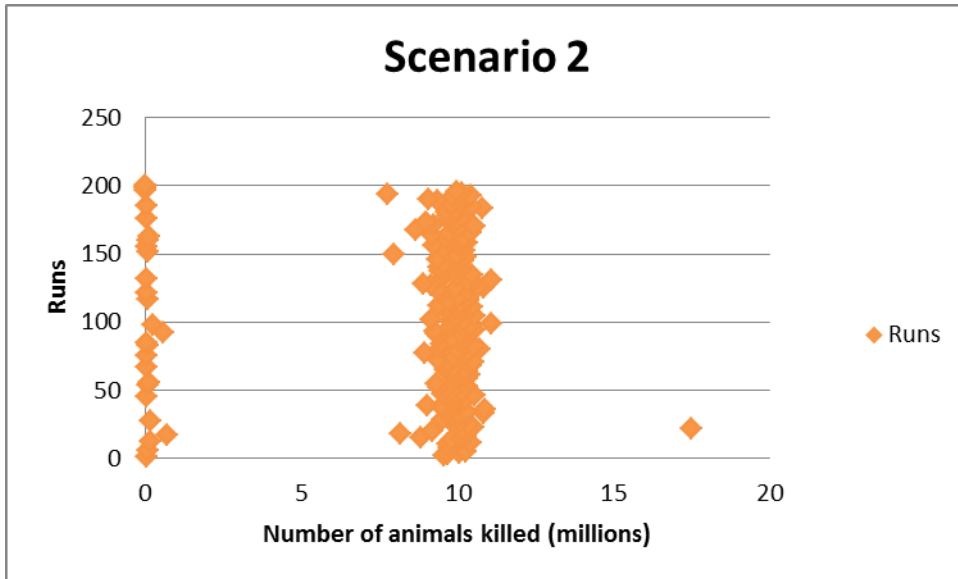


Figure 3-12 Scatter plot of number of animals killed across runs in scenario 12

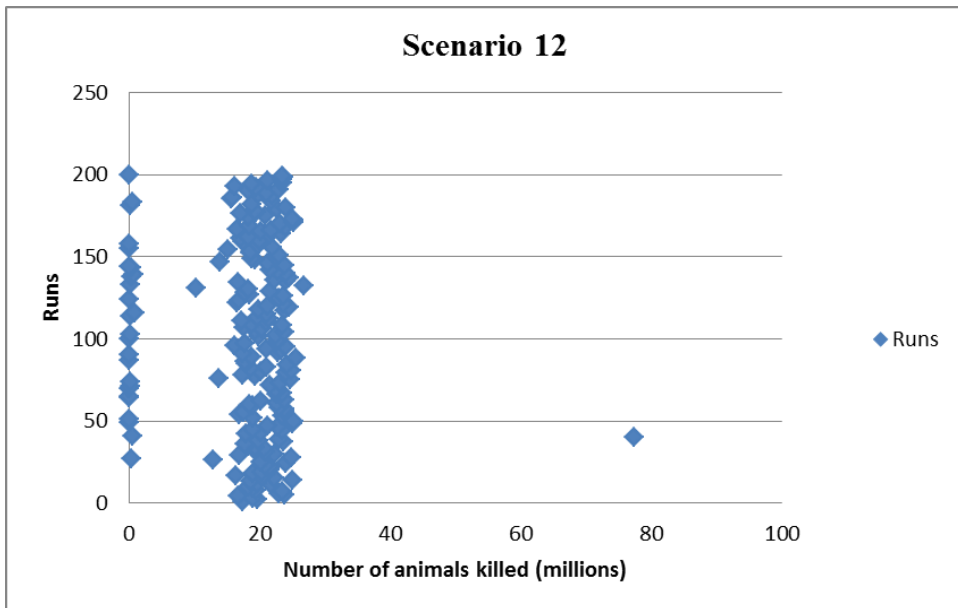
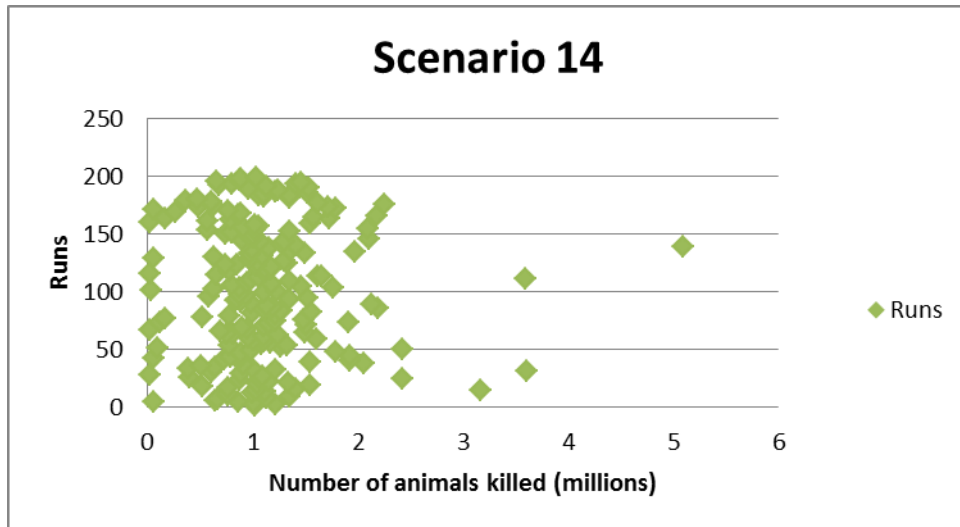


Figure 3-13 Scatter plot of number of animals killed across runs in scenario 14



3.4 - National Animal Disease Spread Model and Equilibrium Displacement Model

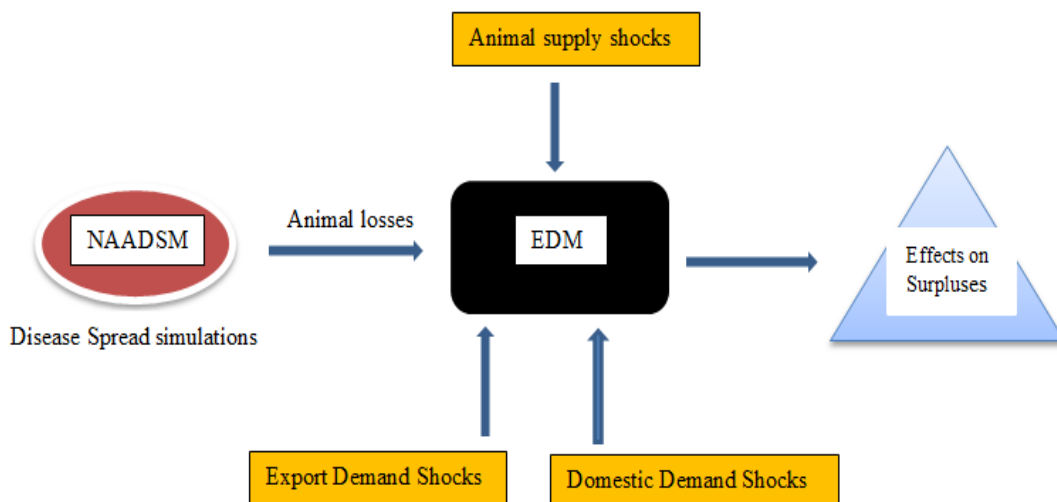
In accessing full impact of FMD, economical and physical impacts, the incorporation of NAADSM and EDM will gives in detail how the impact is distributed. NAADSM is focused mostly on the outbreak of the disease, and also try to see how it is spread, including the best mitigation strategies that can be adopted in reducing the number of animal deaths that can results from an outbreak.

FMD is recognized as an economic disease, because the disease does not have effect only on the livestock producers, it also has significant effect on both the wholesale and the retail sectors of the livestock industry. FMD outbreak even has much bigger effect on the international livestock markets. There are policies that govern international trades of livestock and livestock products. For instance, in any outbreak of FMD, the type of vaccination strategy and the length of the disease duration will affect the international trade of the country of origin of the disease outbreak.

Since NAADSM is mainly focused of the control strategies, incorporation Equilibrium Displacement Model will help to determine the mitigation strategies outcome that will be more economically efficient to the different market chains (producers, wholesales, and the retailers) involve in the livestock business.

EDM use the outcomes from the NAADSM and incorporate the demand and supply shocks to get the changes in the surplus at different market chains in each livestock industry. It is believed that the outbreak of the disease will lead to instant reduction in demand in livestock products both domestically and internationally. This reduction in demand supposed to affect the prices of animals in both local and international markets. Later on, the destruction of the infected animals will lead to reduction in the supply of the animals into the market. This reduction in the market supply will raise the market price back up. But the effect of the demand shift is more powerful than the effect of the supply shift. In this case, the producers will be more affected. The EDM considered both demand and supply shifts. The demand shocks in the EDM model include both local and international. The EDM also put into consideration the price elasticities.

Figure 3-14 The combination of National Animal Disease Model and Equilibrium Displacement Model



3.5 - The Equilibrium Displacement Model (EDM)

In this study, an Equilibrium Displacement Model (EDM) is used to analyze the economic welfare effects of the potential outbreak of FMD in the United States livestock market. The EDM set up follows Schroeder and Tonsor, (2011). The EDM was designed for three

livestock industry sectors: beef, pork, and poultry. FMD does not affect poultry health, but it has an indirect economic effect on poultry markets. Poultry is a substitute to beef and pork, so any change in price or change in supply of these meat products will affect the poultry industry.

The beef industry in the EDM has four sectors: retail (which comprises of the consumers), wholesale (the processor and packer are included in this sector), slaughter (this is the feedlots where the cattle are being fed before they are transferred to the processor/packer), and feeder cattle (farm). The pork industry is classified into three marketing chain sectors: retail, wholesale, and the slaughter hog. The poultry industry is only grouped into two sectors: retail, and wholesale. Demand and supply shocks were developed for all the three livestock species. International trade (Demand) was also incorporated since the United States is a major meat and poultry exporter.

In the structural model, which included series of general demand and supply equations, subscripts r, w, s, and f represents retail, wholesale, slaughter, and farm market levels respectively; subscripts B, K, and Y also represent beef, pork, and poultry respectively. P represents price, Q, Z and W represent quantity, demand and supply shifters, respectively. The model also captures imports (subscript i) and exports (subscript e) of beef, pork, and poultry. Due to the fact that market clearing conditions are imposed requiring demand and supply to be equal, superscripts for demand and supply were omitted in equations (1) – (25).

3.5.1 - Beef Marketing Chain

- 1) Retail beef primary demand

$$Q_B^r = f_1(P_B^r, P_K^r, P_Y^r, Z_B^r),$$

- 2) Retail beef derived supply

$$Q_B^r = f_2(P_B^r, Q_B^w, W_B^r),$$

- 3) Wholesale beef derived demand

$$Q_B^w = f_3(P_B^w, Q_B^r, Z_B^w),$$

4) Wholesale beef derived supply

$$Q_B^w = f_4(P_B^w, Q_B^s, Q_{Bi}^w, Q_{Be}^w, W_B^w),$$

5) Imported wholesale beef derived demand

$$Q_{Bi}^w = f_5(P_{Bi}^w, Q_B^w, Z_{Bi}^w),$$

6) Imported wholesale beef derived supply

$$Q_{Bi}^w = f_6(P_{Bi}^w, W_{Bi}^w),$$

7) Exported wholesale beef derived demand

$$Q_{Be}^w = f_7(P_B^w, Z_{Be}^w),$$

8) Slaughter cattle derived demand

$$Q_B^s = f_8(P_B^s, Q_B^w, Z_B^s),$$

9) Slaughter cattle derived supply

$$Q_B^s = f_9(P_B^s, Q_B^f, W_B^s),$$

10) Farm (feeder cattle) derived demand

$$Q_B^f = f_{10}(P_B^f, Q_B^s, Z_B^f),$$

11) Farm (feeder cattle) primary supply

$$Q_B^f = f_{11}(P_B^f, W_B^f)$$

3.5.2 - Pork Marketing Chain

12) Retail Pork primary demand

$$Q_K^r = f_{12}(P_B^r, P_K^r, P_Y^r, Z_B^r),$$

13) Retail pork derived supply

$$Q_K^r = f_{13}(P_K^r, Q_K^w, W_K^r),$$

14) Wholesale pork derived demand

$$Q_K^w = f_{14}(P_K^w, Q_K^r, Z_K^w),$$

15) Wholesale pork derived supply

$$Q_K^w = f_{15}(P_K^w, Q_K^s, Q_{Ki}^w, Q_{Ke}^w, W_K^w),$$

16) Imported wholesale pork derived demand

$$Q_{Ki}^w = f_{16}(P_{Ki}^w, Q_K^w, Z_{Ki}^w),$$

17) Imported wholesale pork derived supply

$$Q_{Ki}^w = f_{17}(P_{Ki}^w, W_{Ki}^w),$$

18) Exported wholesale pork derived demand

$$Q_{Ke}^w = f_{18}(P_K^w, Z_{Ke}^w),$$

19) Slaughter hog derived demand

$$Q_K^s = f_{19}(P_K^s, Q_K^w, Z_K^s),$$

20) Slaughter hog derived supply

$$Q_K^s = f_{20}(P_K^s, W_K^s),$$

3.5.3 - Poultry Marketing Chain

21) Retail Poultry primary demand

$$Q_Y^r = f_{21}(P_B^r, P_K^r, P_Y^r, Z_B^r),$$

22) Retail poultry derived supply

$$Q_Y^r = f_{22}(P_Y^r, Q_Y^w, Q_{Y_e}^w, W_Y^r),$$

23) Wholesale poultry derived demand

$$Q_Y^w = f_{23}(P_Y^w, Q_Y^r, Z_Y^w),$$

24) Wholesale poultry derived supply

$$Q_K^w = f_{24}(P_Y^w, W_Y^w),$$

25) Exported wholesale poultry derived demand

$$Q_{Y_e}^w = f_{25}(P_Y^w, Z_{Y_e}^w),$$

Variable input proportions are incorporated by allowing production quantities to vary across the market levels in the marketing chain. This was done to be in consistent with Schroeder and Tonsor (2011) and Wohlgenant (1993). Then I totally differentiated all the equations across the three livestock industry, including variable input proportions, and placing all the endogenous variables on the left-hand side of each equation and isolating exogenous effects to the right-hand side of each equation results in the following EDM. E represents a relative change operator (i.e.,

$EQ = d \ln Q = dQ/Q$); η_{α}^m is the own-price elasticity of meat/species a demand at market level m ;

$\eta_{\alpha b}^m$ is the cross-price elasticity of demand for meat a with respect to retail prices of meat b ; ϵ_{α}^m is

the own-price elasticity of meat/species a supply at market level m ; β^{lm} is the percentage change in quantity demanded at market level m given a 1% change in quantity demanded at market level

l ; γ^{lm} is the percentage change in quantity supplied at market level m given a 1% change in quantity supplied at market level l (Schroeder and Tonsor, 2011)

(1*) Retail beef primary demand:

$$EQ_B^r - \eta_B^r EP_B^r - \eta_{BK}^r EP_K^r - \eta_{BY}^r EP_Y^r = EZ_B^r,$$

(2*) Retail beef derived supply

$$EQ_B^r - \varepsilon_B^r EP_B^r - \Upsilon_B^{wr} EQ_B^w = EW_B^r,$$

(3*) Wholesale beef derived demand

$$EQ_B^w - \eta_B^w EP_B^w - \beta_B^{wr} EQ_B^r = EZ_B^w,$$

(4*) Wholesale beef derived supply

$$EQ_B^w - \varepsilon_B^w EP_B^w - \Upsilon_B^{sw} \left(\frac{Q_B^s}{Q_B^w} \right) EQ_B^s - \left(\frac{Q_{Bi}^w}{Q_B^w} \right) EQ_{Bi}^w + \left(\frac{Q_{Be}^w}{Q_B^w} \right) EQ_{Be}^w = EW_B^w,$$

(5*) Imported wholesale beef derived demand

$$EQ_{Bi}^w - \eta_{Bi}^r EP_{Bi}^w - \beta_B^{wr} EQ_B^w = \left(\frac{Q_{Bi}^w}{Q_B^w} \right) EZ_{Be}^w + EZ_{Bi}^w$$

(6*) Imported wholesale beef derived supply

$$EQ_{Bi}^w - \varepsilon_{Bi}^w EP_{Bi}^w = EW_{Bi}^w,$$

(7*) Exported wholesale beef derived demand

$$EQ_{Be}^w - \eta_{Be}^w EP_B^w = EZ_{Be}^w,$$

(8*) Slaughter cattle derived demand

$$EQ_B^s - \eta_B^s EP_B^s - \beta_B^{ws} EQ_B^w = \left(\frac{Q_{Be}^w}{Q_B^w} \right) EZ_{Be}^w + EZ_B^s,$$

(9*) Slaughter cattle derived supply

$$EQ_B^s - \varepsilon_B^s EP_B^s - \Upsilon_B^{fs} EQ_B^f = EW_B^s,$$

(10*) Farm (feeder cattle) derived demand

$$EQ_B^f - \eta_B^f EP_B^f - \beta_B^{sf} EQ_B^s = EZ_B^f,$$

(11*) Farm (feeder cattle) primary supply

$$EQ_B^f - \varepsilon_B^f EP_B^f = EW_B^f$$

3.5.4 - Pork Market Chain

(12*) Retail pork primary demand:

$$EQ_K^r - \eta_{KB}^r EP_B^r - \eta_K^r EP_K^r - \eta_{KY}^r EP_Y^r = EZ_K^r,$$

(13*) Retail pork derived supply

$$EQ_K^r - \varepsilon_K^r EP_K^r - \Upsilon_K^{wr} EQ_K^w = EW_K^r,$$

(14*) Wholesale pork derived demand

$$EQ_K^w - \eta_K^w EP_K^w - \beta_K^{wr} EQ_B^r = EZ_K^w,$$

(15*) Wholesale pork derived supply

$$EQ_K^w - \varepsilon_K^w EP_K^w - \Upsilon_K^{sw} \left(\frac{Q_K^s}{Q_K^w} \right) EQ_K^s - \left(\frac{Q_{Ki}^w}{Q_K^w} \right) EQ_{Ki}^w + \left(\frac{Q_{Ke}^w}{Q_K^w} \right) EQ_{Ke}^w = EQ_K^w,$$

(16*) Imported wholesale pork derived demand

$$EQ_{Ki}^w - \eta_{Ki}^r EP_{Ki}^w - \beta_K^{wr} EQ_K^w = \left(\frac{Q_{Ki}^w}{Q_K^w} \right) EZ_{Ke}^w + EZ_{Ki}^w$$

(17*) Imported wholesale pork derived supply

$$EQ_{Ki}^w - \varepsilon_{Ki}^w EP_{Ki}^w = EW_{Ki}^w,$$

(18*) Exported wholesale pork derived demand

$$EQ_{Ke}^w - \eta_{Ke}^w EP_{Ke}^w = EZ_{Ke}^w,$$

(19*) Slaughter hog derived demand

$$EQ_K^s - \eta_K^s EP_K^s - \beta_K^{ws} EQ_K^w = \left(\frac{Q_{Ke}^w}{Q_K^w} \right) EZ_{Ke}^w + EZ_K^s,$$

(20*) Slaughter hog derived supply

$$EQ_K^s - \varepsilon_K^s EP_K^s = EW_K^s,$$

3.5.5 - Poultry Marketing Chain

(21*) Retail poultry primary demand:

$$EQ_Y^r - \eta_{YB}^r EP_B^r - \eta_{YK}^r EP_K^r - \eta_Y^r EP_Y^r = EZ_Y^r,$$

(22*) Retail poultry derived supply

$$EQ_Y^r - \varepsilon_Y^r EP_Y^r - \Upsilon_Y^{wr} EQ_Y^w = EW_Y^r,$$

(23*) Wholesale poultry derived demand

$$EQ_Y^w - \eta_Y^w EP_Y^w - \beta_Y^{wr} EQ_Y^r = EZ_Y^w,$$

(24*) Wholesale poultry derived supply

$$EQ_Y^w - \varepsilon_Y^w EP_Y^w + \left(\frac{Q_{Y\varepsilon}^w}{Q_Y^w} \right) EQ_{Y\varepsilon}^w = EQ_Y^w,$$

(25*) Exported wholesale pork derived demand

$$EQ_{Y\varepsilon}^w - \eta_{Y\varepsilon}^w EP_Y^w = EZ_{Y\varepsilon}^w,$$

The model is then expressed in matrix form as $RY=Z$ (Schroeder and Tonsor, 2011). R stands for the model matrix parameters (elasticities), Y is the column vector and it represents the endogenous changes in prices and quantities relative to initial equilibrium, and Z is a column vector of percentage changes associated with the occurrence of an FMD outbreak. The model also defined proportional changes in equilibrium prices and quantities for each evaluated market level in response to the exogenous changes due to the FMD outbreak. The proportional changes are represented below:

$$(26*) \quad Y=R^{-1}Z$$

Producer surplus is used to measure the net economic impact of FMD outbreak in the three scenarios. The changes that occur in both consumer and producer surplus due to the FMD outbreak can be calculated in terms of changes in prices and quantities and can be represented by the EDM as the two equations below:

$$(27*) \quad \Delta PS_{\alpha}^m = P_{\alpha}^m Q_{\alpha}^m (EP_{\alpha}^m + EW_{\alpha}^m)(1 + 0.5EQ_{\alpha}^m),$$

In the above equation, producer surplus is denoted PS (Lusk and Anderson, 2004, Schroeder and Tonsor, 2011). The superscript m denotes the market level and subscript a denotes the industry/species evaluated (i.e., beef, pork, or poultry).

Change in total producer surplus is the sum of the change in producer surplus from each market level for a species,

$$\Delta PS_{\alpha} = \sum_m \Delta PS_{\alpha}^m$$

Similarly, total changes in meat industry producer is given by

$$\Delta PS = \sum_m \sum_{\alpha} \Delta PS_{\alpha}^m$$

Solutions to equation (26) require elasticity estimates for the matrix of parameters (R). Identifying these estimates by econometrically estimating structural supply and demand equations for the 25-equation EDM is very difficult to accomplish. As in most EDM applications, direct estimation of elasticities is prohibited by the large number of equations and by identification problems in jointly estimating supply and demand relationships (Brester, Marsh, and Atwood, 2004; Schroeder and Tonsor, 2011).

To capture the dynamic nature of adjustments to livestock and meat markets after the FMD outbreak, the model was simulated quarterly for forty consecutive quarters. Consistent with historical beef cattle cycles, we assume that it takes the marketplace ten years to fully adjust from short run to long-run relationships (Schroeder and Tonsor, 2011). Ten years of market effects were simulated by linearly adjusting all elasticities between short-run (year 1) and long-run (year 10) using elasticity estimates employed by Pendell *et al.* (2010). Supply and Demand Elasticity Definitions, and Estimates and quantity transmission elasticities are summarized in tables 3-3 and 3-4. Similarly, base price and quantity values are necessary to estimate surplus calculations. The market price and quantity values are summarized in table 3-5. Each reflects annual average values for calendar year 2011 as reported by the Livestock Marketing Information Center (LMIC).

The economic impacts are simulated over a 40 quarter period starting from 1st quarter of 2009 through the 4th quarter 2018. All the parameters used are the updated information as defined by (Schroeder and Tonsor, 2011) which include supply and demand elasticity estimates, Quantity Transmission Elasticity Estimates, and Price and Quantity Estimates.

Table 3-3 Supply and Demand Elasticity Definitions and Estimates

Definition	Short-run Estimate	Long-Run Estimate
Own-price elasticity of demand for retail beef	-0.86	1.17
Own-price elasticity of supply for retail beef	0.36	4.62
Own-price elasticity of demand for wholesale beef	-0.58	-0.94
Own-price elasticity of supply for wholesale beef	0.28	3.43
Own-price elasticity of demand for wholesale beef imports	-0.58	-0.94
Own-price elasticity of supply for wholesale beef imports	1.83	10.00
Own-price elasticity of demand for wholesale beef exports	-0.42	-3.00
Own-price elasticity of demand for slaughter cattle	-0.40	-0.53
Own-price elasticity of supply for slaughter cattle	0.26	3.24
Own-price elasticity of demand for feeder cattle	-0.14	-0.75
Own-price elasticity of supply for feeder cattle	0.22	2.82
Cross-price elasticity of demand for retail beef with respect to the price of retail pork	0.10	0.10
Cross-price elasticity of demand for retail beef with respect to the price of retail poultry	0.05	0.05
Own-price elasticity of demand for retail pork	-0.69	-1.00
Own-price elasticity of supply for retail pork	0.73	3.87
Own-price elasticity of demand for wholesale pork	-0.71	-1.00
Own-price elasticity of supply for wholesale pork	0.44	1.94
Own-price elasticity of demand for wholesale pork imports	-0.71	-1.00
Own-price elasticity of supply for wholesale pork imports	1.41	10.00
Own-price elasticity of demand for wholesale pork exports	-0.89	-1.00
Own-price elasticity of demand for slaughter hogs	-0.51	-1.00
Own-price elasticity of supply for slaughter hogs	0.41	1.80
Cross-price elasticity of demand for retail pork with respect to the price of retail beef	0.18	0.18
Cross-price elasticity of demand for retail pork with respect to the price of retail poultry	0.02	0.02
Own-price elasticity of demand for retail poultry	-0.29	-1.00
Own-price elasticity of supply for retail poultry	0.18	13.10
Own-price elasticity of demand for wholesale poultry	-0.22	-1.00
Own-price elasticity of supply for wholesale poultry	0.14	14.00
Own-price elasticity of demand for wholesale poultry exports	-0.31	-1.00
Cross-price elasticity of demand for retail poultry with respect to the price of retail beef	0.18	0.18
Cross-price elasticity of demand for retail poultry with respect to the price of retail pork	0.04	0.04

Note: All supply and demand elasticities estimates correspond to those used by Schroeder and Tonsor (2011) and Pendell et al. (2010) assumptions. Short-run and long-run refer to quarters one and ten, respectively.

Table 3-4 Quantity Transmission Elasticity Definitions and Estimates

Definition	Estimate
Percentage change in retail beef supply given a 1% change in wholesale beef supply	0.771
Percentage change in wholesale beef supply given a 1% change in slaughter cattle supply	0.909
Percentage change in slaughter cattle supply given a 1% change in feeder cattle supply	1.07
Percentage change in wholesale beef demand given a 1% change in retail beef demand	0.995
Percentage change in slaughter cattle demand given a 1% change in wholesale beef demand	1.09
Percentage change in feeder cattle demand given a 1% change in slaughter cattle demand	0.957
Percentage change in retail pork supply given a 1% change in wholesale pork supply	0.962
Percentage change in wholesale pork supply given a 1% change in slaughter hogs supply	0.963
Percentage change in retail pork supply given a 1% change in wholesale pork supply	0.962
Percentage change in slaughter hogs demand given a 1% change in wholesale pork demand	0.961
Percentage change in retail poultry supply given a 1% change in wholesale poultry supply	0.806
Percentage change in retail poultry supply given a 1% change in wholesale poultry supply	1.035

Note: all values equal to NAIS Ben-Cost; Pendell et al. AJAE assumptions

Table 3-5 Price and Quantity Definitions and Estimates

Definition	Estimate
Quantity of retail beef, billion pounds (retail weight)	17.948
Quantity of wholesale beef, billion pounds (carcass weight)	26.199
Quantity of beef obtained from slaughter cattle, billion pounds (live weight)	43.284
Quantity of wholesale beef imports, billion pounds (carcass weight)	2.056
Quantity of wholesale beef exports, billion pounds (carcass weight)	2.788
Quantity of beef obtained from feeder cattle, billion pounds (live weight)	27.791
Price of retail (Choice) beef, cents per pound	482.717
Price of wholesale (Choice) beef, cents per pound	180.03
Price of wholesale beef imports, cents per pound	191.998
Price of slaughter cattle, \$/cwt (live weight)	114.74
Price of feeder cattle, \$/cwt	135.04
Quantity of retail pork, billion pounds (retail weight)	13.459
Quantity of wholesale pork, billion pounds (carcass weight)	22.556
Quantity of pork obtained from slaughter hogs, billion pounds (live weight)	30.143
Quantity of wholesale pork imports, billion pounds (carcass weight)	0.803
Quantity of wholesale pork exports, billion pounds (carcass weight)	5.193
Price of retail pork cents per pound	343.35
Price of wholesale pork, cents per pound	93.8
Price of wholesale pork imports, cents per pound	58.974
Price of slaughter hogs, \$/cwt (live weight)	65.235
Quantity of retail poultry, billion pounds (retail weight)	25.904
Quantity of wholesale poultry, billion pounds (carcass weight)	47.814
Quantity of wholesale poultry exports, billion pounds (carcass weight)	6.991
Price of retail poultry, cents per pound	176.6
Price of wholesale poultry, cents per pound	82.48

Note: All quantity and price values are based on 2011 annual average as obtained from the Livestock Marketing Information Center

3.6.0 Other assumptions in the equilibrium Displacement Model

3.6.1 - 2011 prices and quantities:

1. Cow-herd losses: one-half are cows; one half are equally split steers and heifers
2. Swine losses are valued as 10% sows and 90% market hog losses
3. Dairy losses are all dairy cow losses

3.6.2 - Losses at the slaughter cattle level:

1. Beef Cows (1/2 of beef cows) head * 12.80cwt * \$114.74/cwt = VALUE LOSS
 2. Dairy cows head * 12.80 cwt * \$114.74/cwt = VALUE LOSS
 3. Fed cattle head * 12.80 cwt * \$114.74/cwt = VALUE LOSS
- Sum Total Slaughter Cattle loss = SUM of the LOSSES

3.6.3 - Losses at feeder cattle level:

1. ½ of beef cows head * 5.50 cwt * \$135.04/cwt = VALUE LOSS

3.6.4 - Losses at Swine level:

1. Swine head * 2.74 cwt * \$65.238/cwt = VALUE LOSS

3.6.5 - Market Demand Assumptions:

1. Domestic demand – Even though FMD has not proven to be zoonotic, consumers may have concerns about outbreak of any disease. This kind of perception towards food and health safety by domestic consumers could impact domestic demand of livestock products in case of any outbreak of FMD. The same rule was used recently in NBAF (2012) with outbreaks that last only a quarter with the demand shock being a 5% reduction that quarter and 2.5% the next on beef and pork but 2.5% for dairy products reducing to 0% the second quarter. For outbreaks that last more than a quarter, go 10% reduction in meat demands for each quarter of outbreak (5% for dairy products) then go to 5% for meat (2.5 for dairy) first quarter after outbreak and 2.5% meat (0% dairy) second quarter after outbreak.
2. Export market- Since the international trade is a very important part of US livestock markets, international trade is evaluated by allowing for export market bans on livestock and meat products. This study used the same rules used in NBAF. With a 95% reduction

in trade from start of outbreak until the first quarter where there is no outbreak, then decrease to 85%, 70%, 50%, 40%, 30%, 10%, and 5% through subsequent quarters.

Supply – In vaccinated to die scenarios, animals infected by FMD virus were depopulated immediately after vaccination. The numbers of animals depopulated were taken from NAADSM simulations. The animals killed were converted to percentage changes in supply and incorporated into the economic model.

Chapter 4 - RESULTS

The results were grouped into different categories comprised of the beef, pork, and poultry sectors. The combined result of the three scenarios is presented in Table 4-1 below. The result show the average economic impact experienced at each market chain across the three scenarios. The result is presented in mean value, our main focus is to know the distribution of the economic impact. The mean/median values reported by most researchers do not actually show how the outcomes are distributed. In some cases, there may be outliers that will make the economic impact distribution to be skewed. In situation of a skewed distribution, it means that the outcomes were not normally distributed, and the mean or median value cannot be used in measuring the economic impact. The result in Table 4-1 is in million dollars. Those negative values means there is loss to the surplus while positive value means that there is gain to the surplus. In the table, the producers' surpluses were presented differently for the three livestock industries. The producers' surpluses were also differentiated into different market levels. The beef industry has four market chains which include; retailer, wholesale, slaughter, and feeders. But in the pork sector, it has only three market chains comprised of retailer, wholesale, and slaughter hog. There are only two market chains in the poultry market, retailer and wholesale. The consumer surplus was presented for the whole meat industry under each scenario. The net surplus is also included.

Table 4-1 The result (mean values) of the three scenarios (2, 12, and 14) across all the market chain level in million dollars

Scenario Number	Scenario 2	Scenario 12	Scenario 14
NPV - Retailer Beef PS:	1,407	1,921	653
NPV - Wholesale Beef PS:	1,526	1,988	707
NPV - Slaughter Cattle PS:	-1,339	-1,616	-764
NPV - Feeder Cattle PS:	-2,770	-3,445	-1,457
NPV - Retailer Pork PS:	-225	-180	-173
NPV - Wholesale Pork PS:	-149	-147	-104
NPV - Slaughter Hog PS:	-292	-285	-190
NPV - Retailer Poultry PS:	30.78	44.65	13.52
NPV - Wholesale Poultry PS:	-0.00	-0.00	-0.00
NPV - Beef Ind. PS:	-1,177	-1152	-861
NPV - Pork Ind. PS:	-666	-612	-467
NPV - Poultry Ind. PS:	30.78	44.58	13.52
Net producer Surplus	-1,812	-1,719	-1,315

Beef: The result shows that in the beef industry, most losses occur at the slaughter cattle and feeder cattle level. The retailers and the wholesalers enjoyed incremental gains in their surplus. The greatest loss occurred in scenario 12 at the feeder cattle level. The feeder cattle experienced about 3.4 billion dollars reduction in income compared to scenario 2 and 14 with about 2.8 billion and 1.5 billion dollars losses respectively. In other words, the wholesale Beef and Retail beef section experienced the highest incremental welfare gain. Each of the two sectors had about 2 billion dollars gain in welfare.

Pork: Unlike the beef industry, the pork industry suffers surplus losses at each market sector. The greatest loss occurred in the slaughter hog sector followed by the retail level. Scenario 2 experienced the greatest welfare loss in all the three marketing chains under the pork industry.

Poultry: The poultry industry only contains two marketing chains; retail and wholesale. The effect of Foot-and-mouth disease outbreak on the poultry industry is negligible at the wholesale level. The retail level experienced a gain in surplus. Scenario 12 had the highest gain with about 44 million dollars added to welfare, followed by scenario 2 with gain of approximately 31 million dollars. Scenario 14 has the least gain amounting to 13.5 million dollars.

All the three scenarios had huge loss in the total producer surplus but the highest loss occurred under scenario 2, scenario 14 had the smallest loss in producer surplus.

Consumer surplus: Consumer surpluses are reduced in all the three livestock industries, except in scenario 14 at the pork industry. In scenario 14, consumers experienced gain in surplus amounting to approximately 12 million dollars. Scenario 12 had the largest loss in all the three livestock industry. When putting the net consumer loss in the meat industry together, the three livestock industries underwent loss in consumer surplus. Scenario 12 lost about 2.7 billion in total consumer surplus followed by scenario 2 with lost aggregate of about 2.1 billion dollars. Just like the producer surplus, scenario 14 also had the smallest loss in the consumer surplus, it only lost 950 million dollars.

Going through the outcome under the three scenarios, the loss to consumer surplus is higher than that of the producer surplus except in scenario 14 that has greater loss to the producer surplus than the consumer surplus.

4.1 - Graphical representation of the welfare distribution

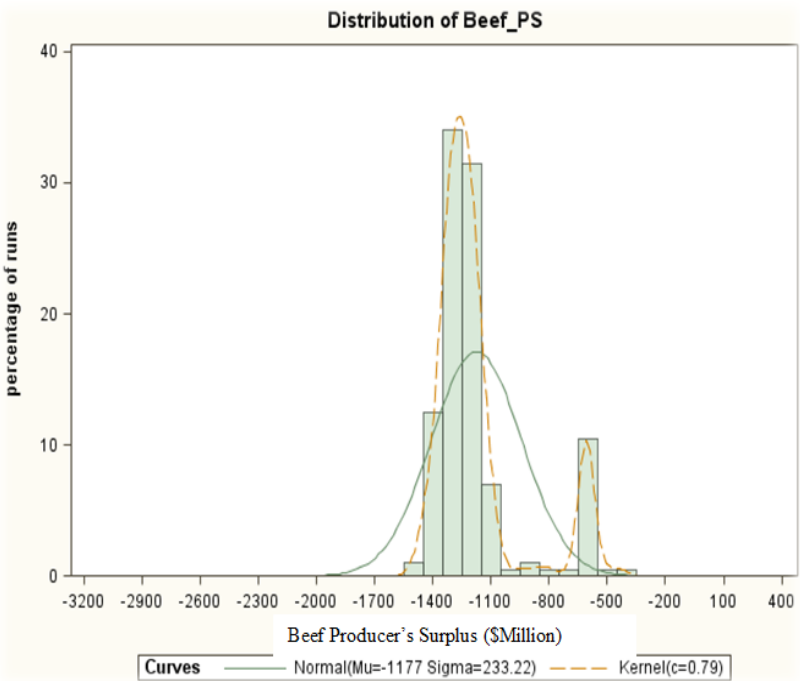
In order to be able to relate the losses at each marketing chain within the three different livestock industries, a Normal curve with a Histogram is used to see the distribution of the effect on consumer surplus in each scenario. These distribution curves can also help the decision makers to easily compare the scenario within and among livestock industries.

4.1.1 - Beef industry

The normal distribution curve/ bell curve give detail on how the outcome of each scenario is distributed. It also allows us to see if there is any outlier in the data. In the beef sector, the distribution of producer surplus is different across the three scenarios (2, 12 and 14). Both scenario 2 and 14 are positively skewed while scenario 12 distribution is negatively skewed. The

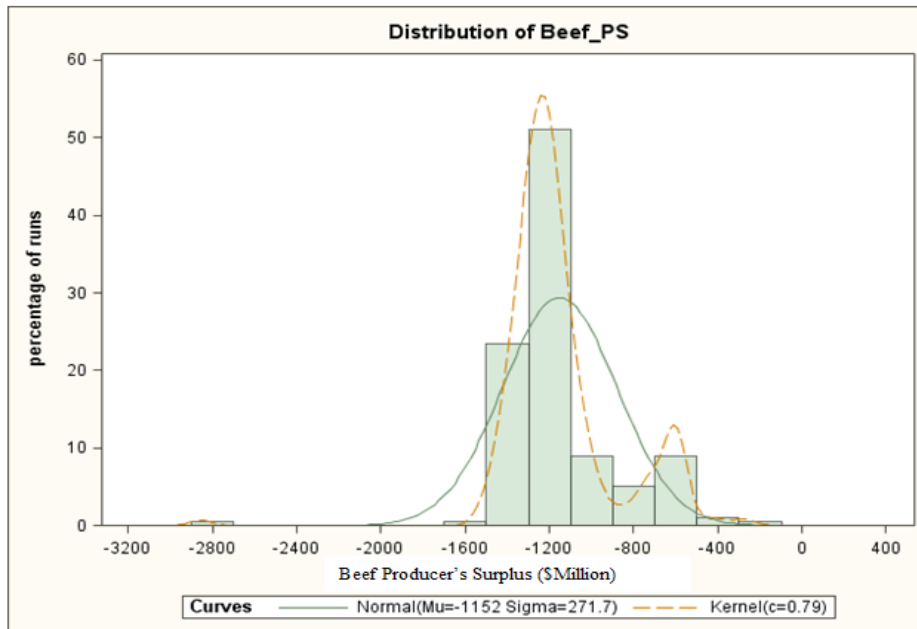
curves showed that the three scenarios have very low probability ($p < 0.00003$) of not experiencing loss, that is, zero loss or positive gain to the producer surplus. But the rate of loss is different across the three scenarios. Putting the loss level at \$1 billion scenario 2 has the greatest probability of losing more than \$1 billion than the other two scenarios (12 and 14). Scenario 12 (figure 4-2) has a 0.78 probability of losing more than \$1 billion in surplus to the producer, while scenarios 2 and 14 chances of losing more than \$1 billion to the producer surplus are 0.71 and 0.14 respectively. Scenarios 12 and 2 are close in the size risk of loss they possess to the producers. The outcome is not normally distributed, we cannot use the mean and the standard normal deviation from the mean to predict future outcome in all the three scenarios. But using confidence interval gotten from the outcome data directly, Scenario 14 is better than both scenario 2 and 12. In other words, if the scenario is repeated several times, there is 95% confidence of having the loss to the producer surplus to fall between \$602 million to \$1.44 billion, \$601 million to \$1.442 billion, and \$603 million to \$1.023 billion, for scenario 2, 12, and 14 respectively. In figure 4-1, the curve showed that there are outliers in the data outcome. Also in scenario 14 (figure 4-3), but the outliers in scenario 14 are not far from mean like scenario 2. All the three curves are not normally distributed under Shapiro-Wilk test for normality ($p < 0.0001$). The outcome data in Scenario 2 is more spread from the mean than other two scenarios. Scenario 14 has the most of its outcome close to the mean value. Since the distribution is not normally distributed in the three scenarios, this shows the fact that it is inaccurate to make decision solely on the mean and the standard deviation values. For instance, in Scenario 2, there were lots of outliers (about 15%) which definitely had effect on outcome of the mean and median value. In case of an outbreak and scenario 2 strategy is adopted, there is very high chance of outcome may fall between \$500 million to \$700 million loss to the producer surplus, whereas the average loss to the producer surplus was \$1.2 billion dollars from the outcome data. This shows that it will be very difficult to conclude with the mean value. From the three curves, it shows the best strategy that will be more beneficial to the beef producer is the scenario 14, under which the vaccination trigger is 10, 50 km vaccination zone, and 50, 80 vaccination capacity at 22 and 40 days respectively.

Figure 4-1 The normal distribution curve with Histogram of beef producer surplus under Scenario 2



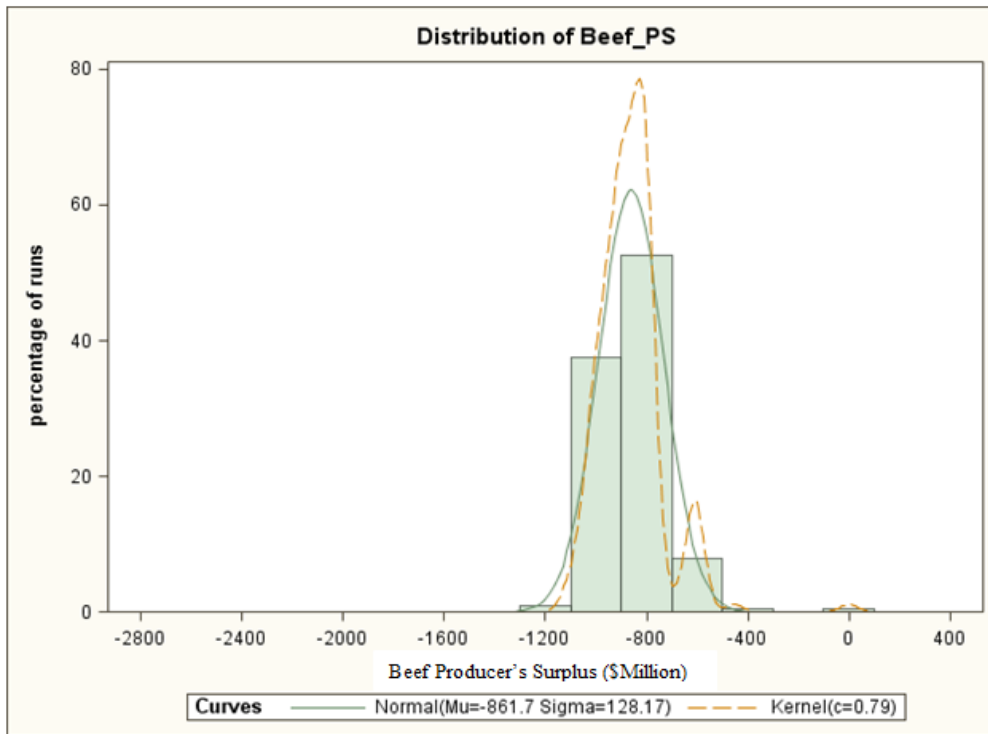
In Scenario 2, the beef industry has an average of \$1.177billion loss to the producer. The median loss stood at \$1.24 billion. Across the 200 runs, the highest loss was \$1.5 billion and lowest loss \$434 million which put the range in losses to stand at \$1.065 billion

Figure 4-2 The normal distribution curve with Histogram of beef producer surplus under Scenario 12



The beef industry, under Scenario 12 acquired an average of \$1.152billion loss to the producer. The median loss stood at \$1.209 billion. Also check across the 200 runs, the highest loss was \$2.858 billion and lowest loss \$269 million which put the range in losses to stand at \$2.589 billion.

Figure 4-3 The normal distribution curve with Histogram of beef producer surplus under Scenario 14



The beef industry, under Scenario 14 has an average of \$862million loss to the producer. The median loss stood at \$872 million. Across the 200 runs, the highest loss was \$1.118 billion and lowest loss \$0.000 million which put the range in losses to stand at \$1.118 billion.

From the distribution shown above, it showed that the major difference is in Scenario 14, scenario 2 and 12 are similar under in the loss to the beef producer surplus. Scenario 12 and 14 have the same vaccination capacities, but different in vaccination zone area. In order words, scenario 2 and 12 also have size of vaccination's zone in common, but differ in the vaccination capacity. The result showed that the vaccination capacity does not have strong impact in determining the best mitigation strategy to employed in case of any outbreak. Since scenario 14 is differ from the two other scenarios in size of vaccination zone (scenario 14 is 50 km while scenario 2 and 12 is 10km), and there is major difference in the outcome from scenario 14 to the two other scenarios, it means size of vaccination zone is very important in reducing the loss to the beef producer surplus. Scenario 12 is slightly better than scenario 2 when the probability of loss to occur is increased. For instance, probability that the beef producer surplus will lose more than \$1.25 billion is 0.48 for scenario 2 while is 0.38 for scenario 12, but less than 0.005 for

scenario 14. We can also say that the probability that greater loss will occur in both scenarios 2 and 12 than scenario 14 is high. Table 4-2 below summarized the probability at the two different loss level we used above.

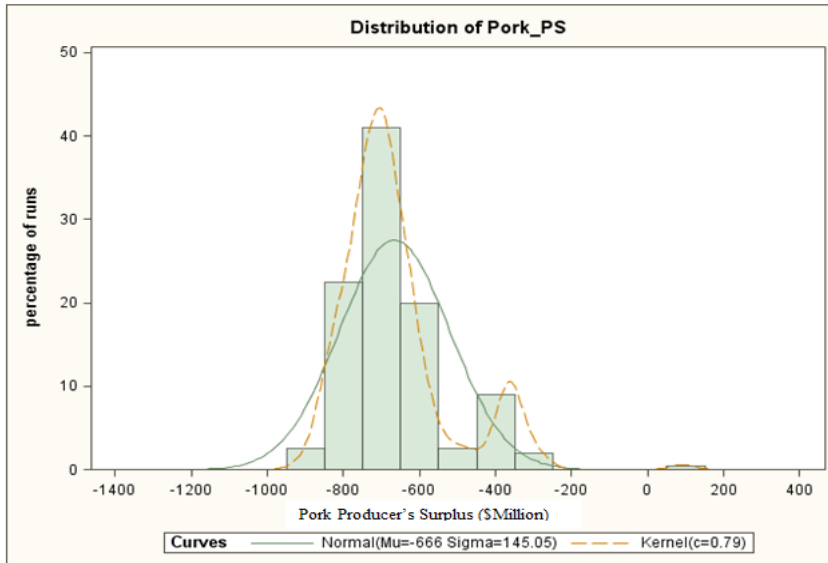
Table 4-2 The probability of loss occurrence at different levels across scenario 2, 12, and 14

Loss Probability	SCENARIOS		
	2	12	14
P(Loss > \$1.00billion)	0.86	0.84	0.1
P(Loss > \$1.25billion)	0.48	0.38	<0.005

4.1.2 - Pork industry

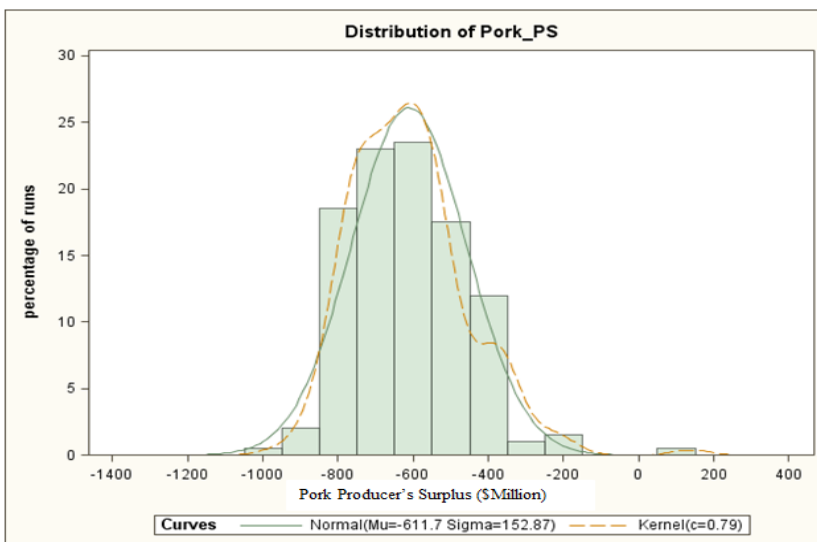
Just like what the distribution of impact look like in the beef producer surplus, Figure 4-4, figure 4-5, and figure 4-6 show the distribution of economic impact FMD outbreak on the pork producer surplus under scenario 2, 12, and 14 respectively. The bell shape in scenario 2 is highly positively skewed, most of the data are towards the left side of the bell curve, but scenario 12 in figure 4-4 is slightly positively skewed. The outcome data in scenario 14 is symmetrically distributed, this makes most of the data to be close to the mean (\$467 million), also indicate very low deviation (\$92 million) from the average loss. There is very high chance of loss under scenario 2 than the two other scenarios. In scenario 2, chance of having more than \$1billion loss to the producer’s surplus is 10.72%. But the chance is very low in Scenario 12 and 14 with 0.55% and less than 0.003% respectively. To find the Scenario that is can be refer to best mitigation strategy to the pork producer, the chance of having more than \$500 million loss to the pork producer surplus was put into consideration. Distribution in figure 4-4 shows that using the mitigation strategy in Scenario 2, the pork producers will have 87.40 % chance of losing more than \$500 million to their surplus. Figure 4-5 indicates the loss of more than \$500 million to the pork producer surplus stands at 0.77 probability. Scenario 14, just like in the beef section seems to be the mitigation strategy to the pork producers because it has low probability of loss more than \$500 million occurring.

Figure 4-4 The normal distribution curve with Histogram of pork producer surplus under Scenario 2



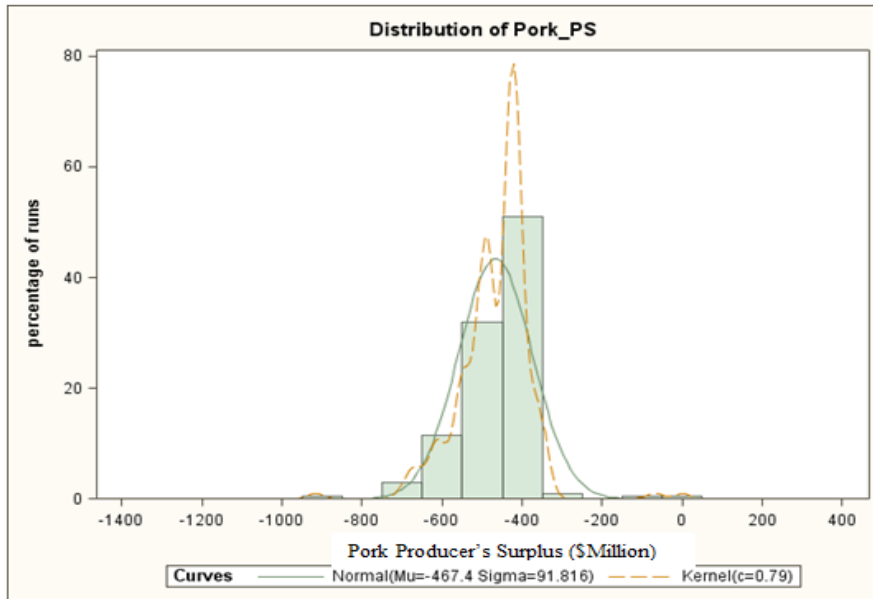
The Pork industry, under Scenario 2 has an average of \$666 million loss to the producer. The median loss stood at \$693 million. Across the 200 runs, the highest loss was \$916 million and highest gain \$91 million which put the range between highest loss and top gainer to be \$1.007 billion

Figure 4-5 The normal distribution curve with histogram of pork producer surplus under Scenario 12



The Pork industry, under Scenario 12 has an average of \$612 million loss to the producer. The median loss stood at \$621 million. Across the 200 runs, the highest loss was \$964 million and highest gain \$139 million which put the range between highest loss and top gainer to be \$1.103 billion

Figure 4-6 The normal distribution curve with histogram of pork producer surplus under Scenario 14



The Pork industry, under Scenario 14 has an average of \$467 million loss to the producer. The median loss stood at \$432 million. Across the 200 runs, the highest loss was \$917 million and highest gain \$0.000 million which put the range between highest loss and top gainer to be \$917 million

4.1.3 - Poultry industry

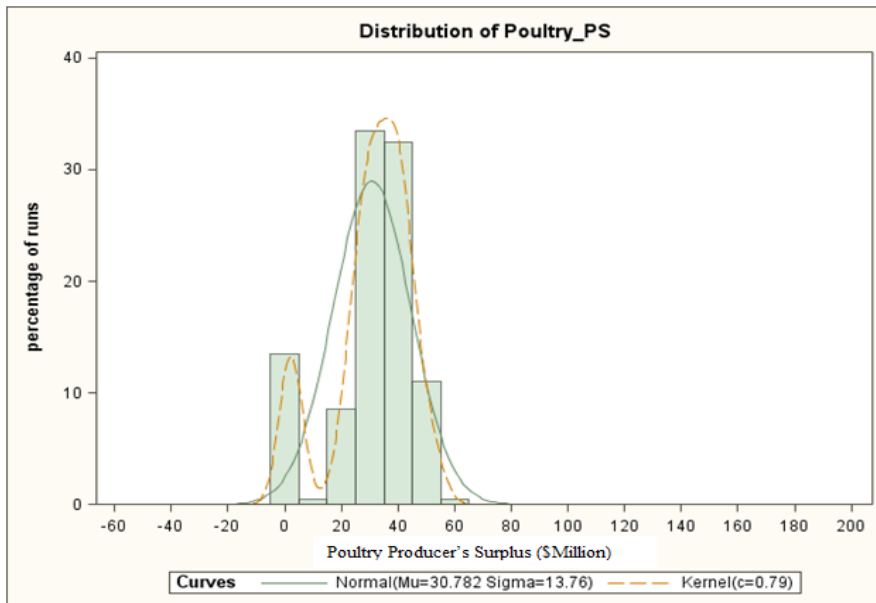
Since Foot and Mouth Disease only affect ruminant animals. In case of any outbreak of the disease, poultry stand as immediate substitute to both pork and beef. It is expected that the supply of beef and pork will reduce, and consumer will prefer to shift to their demand on poultry product. The poultry price is expected to increase and also lead to increase in the surplus to the poultry producers.

Figure 4-7, figure 4-8 and figure 4-9 shows how the impact on the surplus from 200 runs in each scenario is distributed across scenario 2, 12, and 14 respectively. In the three distribution curves, it shows that the chance of a poultry producer losing part of his surplus is very low; rather, there is high chance of gaining. Scenarios 12 and 14 have high probability of gaining more in the surplus which stand at 98.9% and 99.11% for scenario 12 and 14 respectively. Distributions in scenario 2 and 12 have outliers which make both distributions to be highly skewed to the left (negatively skewed). Scenario 14 outcomes are symmetrically distributed. From another statistical view, if there is an outbreak of FMD with these mitigation strategies in

place, the chance for the gain to be between \$3.26 million and \$58.30million is 95% in scenario 2. Also at 95% confidence interval, the gain to poultry producer surplus in scenario will fall between \$5.7million and \$83.45million. The gain will be between \$2.14 million and \$24.91 million for scenario 14 also at 95% confidence interval.

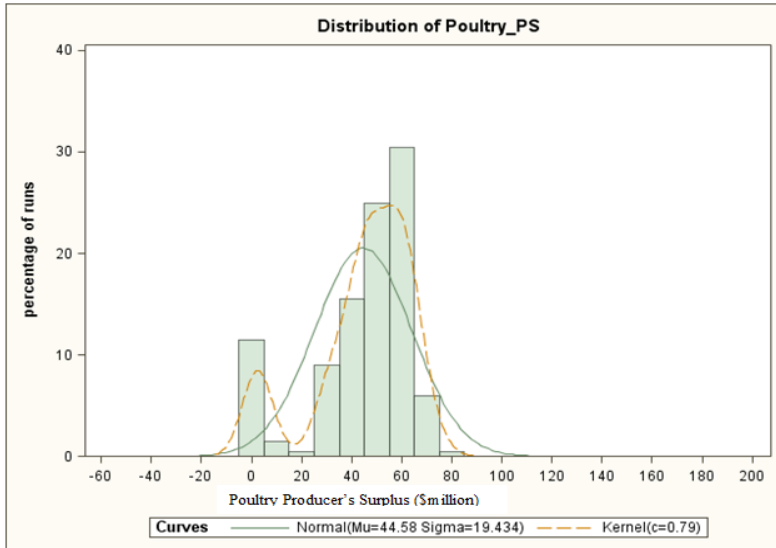
Across the three livestock industries, producer surplus suffer most lost under scenario 2, while the least loss was under scenario 14. In all the industries, scenario 2 and 12 outcome are similar. But scenario 14 is much different from the others. But the gain to the poultry producer surplus is lowest in scenario 14. As expected, the more the loss in beef and pork sectors due to an FMD outbreak, the more the gain in the surplus to the poultry producers. From the outcome, the indirect impact of FMD on the producer surplus in the poultry sector is not as large as the direct impact on the producers' surplus in both beef and pork sectors.

Figure 4-7 The normal distribution curve with histogram of poultry producer surplus under Scenario 2



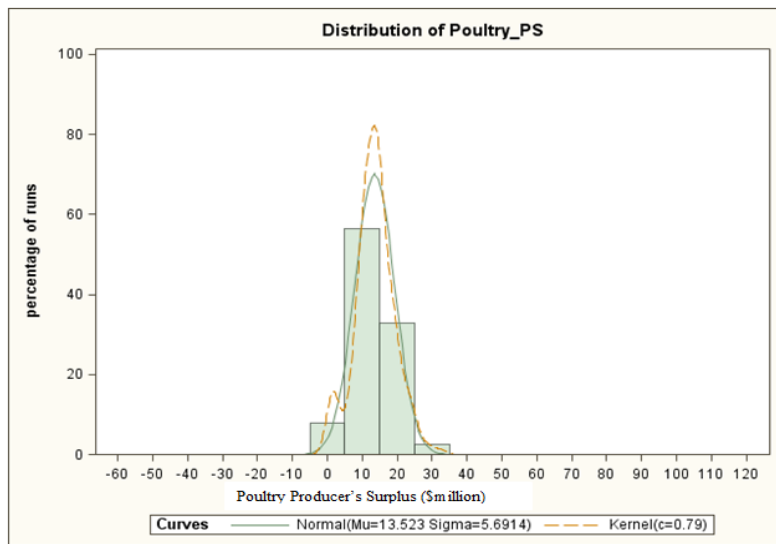
The Poultry industry, under Scenario 2 has an average of \$30.8 million in gain to the producer. The median gain stood at \$33 million. Across the 200 runs, the lowest gain was \$0.77 million and highest gain \$56 million which put the range between lowest and top gainer to be \$55 million

Figure 4-8 The normal distribution curve with histogram of poultry producer surplus under Scenario 12



The Poultry industry, under Scenario 12 has an average of \$44.6 million in gain to the producer. The median gain stood at \$48 million. Across the 200 runs, the lowest gain was \$158,000 and highest gain \$75.74 million which put the range between lowest and top gainer to be \$75.73 million

Figure 4-9 The normal distribution curve with histogram of poultry producer surplus under Scenario 14

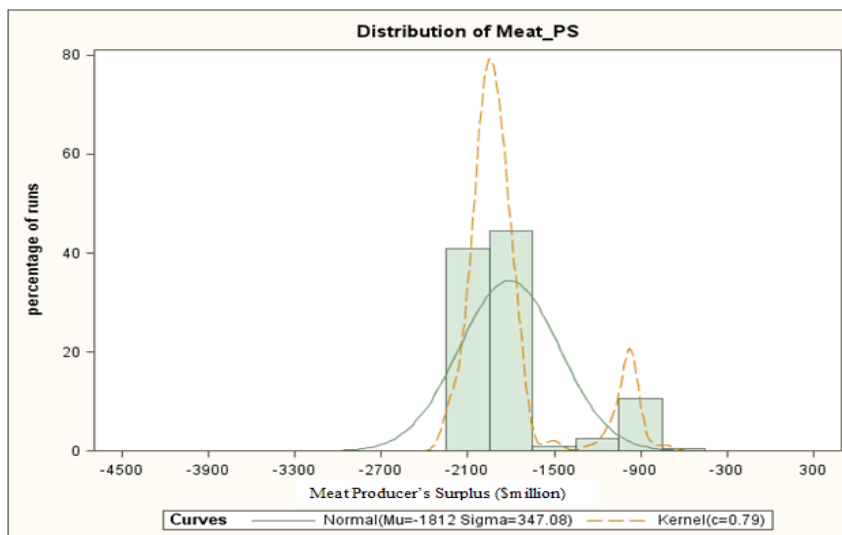


The Poultry industry, under Scenario 14 has an average of \$13.52 million in gain to the producer. The median gain stood at \$13.50 million. Across the 200 runs, the lowest gain was \$0.000 million and highest gain \$32.45 million which put the range between lowest and top gainer to be \$32.45 million.

4.1.4 - Producer surplus all meat industry

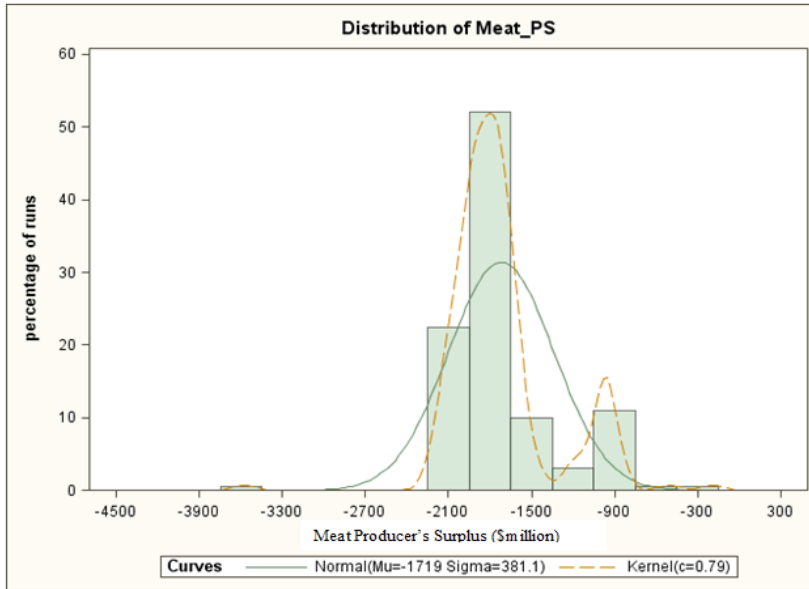
Measuring the welfare impact on producer surplus in the livestock industry as a whole is very important. The distribution curves in figure 4-10, figure 4-11 and figure 4-12 shows the how the outcome of 200 runs of impacts are being distributed in each scenario. In the distribution curves, as it is shown in figure 4-10 have outliers that are little bit far from the mean. This makes the curve to be highly positively skewed. Scenario 12 (figure 4-11) has the less skewed curve towards the right. Scenario 14 is also positively skewed. The probability of observing any outcome with no loss to the producer surplus is very low ($p < .003\%$) for all the three scenarios. To determine the Scenario that is more economically beneficial among the three different scenarios, if we put the loss level on \$2 billion, scenario 2 has the highest risk of losing more than \$2 billion to the producers' surplus at probability of 0.299 compare to Scenario 12 that stand at 0.229, while Scenario 14 has the lowest risk of losing more than \$2 billion at 0.0004 probability level. But the probabilities increased if the loss level is put at \$1 billion. Scenario 2, 12, and 14 have 99.04%, 96.99%, and 93.94% respectively as chances of losing more than \$1 billion to the producers' surplus in the meat industry.

Figure 4-10 The normal distribution curve with histogram of Producer surplus for all meat industry under Scenario 2



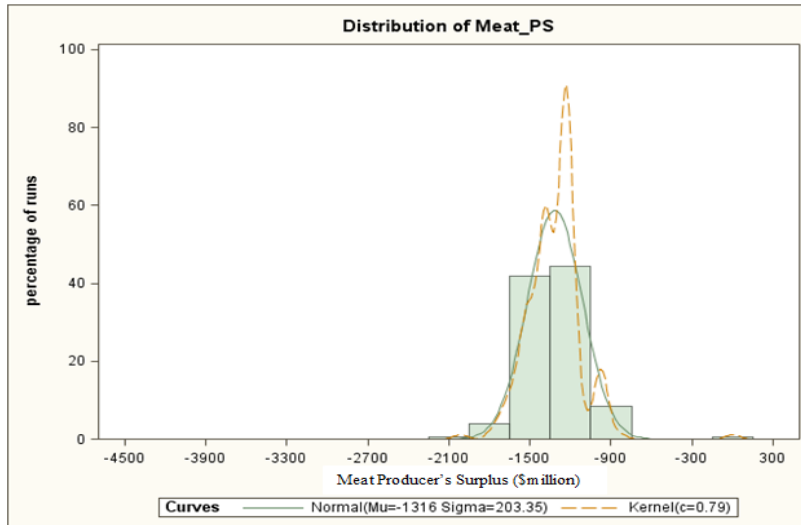
The Meat industry, under Scenario 2 has an average of \$1.812 billion as total loss to the producer. The median total loss stood at \$1.921 billion. Across the 200 runs, the lowest total loss in meat industry to the producers recorded was \$714.955 million and highest is \$2.244 billion which put the range of loss at \$1.529 billion

Figure 4-11 The normal distribution curve with histogram of Producer surplus for all meat industry under Scenario 12



The Meat industry, under Scenario 12 has an average of \$1.719 billion as total loss to the producer. The median total loss stood at \$1.792 billion. Across the 200 runs, the lowest total loss in meat industry to the producers recorded was \$188.664 million and highest is \$3.574 billion which put the range of loss at \$3.385 billion

Figure 4-12 The normal distribution curve with histogram of Producer surplus for all meat industry under Scenario 14



The Meat industry, under Scenario 14 has an average of \$1.316 billion as total loss to the producer. The median total loss stood at \$1.271 billion. Across the 200 runs, the lowest total loss in meat industry to the producers recorded was \$0.000 million and highest is \$2.014 billion which put the range of loss at \$2.014 billion

4.2 Effect of FMD outbreak on equilibrium prices

In evaluation of the effects of an FMD outbreak on consumers, generally consumer surplus is measured in the similar way as was producer surplus. However, in this particular application where beef and pork demand are each shifting exogenously and beef, pork, and poultry are demand substitutes, direct consumer surplus measures from each sector will not be measured correctly using the same direct approach as was done for producer surplus (e.g., see Thurman, 1991). Thus, here instead of measuring consumer surplus changes associated with an FMD outbreak, distributions of retail price changes (as well as farm price changes) are examined to infer how domestic consumers would be impacted.

4.2.1 Effect of FMD Outbreak on Retail Beef Prices

Retail beef price outcomes from each FMD outbreak scenario are not normally distributed. In Scenario 2 (Figure 4-13), about 18 percent experienced between 0.1 to 0.3 percent increases in prices while the majority of the runs realized percentage increase between 1.10% to 2.9%. As such, using mean values to check the economic impact of FMD under Scenario 2 will not give representative results of central tendency. It will also be difficult to predict price outcomes under Scenario 2 because of the outliers. Overall, consumers would expect to realize price increases in the 1 to 3% range under this scenario. Scenario 12 (Figure 4-14) is less spread compared to Scenario 2. The price is also increased in this Scenario. The percentage increase in prices is between 1.6 to 2.8 percent.

Under Scenario 14 (Figure 4-15), the increased in retail price of beef is between 0.1 to 1.1 percent. The outcome data is also negatively skewed, meaning is not normally distributed. Clearly, consumers would strongly prefer scenario 14 where they would most likely realize the lowest retail price increases for beef, *ceteris paribus*.

Figure 4-13 Effect of FMD on the equilibrium prices at the retail level in beef industry under Scenario 2

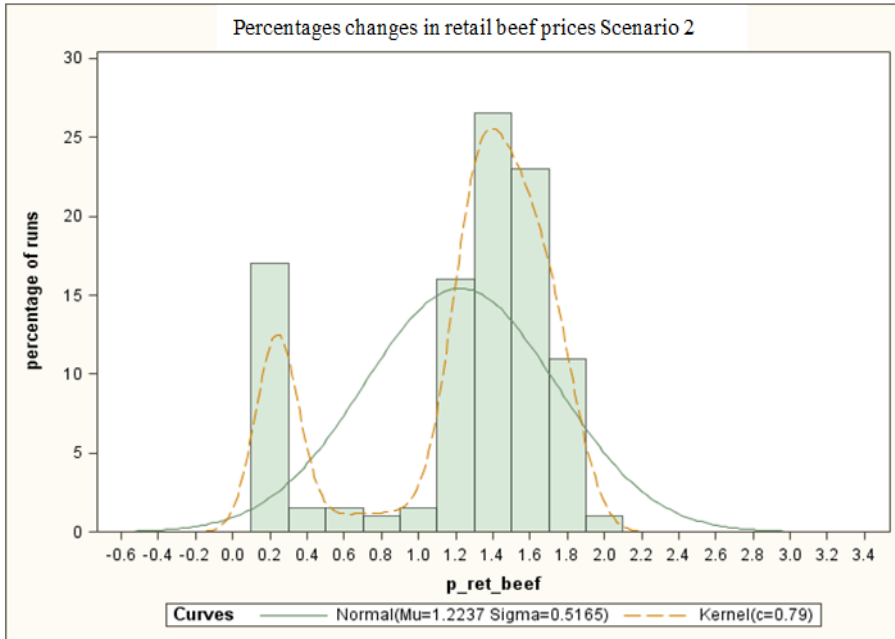


Figure 4-14 Effect of FMD on the equilibrium prices at the retail level in beef industry under Scenario 12

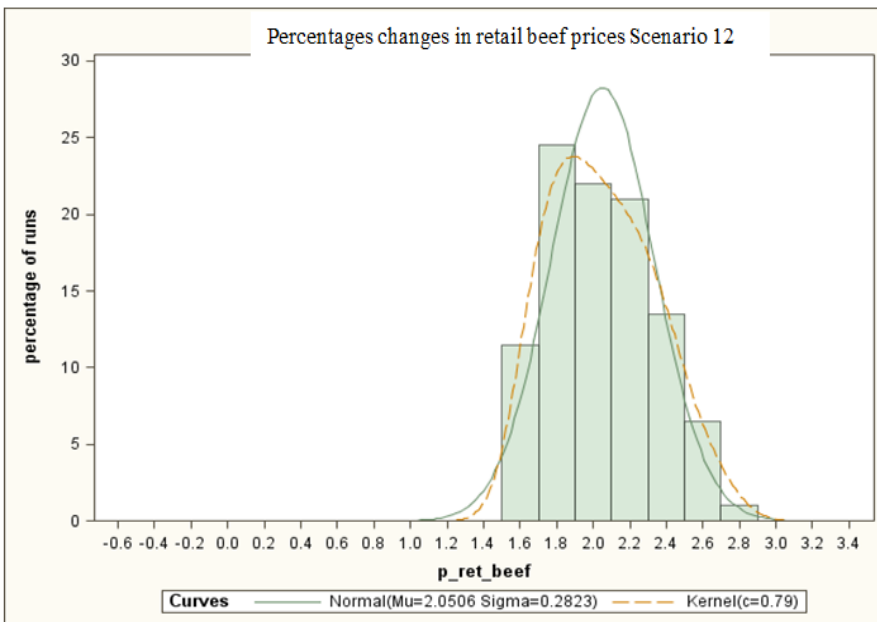
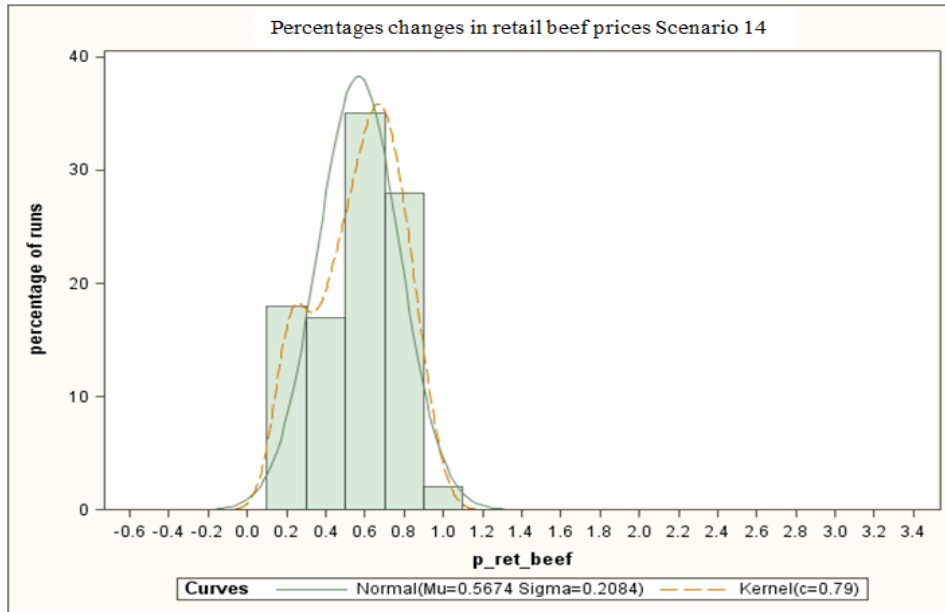


Figure 4-15 Effect of FMD on the equilibrium prices at the retail level in beef industry under Scenario 14



4.2.2 Effect of FMD outbreak Retail Pork prices

The outcomes across the 200 runs under Scenario 2 are widely spread with a larger tail. In the pork sector, there is a reduction in the prices of pork at the retail level. This may be due to the fact that pork is a substitute to beef and there would be relatively more pork on the domestic market due to export market closures. The range of reduction in prices under scenario 2 (Figure 4-16) is wider than that of scenario 12 (Figure 4-17). The reduction in prices falls between 0.20 to 0.50 percent and 0.26 to 0.50 percent in scenario 2 and 12 respectively. Scenario 14 outcome distribution is less skewed compare to both scenarios 2 and 12. Though Scenario 14 is negatively, as shown in Figure 4-18, but the percentage reduction in prices is between 0.20 to 0.46 percent.

Figure 4-16 Effect of FMD on the equilibrium prices at the retail level in pork industry under Scenario 2

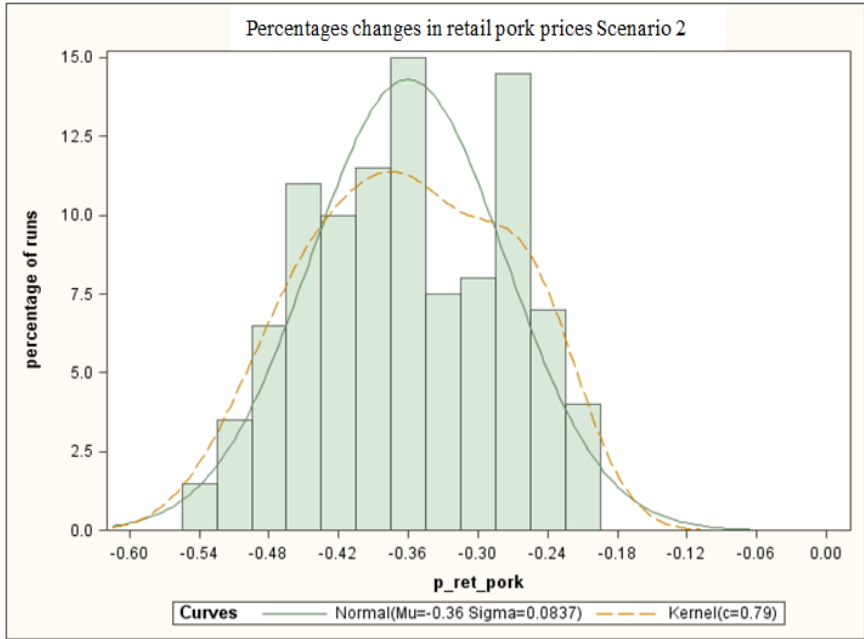


Figure 4-17 Effect of FMD on the equilibrium prices at the retail level in pork industry under Scenario 12

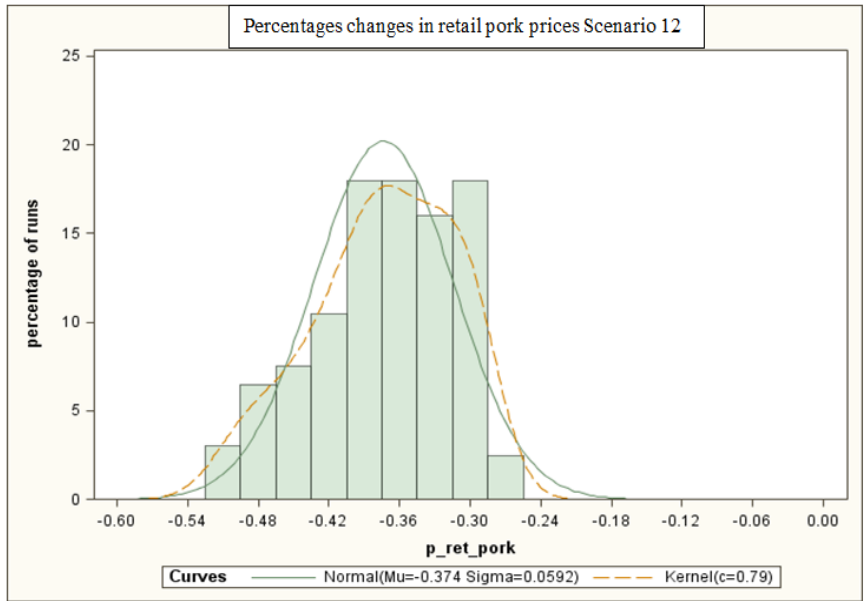
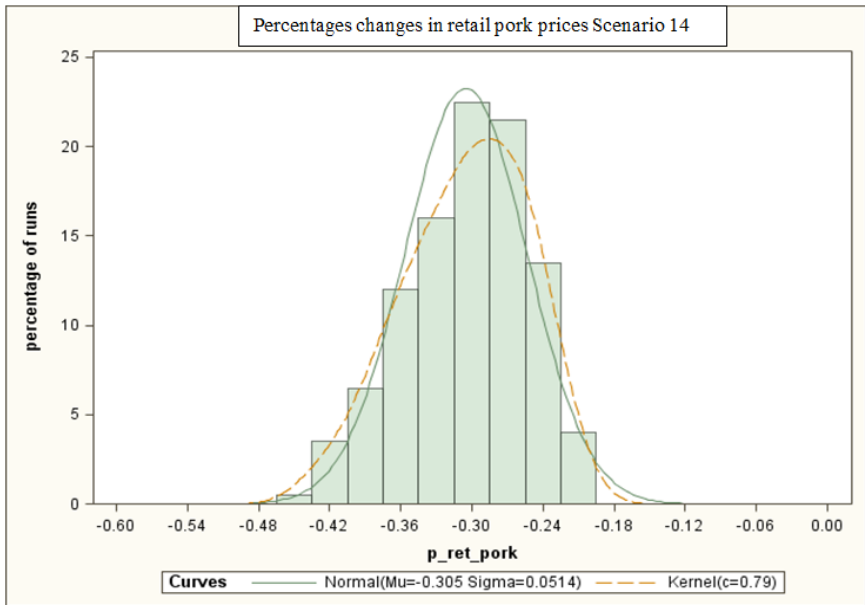


Figure 4-18 Effect of FMD on the equilibrium prices at the retail level in pork industry under Scenario 14



4.2.3 Effect of FMD outbreak Retail Poultry prices

Changes in the equilibrium prices bring about the changes in the surplus at each market level. The EDM output shows that the outbreak of FMD causes little change in the prices of poultry. In Scenario 2, the changes range between 0.01 percent reduction in price and 0.05 percent increase in prices of poultry. The outcome is not normally distributed. Scenario 12 with 50 and 80 herds vaccination capacity at 22 and 40 days respectively is more spread than Scenario 2 with 5 and 8 herds vaccination capacity at 22 and 40 days respectively. The increase in prices in Scenario 12 falls between 0.05 and 0.15 percent. The outcome in Scenario 14 also has outliers, but it is less spread compare to outcomes in Scenario 2 (Figure 4-19) and 12 (Figure 4-20). There is also increase to the retail prices of poultry under Scenario 14, but very small in comparison with outcome in Scenarios 2 and 12.

Scenario 14 involves a very intensive control strategy to reduce economic losses to FMD, Figure 4-21 shows that the loss at farm level is reduced. The reduced loss in the farm level will only lead to small effect on the poultry industry, which is close substitute to both beef and pork.

Figure 4-19 Effect of FMD on the equilibrium prices at the retail level in poultry industry under Scenario 2

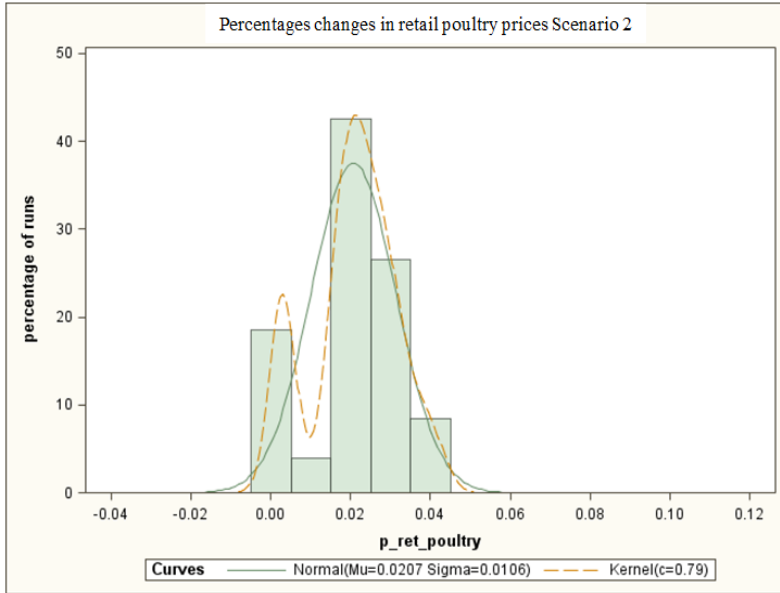


Figure 4-20 Effect of FMD on the equilibrium prices at the retail level in poultry industry under Scenario 12

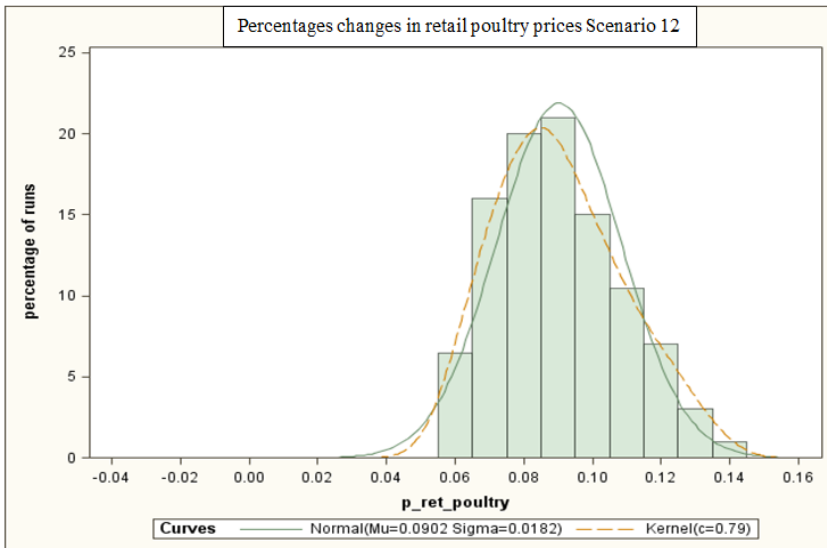
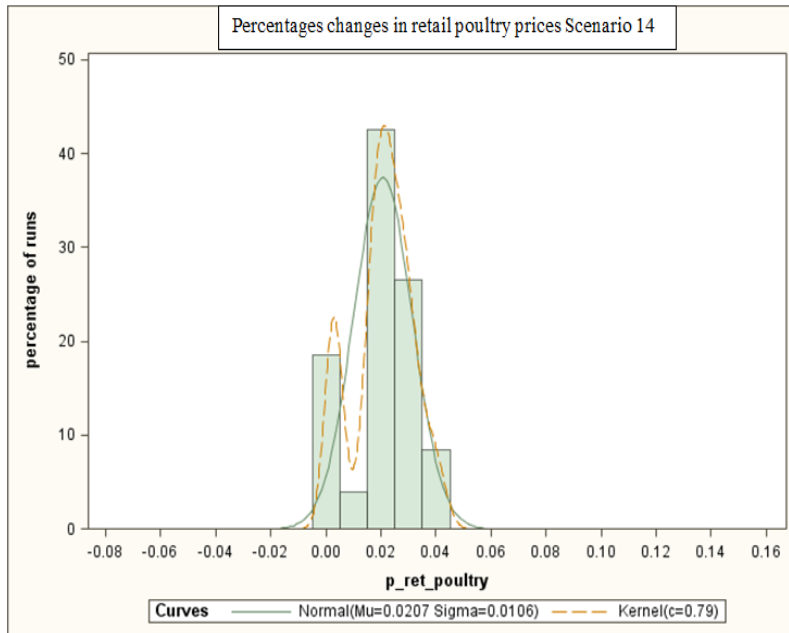


Figure 4-21 Effect of FMD on the equilibrium prices at the retail level in poultry industry under Scenario 14



4.2.4 Effect of FMD Outbreak on Farm Beef Prices

Scenario 2 experienced a large reduction in the prices of cattle at the farm level. The outcome is widely spread (Figure 4-22) which will make it difficult to predict possible outcomes of impact of FMD on the farm beef prices if Scenario 2 is employed as the mitigation strategy. The reduction in price of beef at farm level ranges from 4 to 9 percent, but there a lot of outliers as prices decrease between 1 to 3 percent. Scenario 12 (Figure 4-23) outcomes are less spread (compared to Scenario 2) but negatively skewed. There is a large decrease in price under Scenario 12, where prices would decline by 6 to 12 percent, but most of the outcomes are closer to the mean than those under Scenario 2. It will be easier to predict outcomes in Scenario 12 than in Scenario 2. Scenarios 2 and 12 have vaccination trigger (10 herds), and vaccination zone (10 km²) in common, but differ in vaccination capacity which is 5 herds and 8 herds at 22 days and 40 days respectively for Scenario 2. The vaccination capacity for Scenario 12 is 50herds and 80 herds at 22 days and 40 days respectively.

Figure 4-24, shows that Scenario 14 is the best mitigation strategy among the three Scenarios in this study. The decreases in prices at Farm level are lowest in Scenario 14 compared to reduction in prices under Scenario 2 and 12. The decreases in prices of Farm beef under Scenario 14 are between 1 to 5 percent. The distribution of percentage changes in prices under Scenario 14 has smaller tail, and most values are close to the mean value. Scenario 14 is differ from Scenarios 2 and 12 by the Vaccination Zone area (50km²) but have vaccination capacity in common with Scenario 2, also vaccination trigger in common with both Scenarios 2 and 12. The large vaccination zone brings about less negative impacts of FMD outbreak on the Farm beef prices.

Figure 4-22 Effect of FMD on the equilibrium prices at the farm level in beef industry under Scenario 2

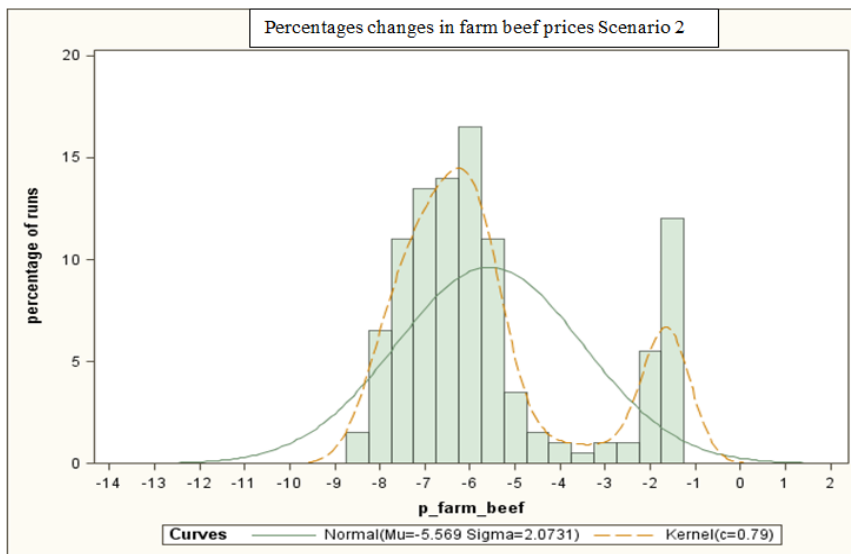


Figure 4-23 Effect of FMD on the equilibrium prices at the farm level in beef industry under Scenario 12

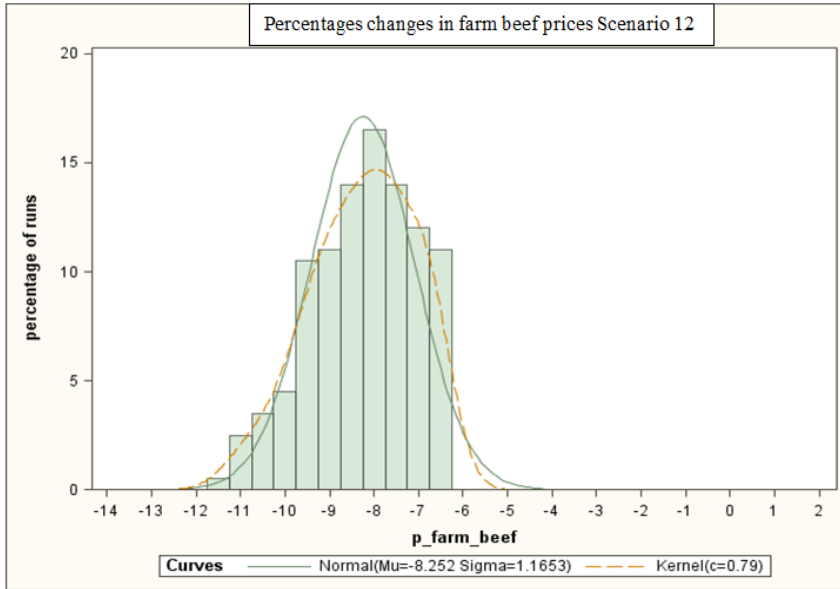
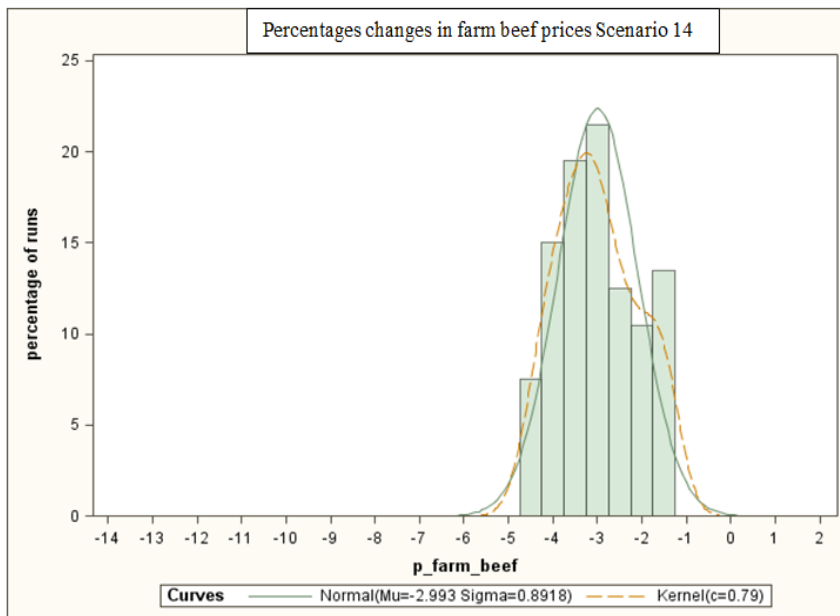


Figure 4-24 Effect of FMD on the equilibrium prices at the farm level in beef industry under Scenario 14



4.2.5 Effect of FMD outbreak on Farm Slaughter hog prices

The impact of FMD is larger in the beef industry than pork industry. There is not much difference in the impact on slaughter hog prices among the three Scenarios. Scenarios 2 and 12 (Figure 4-25 and Figure 4-26 respectively) are similar in the decrease in prices, which range from 0.5 to 1.7 percent in Scenario 2 and between 0.7 to 1.9 percent in Scenario 12. Scenario 14 (Figure 2-27) is better than both Scenarios 2 and 12 on the effect of the FMD outbreak on slaughter hog prices. Price decreases by 0.5 to 1.3 percent under Scenario 14. Despite the fact that Scenario 14 is negatively skewed, it is less skewed compared to Scenarios 2 and 12

Figure 4-25 Effect of FMD on the equilibrium prices at the slaughter hog level in pork industry under Scenario 2

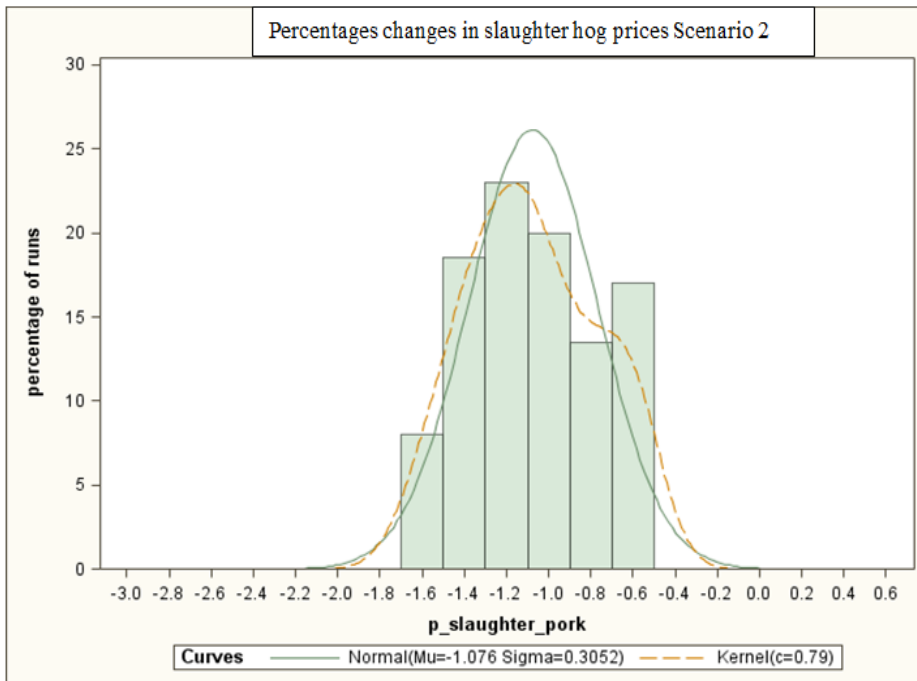


Figure 4-26 Effect of FMD on the equilibrium prices at the slaughter hog level in pork industry under Scenario 12

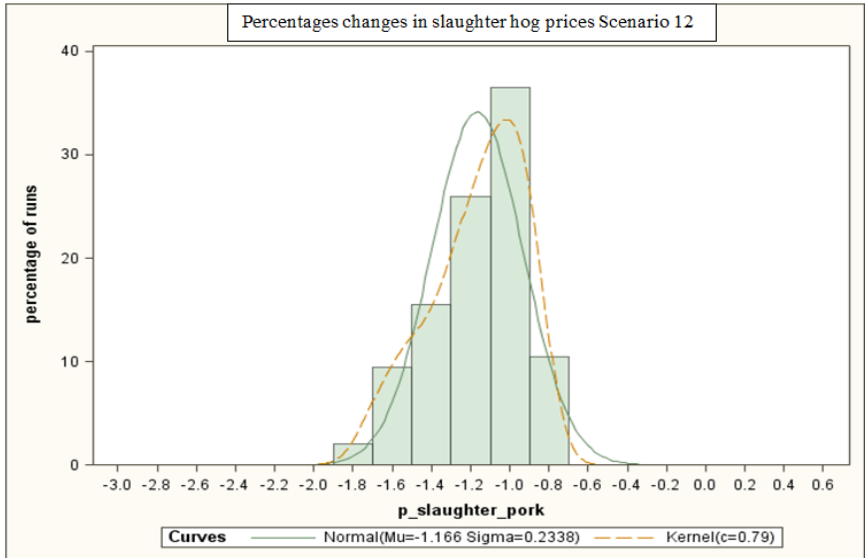


Figure 4-27 Effect of FMD on the equilibrium prices at the slaughter hog level in pork industry under Scenario 14

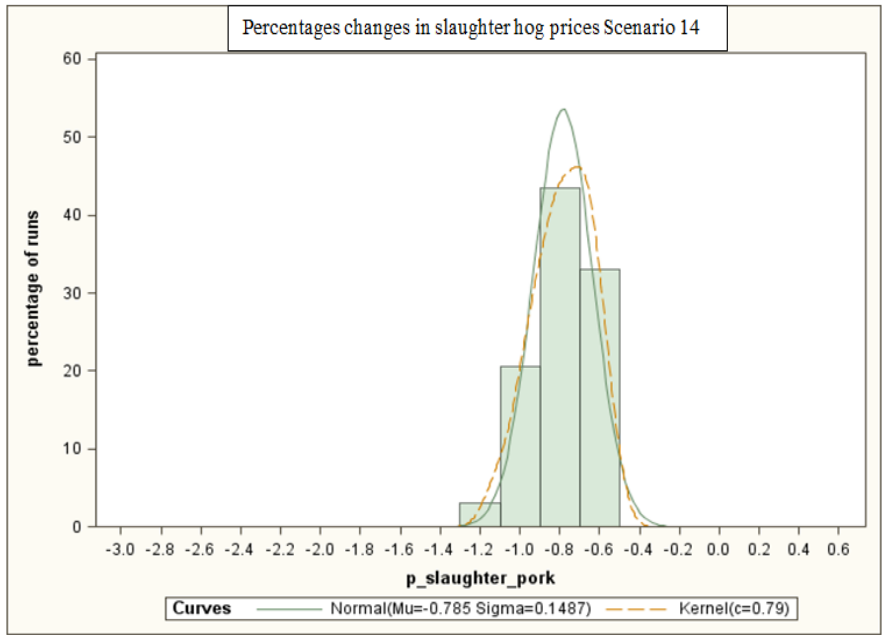


Figure 4-28 The demand and supply curves of impact of FMD outbreak on equilibrium prices at Retail and Farm level

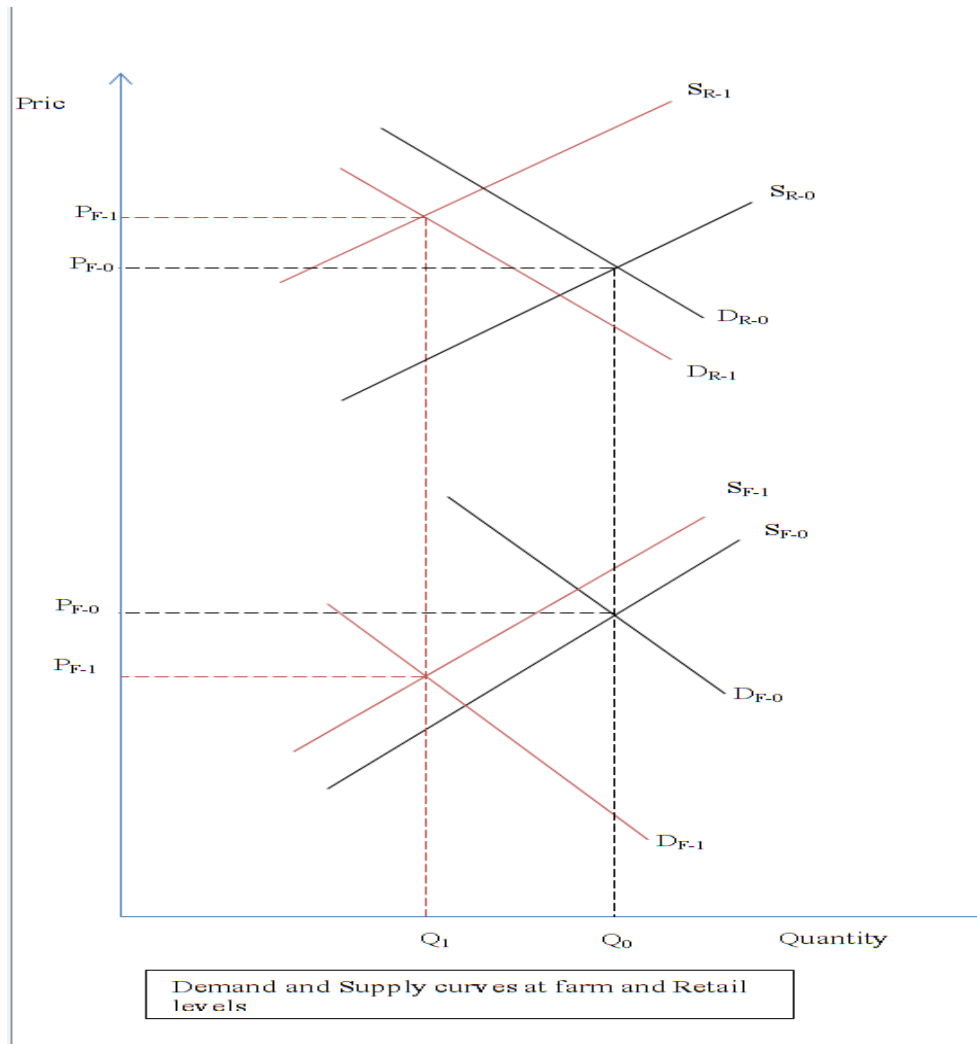


Figure 4-28 is a simple illustration of the impact of FMD outbreak on the retail and farm market. The outbreak of FMD will lead to slight reduction in demand for beef at the retail level. The demand curve shifted from D_{R-0} to D_{R-1} . Because of the slight decrease reduction in the demand will make the retailer to reduce its demand for beef, the reduction in retailer demand for beef can be measure by the shift in retailer supply curve from S_{R-0} to S_{R-1} . Since the shift in supply at retailer level is bigger that the shift in demand at the retailer level. This will make the equilibrium price of beef at retail level increase from P_{R-0} to P_{R-1} .

On the farm level, since Retailers demand less beef, the demand curve at the farm level is reduced by shifting from D_{F-0} to D_{F-1} , since farms continue to produce animals, the supply is

only reduced from S_{F-0} to S_{F-1} due to the animals killed due to FMD. The shifts in the demand and supply curves at the farm level will make the farm price for beef to reduce from P_{F-0} to P_{F-1} .

4.3 Importance of distribution curve in presenting the economic impact

The distribution of economic outcomes helps to compare in detail the differences in the three scenarios. It does not just show the mean, median and mode value, it also show how the outcomes are distributed. It also shows any of the outcomes that have outliers in the data output from the epidemic displacement model. The distribution curve also gives us the knowledge of the interval we expect the loss to surplus can fall if use the three different scenarios. The curve also show how skewed the dataset which bring about the deviation from the mean each data set. We can also use the normal distribution curve to predict the chance of recording a given amount of loss in any mitigation strategy employed in any potential outbreak of foot and mouth disease.

Chapter 5 - CONCLUSIONS

5.1 Summary of study

The three different scenarios resulted in three different results. Scenario 14 with vaccination capacity of 50 herds at 22 days and 80 herds at 40 days, vaccination trigger of 10 herds, and vaccination of 50 km resulted in less loss to both producers and consumers in general. Scenario 14 always has lower probability of realizing welfare loss among the three scenarios. Putting the net welfare loss at \$2billion, there is 0.37 probability that scenario 14 will have less welfare loss than both scenario 2 and 12. Scenario 2 and 12 are very similar, slight difference can only be realized at level of checking the probability of losing over \$4 billion dollars. Scenario 2 has 0.08 probability of having lower loss to the net welfare surplus than scenario 12.

Scenario 14 and scenario 2 only have vaccination trigger in common, Scenario 2 has vaccination capacity of 5 herds at 22 days and 10 herds at 40 days, with vaccination zone of 10 km. Scenario 2 had a welfare net loss of \$2.137 billion on average, while scenario 14 with higher vaccination zone of 50km and more vaccination capacity of 50 herds at 22 days and 80 herds at 40 days have lower loss compare to scenario 2. Using the result, it can be said that increasing the vaccination zone and also increasing the vaccination capacity will bring about less loss to producers.

Results in Scenarios 2 and 12 are similar, but Scenario 12 has the highest loss to both net consumers' surplus on average while Scenario 2 has largest loss to the producers' surplus on average. The only difference between the two Scenarios is their vaccination capacity; the both have the same vaccination zone of 10km. The vaccination capacity in Scenario 2 is 5 and 10 at 22 and 40 days respectively, while the vaccination capacity in Scenario 12 is 50 and 80 at 22 and 40 days respectively. The above result showed that vaccination capacity does not have strong effect on the loss that may be recorded during Foot and Mouth Disease outbreak. This can be interpreted as the larger the vaccination capacity the less the loss recorded in foot and mouth disease outbreak, but it is a relatively very small impact.

Comparing Scenarios 12 and 14 based on the result, Scenario 14 is far better means of controlling the disease outbreak than Scenario 12. Scenario 14 proved to be more effective and brought less loss to producer and consumer surplus. Apart from having the same vaccination trigger, they have different vaccination capacity and size of vaccination zones. Scenario 14 has

50 and 80 herds at 22 and 40 days respectively as the size of vaccination herds, and also has higher vaccination zone size of 50km-sq.

Based on the general result, it can be concluded that the size of vaccination zone has the greatest impact on the economic loss that can be incurred during foot and mouth disease outbreak. The vaccination capacity also have effect but not as effective as the size of vaccination zone.

5.2 Recommendation

Any time there is an outbreak, the size of vaccination zone should be taken into consideration first, and this will allow the control of the spread of the disease. Having bigger vaccination zones helps to reduce the disease duration and also allows the affected region to gain its market back fully on time. The best result can be achieved by combining large vaccination zone with higher vaccination capacity, but the vaccination capacity does not have much impact as size of vaccination zone does. The best decision on which mitigation strategy to employed cannot just be made with the mean and standard deviation of any economic model on FMD because the outcomes are mostly not normally distributed. The outcome data in this study were not normally distributed, so using the mean and standard deviation will not give us the correct possibility of predicting the chance of an outcome level to occur. Using the impact distribution will enable us to know how the data is spread from the mean. We can also determine if the outcome are positively or negatively skewed by using distribution curves. Showing the entire distribution will reveal the outliers in the outcomes, and can show how big the outliers are since big outliers will surely affect the mean and standard deviation of the output data.

5.3 Limitation of study

This study did not consider all the 15 different cases in which the factors responsible for different scenarios (Vaccine strategy, Vaccination capacity, vaccination trigger, and size of vaccination zone). There are may be better result from other Scenarios if considered. This means decision cannot be made solely on the result of these three scenarios without testing other combinations of the factors. Another major limitation is that this study ignored the government

cost in the economic model. The government cost of vaccination can also play important role in the decision making.

REFERENCES

- Animal and Plant Health Inspection Services (APHIS). 2010. "Foot-and-mouth Disease Response plan: The red book." *United States Department of Agriculture Animal and Plant Health Inspection Service Veterinary services*. Washington D.C.
- Aylward, R., Acharya, A., England, S., Agocs, M. and Linkins, J. 2003. "Global health goals: lessons from the worldwide effort to eradicate poliomyelitis." *Lancet*, 362, 909–914.
- Brückner, G., Vosloo, W., Du Plessis, B., Kloeck, P., Connoway, L., Ekron, M., Weaver, D., Dickason, C., Schreuder, F., Marais, T. and Mogajane, M. 2002. "Foot and mouth disease: the experience of South Africa." *Rev. Scient. Tech. Off. Int. Epizoot.*, 21, 751–764.
- Burnett, P., A.J.M. Garland, R.P. Kitching, and C.G. Schermbrucker. 2002. "Aspects of Emergency Vaccination against Foot-and-Mouth Disease." *Comparative Immunology Microbiology & Infectious Diseases* 25:345-364
- Burrell, A.M. and M.J.J. Mangen. 2001. "Animal Disease Epidemics: To Vaccinate or not to Vaccinate." *EuroChoices* 1(April):24-27.
- Chmitelin, I. and Moutou, F. 2002. "Foot and mouth disease: lessons to be learned from the experience of France." *Rev. Scient. Tech. Off. Int. Epizoot.*, 21, 731–737.
- Costelloe, J., Gaynor, M., Gaynor, S., McAteer, W. and O'Reilly, P. 2002. "Control of foot and mouth disease: lessons learned from the experience of Ireland." *Rev. Scient. Tech. Off. Int. Epizoot.*, 21, 739–750.
- Cutts, F., Henao-Restrepo, A.-M. and Olivé, J. 1999 "Measles elimination: progress and challenges." *Vaccine*, 17, suppl. 3, S47–S52.
- Elbakidze, L., L. Highfield, M. Ward, B.A. McCarl, and B. Norby. 2009. "Economics Analysis of Mitigation Strategies for FMD Introduction in Highly Concentrated Animal Feeding Regions." *Review of Agricultural Economics* 31, 4:931-950.
- European Commission. 2003. "Council directive 2003/85/EC of 29 September 2003 on community measures for the control of foot-and-mouth disease repealing directive 85/511/EEC and decisions 89/531/EEC and 91/665/EEC and amending directive 92/46/EEC." *Official Journal of the European Union*, L306: 1-87

- Garabed R. B., W. O. Johnson, J. Gill, A. M. Perez and M. C. Thurmond. 2008. "Exploration of associations between governance and economics and country level foot-and-mouth disease status by using Bayesian model averaging." *Journal of Royal Statistical Society. A* (2008) 171, *Part 3*, pp. 699–722
- Grubman, M.J. and B Baxt. 2004. "Foot-and-Mouth Disease." *Clinical Microbiology Reviews* 17(2):465-493.
- Hagerman, Amy D, Bruce A. McCarl, Tim E. Carpenter, Michael P. Ward, and Joshua O'Brien. 2012. "Emergency Vaccination to Control Foot-and-mouth Disease: Implications of its Inclusion as a U.S Policy Option." *Applied Economics Perspectives and Policy*, Volume 34, number 1, pp. 199-146.
- Harvey, N., A. Reeves, M.A. Schoenbaum, F.J. Zagnutt-Vergara, C. Dubé, A.E. Hill, B.A. Corso, W.B. McNab, C.I. Cartwright, and M.D. Salman. "The *North American Animal Disease Spread Model*: A simulation model to assist decision making in evaluating animal disease incursions." *Preventive Veterinary Medicine* 82(December, 2007):176-197.
- Henao-Restrepo, A.-M., Strebel, P., Hoekstra, E., Birmingham, M. and Bilous, J. 2003. "Experience in global measles control, 1990-2001." *J. Infect. Dis.*, 187, suppl. 1, S15–S21.
- Heymann, D. 2004. "Smallpox containment updated: considerations for the 21st century." *Int. J. Infect. Dis.*, 8, suppl. 2, S15–S20.
- Hull, H., deQuadros, C., Bilous, J., Oblapenko, G., Andrus, J., Aslanian, R., Jafari, H., Okwo Bele, J.-M. and Aylward, R. 1998. "Perspectives from the global poliomyelitis eradication initiative." *Bull. Wrld Hlth Organizn*, 76, suppl. 2, 42–46.
- Mahul, O. and A. Gohin. 1999. "Irreversible Decision Making in Contagious Animal Disease Control Under Uncertainty: An Illustration using FMD in Brittany." *European Review of Agricultural Economics* 26(1):39-58.
- Mathews, K., Buzby, J., 2001. Dissecting the challenges of mad cow and footand- mouth disease. Ag. Outlook, ERS, USDA, August 2001
- Melius, C., A. Robertson, and P. Hullinger. 2006. "Developing Livestock Facility Type Information from USDA Agricultural Census Data for Use in Epidemiological and

- Economic Models.” *Lawrence Livermore National Laboratory*, UCRL-TR-226008. November 10.
- Mohiddin, A. and Johnston, D. 2006. “HIV/AIDS mitigation strategies and the State in sub-Saharan Africa—the missing link?” *Globalizn Hlth*, 2, no. 1.
- Moonsoo Park, Yanhong H. Jin, David A. Bessler. “The impacts of animal disease crises on the Korean meat market.” *Agricultural economics : the journal of the International Association of Agricultural Economists*. - Hoboken, NJ : Wiley-Blackwell, ISSN 0169-5150, ZDB-ID 7428893. - Vol. 39.2008, 2, p. 183-195
- NBAF (National Bio and Agro-Defense Facility). 2012. “Updated Site-Specific Biosafety and Biosecurity Mitigation Risk Assessment. United States Department of Homeland Security, Final Report, February
- Niemi, J.K. and H. Lehtonen. 2010. “Modeling Pig Sector Dynamic Adjustment to Livestock Epidemics with Stochastic-Duration Trade Disruptions.” *European Review of Agricultural Economics* 38,4:529-551.
- Nogueira, L., T.L. Marsh, P.R. Tozer, and D. Peel. 2011. “Foot-and-Mouth Disease and the Mexican Cattle Industry.” *Agricultural Economics* 42:33-44.
- OIE, World Organisation for Animal Health. Countries Notifying Foot and Mouth Disease in 2008 and 2009. Available at <http://www.oie.int/animal-health-in-the-world/fmd-portal/about-fmd/disease-information/> (accessed 10/09/2013)
- Paarlberg, P.L., J.G. Lee, A.H. Seitzinger. 2002. “Potential Revenue Impact of an Outbreak of Foot-and-Mouth Disease in the United States.” *Journal of the American Veterinary Medical Association* 220, 7(April):988-992.
- Pendell, D.L., J. Leatherman, T.C. Schroeder, and G.S. Alward. 2007. “The Economic Impacts of a Foot-and-Mouth Disease Outbreak: A Regional Analysis.” *Journal of Agricultural and Applied Economics* 39(October):19–33.
- Pluimers, F., Akkerman, A., van derWal, P., Dekker, A. and Bianchi, A. 2002. “Lessons from the foot and mouth disease outbreak in the Netherlands in 2001.” *Rev. Scient. Tech. Off. Int. Epizoot.*, 21, 711–721.
- Rennie, S. and Behets, F. 2006. “Desperately seeking targets: the ethics of routine HIV testing in low-income countries.” *Bull. Wrld Hlth Organizn*, 84, 52–57.

- Rich, K.M., A. Winter-Nelson, and N. Brozovic'. 2005. "Modeling Regional Externalities with Heterogeneous Incentives and Fixed Boundaries: Applications to Foot and Mouth Disease Control in South America." *Review of Agricultural Economics*, 27, 3:456-464.
- Rich, K.M., and A. Winter-Nelson. 2007. "An Integrated Epidemiological-Economic Analysis of Foot and Mouth Disease: Applications to the Southern Cone of South America." *American Journal of Agricultural Economics* 89(3, August):682-697.
- Sakamoto, K. and Yoshida, K. 2002 "Recent outbreaks of foot and mouth disease in countries of east Asia." *Rev. Scient. Tech. Off. Int. Epizoot.*, 21, 459–463.
- Schroeder C. T and Glynn T. Tonsor. 2011. "Economic Impacts of Zilmax Adoption in Cattle feeding." *Journal of Agricultural and Resource Economics* 36(3):521-535
- Schroeder T. C, D. Pendell, M. Sanderson, S. McReynolds. 2012. "Economic Impact of Alternative FMD Emergency Vaccination Strategies in the United States". *Working paper, Agricultural Economics, Kansas State University*.
- Scudamore, J. and Harris, D. 2002. "Control of foot and mouth disease: lessons from the experience of the outbreak in Great Britain in 2001." *Rev. Scient. Tech. Off. Int. Epizoot.*, 21, 699–710.
- Stephen Devadoss, David W. Holland, Leroy Stodick, and Joydeep Ghosh. 2006. "A General Equilibrium Analysis of Foreign and Domestic Demand Shocks Arising from Mad Cow Disease in the United States." *Journal of Agricultural and Resource Economics* 3 1 (2):441-453
- Thomas F. Randolph, Jamie A. Morrison, and Colin Poulton. 2012. "Evaluating Equity Impacts of Animal Disease Control: The Case of Foot and Mouth Disease in Zimbabwe." *Review of Agricultural Economics—Volume 27, Number 3—Pages 465–472*
- Thurman, W.N. 1991. "Applied General Equilibrium Welfare Analysis." *American Journal of Agricultural Economics* 73,5(December):1508-1516.
- Wilson Paul, and Lyndsey Kinsella 2004. "The Impact of foot and mouth disease on the price of beef." *Eurochoices* 3(3), pp. 26-31
- Wohlgenant, M. K. 1993. "Distribution of Gains from Research and Promotion in Multi-stage Production Systems: The Case of the U.S. Beef and Pork Industries." *American Journal of Agricultural Economics* 75:642-651.

Zhao Xueyan, J.D. Mullen, G.R. Griffith, W.E. Griffiths, R. R. Piggot. 2000. Economic Research Report No. 4

Zhao, Z., T.I. Wahl, and T.L. Marsh. 2006. "Invasive Species Management: Foot-and-Mouth Disease in the U.S. Beef Industry." *Agricultural and Resource Economics Review* 35 (1, April):98-115.