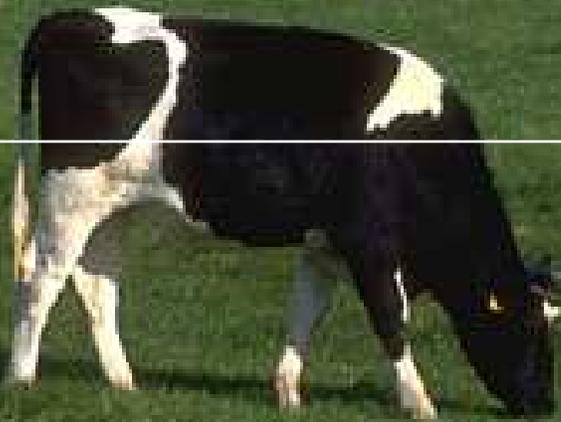


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NATIONAL CENTER FOR FOREIGN ANIMAL
AND ZOOONOTIC DISEASE DEFENSE

Impact of Foot-and-Mouth Disease Management Alternatives in the California Dairy Industry



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October 30, 2009

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Funded by the Department of Homeland Security funded National Center of Excellence for the study of Foreign Animal and Zoonotic Disease Defense headquartered at Texas A&M University.



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Executive Summary

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

Results indicate that earlier detection is always a best response strategy in terms of reducing epidemic size, disease control cost, and national welfare loss. They also show vaccination increases slaughter, as would be expected given US "vaccinate to die" policy. However, vaccination reduces the number of head placed under movement restrictions. Implications of this extend beyond the size of the outbreak. By keeping the quarantine zone as small as is reasonable, it lessens the welfare slaughter potential. Vaccination does come at a higher economic national surplus loss and disease control cost. Examining the distribution of losses and accounting for risk attitude on the part of policy makers, I find that vaccination is a risk reducing strategy. This implies the undesirable tail of the distribution of losses is reduced such that there is less chance of an extremely bad outcome.

Producers suffer the most from the outbreak, but simulation evidence suggests that producers in some non-infected regions gain from the outbreak. In dairy production regions outside of California, producers gain from the outbreak. However, for regions with hog production (an FMD susceptible species and therefore subject to trade restrictions) producers have losses due to international trade restrictions.

1. Introduction

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

This study is a part of the larger research and development effort of the National Center for Foreign Animal and Zoonotic Disease Defense (FAZD) to develop and employ a set of integrated economic and epidemic models and databases as a part of an overall decision support system. The goal of this research is to provide a quantitative approach for analyzing the impact of alternative strategies for prevention, intervention and recovery and provide the resultant information to decision makers in an attempt to assist them in planning and responding to outbreaks of foreign animal and zoonotic disease. The models that have been used here are the Davis Animal Disease Simulation (DADS) model and the Agricultural Sector Model (ASM) component of the Forest and Agricultural Sector Optimization Model (FASOM).

Prior studies within the FAZD have looked at the impact of FMD on the Texas High Plains concentrated beef cattle feeding sector and work at CADMS has looked the economics of FMD in the Central Valley of California. This study will expand prior work and utilize the DADS-ASM link to further examine the impact of FMD and management alternatives in the California dairy sector.

2. Background on California Livestock Agriculture

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

In California milk and other dairy products from cows are the highest value livestock commodity group at \$6.9 billion in value of sales; this represents 22% of the nation's milk supply. This is followed by cattle and calves (\$2.5 billion), and poultry and eggs (\$1.5 billion)

(USDA-NASS, 2009). Swine, sheep, goats and other animals make up a relatively small portion of the state's value of livestock. In terms of numbers of animals, poultry were the largest animal category, but cattle and calves represented 5.5 billion animals (USDA-NASS, 2009).

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

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

3. Study Design

3.1. Scenarios

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

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

Table 1 provides the exact scenarios considered, the results of which are reported throughout this report. The DADS model was used to simulate each scenario 100 times to characterize a distribution of potential outcomes for the detection and vaccination scenarios. In ASM, economic impacts were assessed assuming 100 independent, random trials. Then risk aversion of decision makers in the model was considered and strategies evaluated in relation to their risk preference. The model was also modified to allow greater consideration of welfare slaughter and national trade alternatives.

Table 1. Epidemic Model Scenario Definitions

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

4. Disease Impact Categorizations

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

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

4.1. Direct Losses

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

1.1.1. Lost Animals and Changes in Animal Value

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

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

Welfare slaughter is an issue that has not received much attention in the literature, but has proven to be a real issue in historical animal disease outbreaks that include quarantine zones and strict movement restrictions. In the 2001 U.K. FMD outbreak, 2.5 million animals were slaughtered for welfare reasons; this was the largest slaughter category in the outbreak.

Welfare slaughter occurs when movement restrictions prevents the farmer/rancher's ability to bring feed to the animals, to sell a slaughter weight animal at market, or to sustain very young, susceptible animals. For enterprises employing confined feeding or those raising young animals previous to feeding, the amount of feed on hand and facilities to keep animals would likely not be sufficient beyond normal movement times may be insufficient to allow the animals to be kept. This leads to additional slaughter, and consequently higher indemnity payment levels to producers. As discussed in previous sections, producers expecting lower prices for animals post-outbreak may volunteer animals for welfare slaughter to prevent additional price change losses.

1.1.2. Costs of Disease Management

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

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

Carcass disposal becomes a serious issue in a disease outbreak resulting in large scale animal mortality or large scale slaughter. Factors such as environmental regulations and public health impacts will also determine the disposal method hierarchy established (Scudamore et al.) in addition to the cost per unit for disposal and the time required to dispose of all carcasses. The

type of control strategy employed can also affect the carcass disposal method chosen since it will, hopefully, reduce the number of dead animals (Jin, Huang and McCarl).

1.1.3. Trade Losses

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

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

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

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

4.2. Secondary Losses

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

1.1.4. Related Industries

Disease outbreaks can have effects that extend well beyond the meat production chain (Pritchett, Thilmany and Johnson). While industries directly in the meat production chain will typically experience the greater loss and have consequently been the focus of disease outbreak economics literature, little work has been done to ascertain the impact on service industries linked to the meat industry. Figure 1, adapted from Pritchett, Thilmany and Johnson provides a general idea of how interrelated these markets are. A good example is the feed industry. In countries with large concentrated animal feeding operations, such as the US, a significant source of demand for feed grains is represented by livestock demand. Disease outbreaks leading to large scale animal mortality will reduce the domestic demand for feed grains. In addition, movement restrictions in the quarantine zone will restrict not only the transport of livestock but the transport of feed grain supply trucks/unit trains coming into or out of the region. These disruptions and demand shifts will be reflected in the price of feed grains. Other industries that would be impacted by a disease outbreak are transportation, veterinary service and supply industries, and rendering services (Pritchett, Thilmany and Johnson).

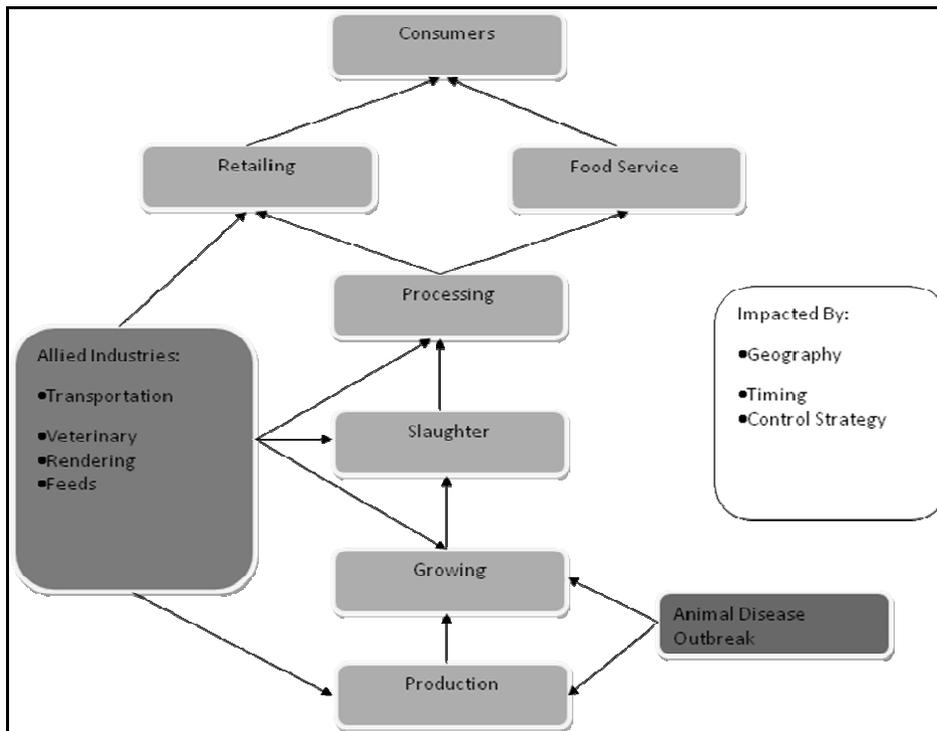


Figure 1. Interrelationship of Livestock Sector (Pritchett, Thilmany and Johnson)

1.1.5. Local Economies

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

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

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

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

The macro-level data from the UK did not show the level of impact that was initially expected considering the impact on UK agriculture. Lessons learned from this outbreak provide valuable

information for increasing the resiliency of the US economy to a similar outbreak. First, timing is everything. The two years prior to the outbreak were strong years for the economy, allowing firms to build up a buffer against a bad year (Phillipson et al.). Similarly, households were in a position to absorb some of the impact. Second, the economic impacts from the outbreak may be spread over multiple years in a 'lag effect' of the outbreak (Rich and Winter-Nelson). This gives firms and households time to make adjustments, softening its immediate impact in the overall economy to a gradual decline and gradual recovery.

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

1.1.6. Environmental Impacts

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

Air quality can be impacted when animal pyre burning or curtain burning of carcasses is employed. Curtain burning is preferred since it reduces the emissions into the air, but it is not always feasible since it requires more time and resources than pyre burning (Scudamore et al.). Studies in the UK, where pyre burning was used extensively at one point in the outbreak, have examined the levels of dangerous compounds in livestock, dairy products and eggs produced nearby. Slight increases in concentrations of dangerous compounds were found in lamb, chicken and eggs, but these were not samples destined for the food chains. Milk tests indicated

dangerous compound concentrations were within acceptable ranges. Overall, the study concludes there is no evidence that the pyres were responsible for contaminating food produced in that region (Rose et al.).

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

1.1.7. Meat Demand

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

4.3. Cost Assumptions Specific to this Study

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

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

this kind of unconstrained information will be useful in guiding policies on what kind of vaccine availability should be in place.

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

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

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

- Fixed surveillance costs were assumed to be \$150, \$200 and \$400 for small (<100 head), medium (100-500) and large (>500) herds.
- It was assumed that suspect herds were visited twice a week during a 30-day period for regular surveillance strategies, and 4 times a week for enhanced surveillance strategies. The cost of these visits were assumed to be \$50, \$75 and \$100 for small (<100 head), medium (100-500) and large (>500) herds.
- The cost per trip (one way) into or out of the movement restriction zone will require truck cleaning in the amount of \$130 per trip.
- The feed cost for dairy blend feed ration for lactating cows is \$310 per ton delivered. This does not include the cost of roughage, which will likely be stored on farm. The number of deliveries required per day is 3 for large dairies, 1 for medium dairies and 0.5 for small dairies. Using a medium representative dairy operation in California, it is estimated that dairy producers will only have to bring in only a portion of feed from the outside; using on-farm production to account for the rest. This is a cost per animal of \$4.97 per cow per day out of the total cost per cow per day of feed of \$7.23. Feed costs typically are about half of the cost cwt of milk, so this number is not unreasonable given recent farm milk prices.

Animal price assumptions are presented in Table 2. These assumptions are used to calculate indemnity payments. The meat demand assumption made here is that international demand for US meat will go to zero as well as international demand for non-pasteurized dairy products. Domestic meat and dairy demand is not assumed to shift as a result of the FMD outbreak. Finally, the trade assumption is that regionalization is not utilized and as a result there is a total lockdown of all livestock, meat and non-pasteurized dairy products.

Table 2. Market Price Assumptions

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

4.4. Herd Demographics

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

Table 3. Herd Definitions from DADS Model

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

Table 4. Inventories of Animals in Susceptible Region When Moved to ASM

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

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

5. Epidemic Model Results

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

5.1. Animals Slaughtered for Disease Control

Summary statistics for the number of head slaughtered is presented in Table 5. For a graphical representation, Figure 2. Spread of Disease Control Slaughter Distribution shows across the different scenarios that slaughter will increase as the delay to detection increases but the maximum of the number slaughtered distribution is reduced by the use of vaccination. These results will motivate examination of delays in detection and slaughter later in the economic results overview.

Table 5. Summary Statistics for Disease Control Slaughter¹

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

¹ Variables for summary statistics tables are defined in Table 9.

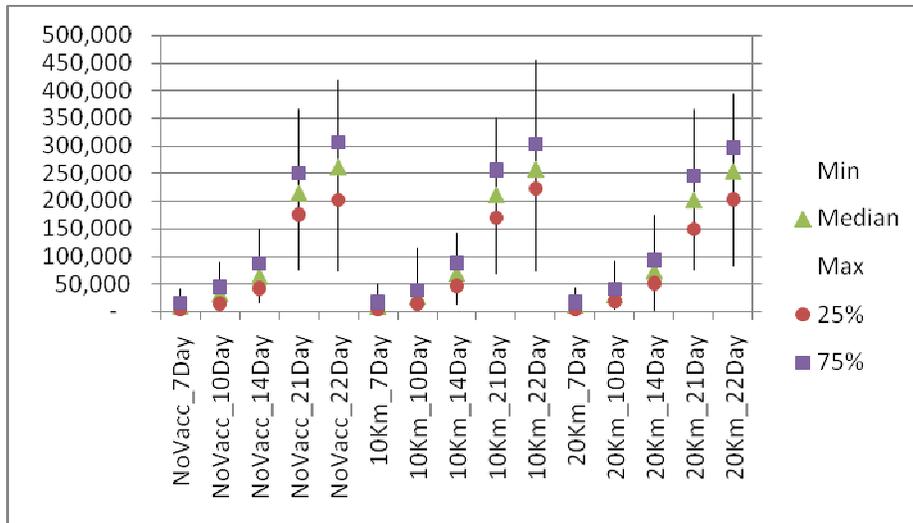


Figure 2. Spread of Disease Control Slaughter Distribution²

5.2. Herds Placed Under Movement Restrictions

Summary statistics for the number of herds quarantined is presented in Table 6. Figure 3 shows across the different scenarios the herds placed under movement restrictions will increase as the delay to detection increases but the maximum herds restricted of the herds quarantined distribution is decreased by vaccination.

² For Figure 2 - Figure 4, the vertical line represents the spread from min to max, the square indicates the 75th percentile, the circle represents the 25th percentile and the triangle represents the median. The vertical axis is in number of head or herds as indicated in the text, and the horizontal axis is the scenario considered. Variables are defined in Table 9.

Table 6. Summary Statistics for Herds Quarantined

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

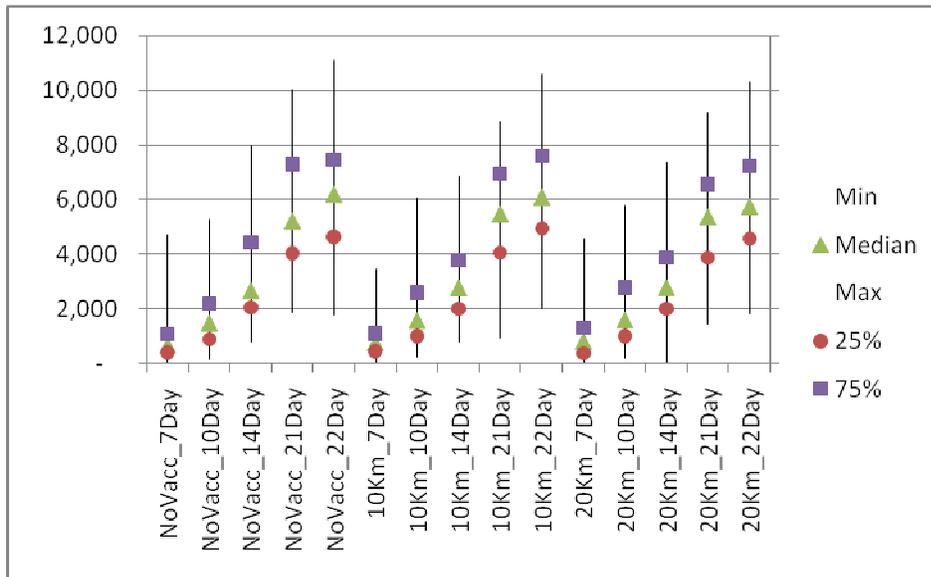


Figure 3. Spread of Herds Quarantined Distribution

5.3. Animals Slaughtered for Welfare Purposes

The movement restrictions put in place create the potential for welfare slaughter in the movement restriction zone because feed and critical services cannot be brought to the livestock in a cost effective manner without increasing the risk of greater disease spread. The summary statistics for the number of head that would be slaughtered for welfare purposes if feed could not be brought into the quarantine zone are presented in Table 7. As shown in Figure 4, vaccination could be an effective way to prevent excessive welfare slaughter under late detection. However, if the disease is caught early enough vaccination may not be necessary. This will be discussed in more detail in the economic results section.

Table 7. Summary Statistics for Head in Danger of Slaughter for Welfare Purposes

	Min	25%	Median	75%	Max	Mean	StDev
NoVacc_7Day	5,940	235,661	352,331	453,797	696,395	332,491	151,155
NoVacc_10Day	51,573	324,767	456,937	545,969	948,431	448,722	150,845
NoVacc_14Day	246,473	510,457	570,849	748,747	1,138,469	615,726	204,872
NoVacc_21Day	195,180	560,001	704,347	967,424	1,197,707	735,976	266,263
NoVacc_22Day	162,137	611,594	839,106	936,171	1,293,811	772,731	263,361
10Km_7Day	27,504	235,996	302,006	434,349	810,378	330,125	155,252
10Km_10Day	89,664	404,407	505,213	587,915	892,516	484,373	155,054
10Km_14Day	268,452	511,539	565,245	659,013	992,671	582,999	152,569
10Km_21Day	181,645	582,792	688,260	868,456	1,182,927	682,257	243,904
10Km_22Day	9,358	630,434	739,431	908,970	1,373,980	747,872	239,304
20Km_7Day	7,660	237,569	300,983	450,758	951,683	342,446	171,887
20Km_10Day	72,470	386,820	490,207	584,427	1,061,914	488,398	188,681
20Km_14Day	28,644	488,024	561,779	684,081	1,063,976	580,934	175,106
20Km_21Day	6,320	564,407	675,494	883,045	1,420,058	672,584	281,457
20Km_22Day	43,638	606,228	761,650	893,865	1,151,420	731,483	227,340

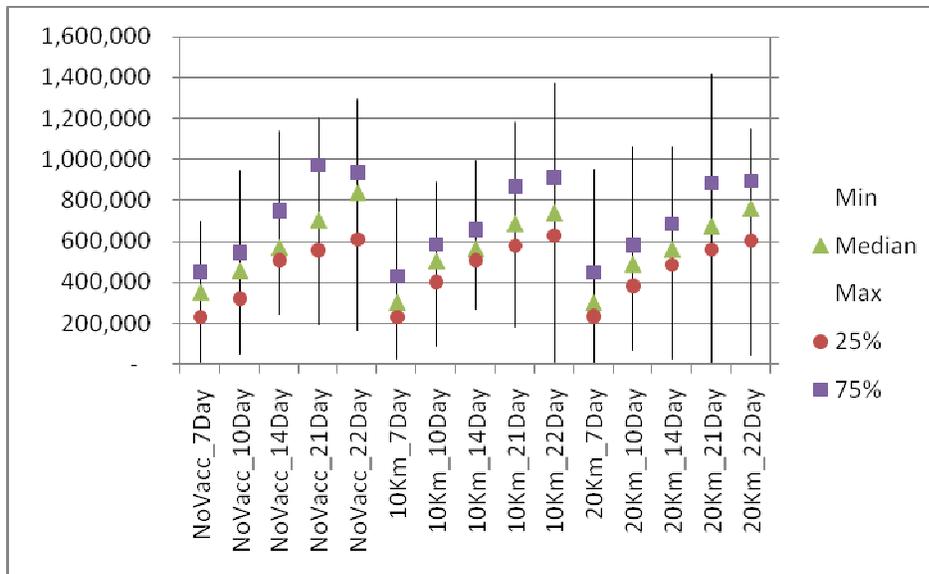


Figure 4. Spread of Head in Danger of Welfare Slaughter

6. Economic Model Results

The data above were used to adjust the sheep, cow/calf, dairy, farrow to finish, and feeder pig production budgets in ASM in the outbreak region, Northern California in this case. All animals infected were assumed to be slaughtered for disease control. Each of these groups will be addressed separately.

In this study the FMD outbreak was restricted to the Northern California region (Figure 5). However, since this region of California is a significant contributor to national supply of livestock products and since the US is a significant player in the world market, effects will be felt through the entire country and the rest of the world. The ASM model captures the change in economic welfare³ or economic surplus from an animal disease because it calculates a dollar loss of value added net income and a welfare cost of commodity prices rising. The trade impacts are also be estimated within ASM. The results presented below include the trade losses assuming the export of FMD affected, non-pasteurized products is closed for the entire country for the remainder of the year after the outbreak is brought under control.

³ Economic welfare loss is the loss in the aggregate well-being of participants in a market based on alternative allocations of scarce resources. This is sometimes referred to as economic surplus. The second term will be used here to prevent confusion with the term welfare slaughter.

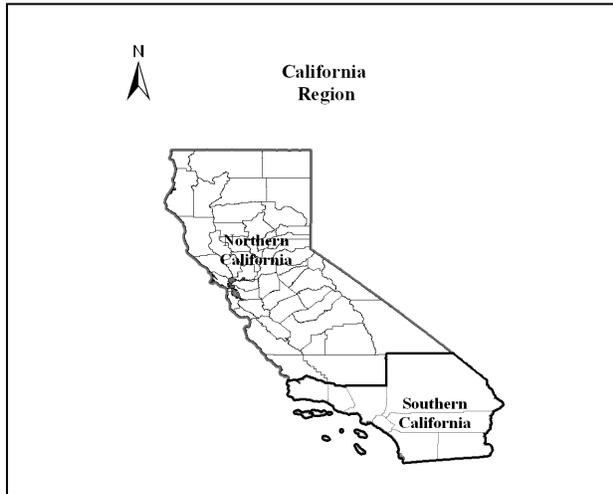


Figure 5. ASM Sub-Regional Breakdown of California

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

Examining results first from a national level, the change in total agricultural economic surplus is examined resulting from the outbreak. These results include international trade impacts, but do not examine a policy of regionalization of production to limit trade impacts. Table 8, Table 9, and Table 10 provide summary statistics for each of the alternative scenarios where losses are measured in millions of year 2004 dollars. As detection of the disease is delayed, median losses increase. Furthermore, median loss under vaccination exceeds losses under no vaccination. This is due to the increased slaughter and costs accompanying a vaccination scenario.

Table 8. Summary Statistics for National Loss in Total Agricultural Surplus-No Vaccination (Millions of 2004\$)

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

Table 9. Summary Statistics for National Loss in Total Agricultural Surplus -- 10 Km Ring Vaccination (Millions of 2004\$)

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

Table 10. Summary Statistics for National Loss in Total Agricultural Surplus -- 20 Km Ring Vaccination (Millions of 2004\$)

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

A graphical representation can help understand the results. Examining the change from the no-disease baseline in millions of dollars, Figure 6 gives the results for no vaccination. The median national agricultural economic surplus loss is increasing as the delay in FMD detection increases as would be expected. The spread of the distribution of national agricultural surplus losses also increases, indicating a greater risk of large scale events.

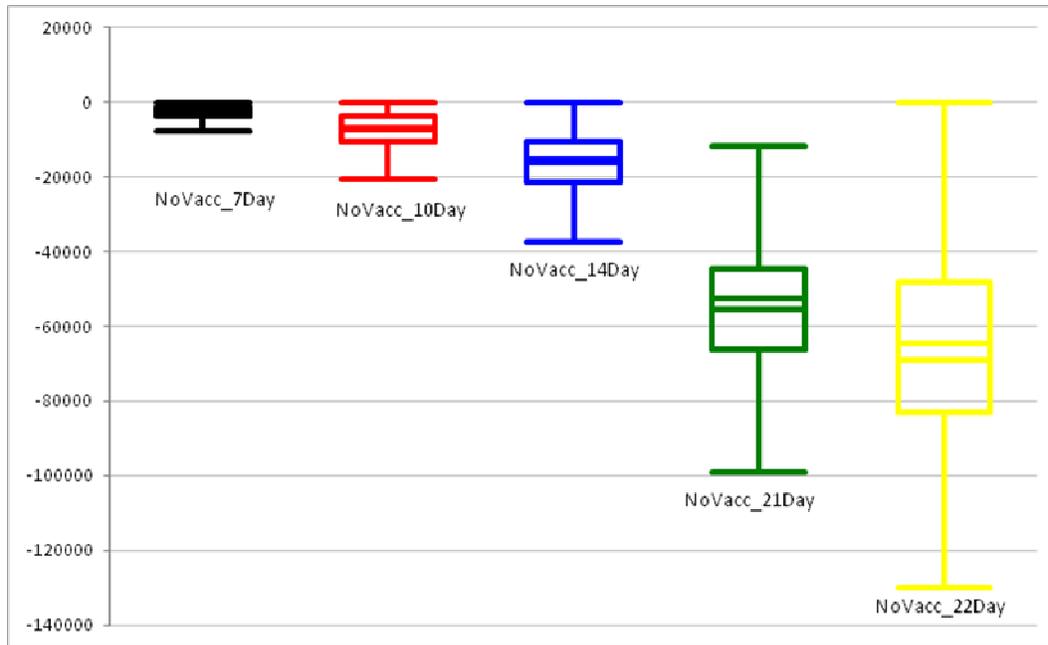


Figure 6. Box Plot of National Agricultural Surplus Loss Spread -- No Vaccination⁴

⁴ The box plot can be read as follows: The vertical axis is the change in national agricultural surplus in millions of dollars. The line closest to zero is the minimum loss in national agricultural surplus from the no-disease base in millions of dollars. The vertical line represents the spread between the minimum and maximum loss. The lowest horizontal line is the maximum loss in national agricultural surplus from the no-disease base in millions of dollars. The box represents the spread from the 25th to 75th percentile in national agricultural surplus losses. The two horizontal lines inside the box represent the mean and median loss value of the distribution of losses.

When vaccination is used as a way of controlling the spread of the disease, the same pattern is seen but with a greater success in reducing the spread of national agricultural surplus losses. Figure 7 shows results when 10 km ring vaccination is employed and Figure 8 shows results when 20 km ring vaccination is employed. Under the latest days to detection (21 and 22) the 10 kilometer ring vaccination is not as successful in reducing the spread of national agricultural surplus loss as the 20 kilometer ring vaccination. However, the mean and median national agricultural surplus loss is not reduced by vaccination. Based on these results, 20 kilometer ring vaccination would be a viable control strategy to minimize national agricultural surplus losses under late detection if decision makers wish to reduce the probability of an extreme outcome, but does not appear to provide any additional benefits under earlier detection scenarios or in reducing mean and median national agricultural surplus losses.

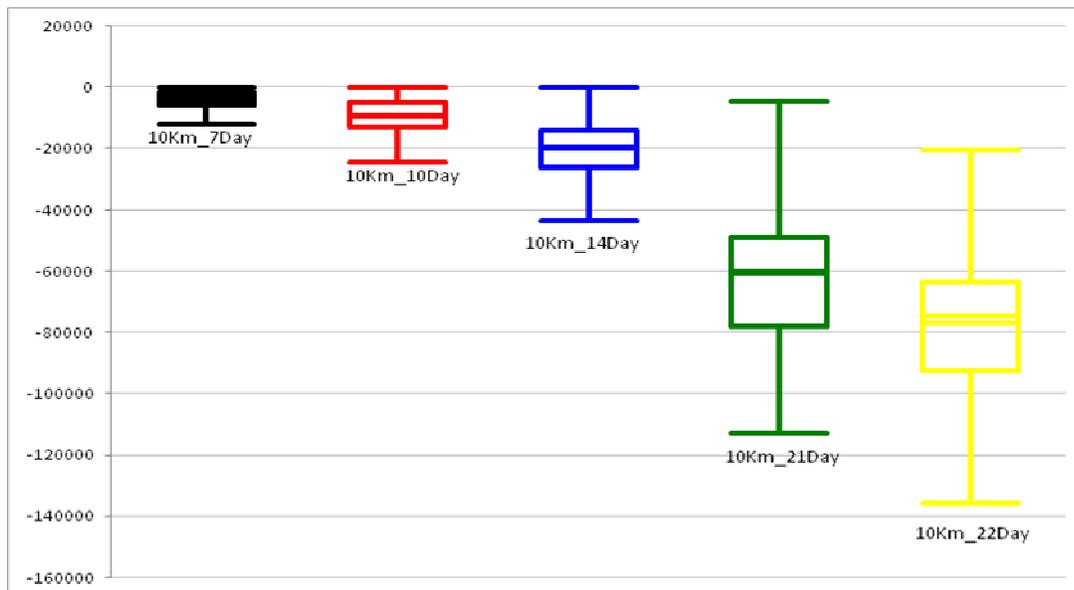


Figure 7. Box Plot of National Agricultural Surplus Loss Spread -- 10 Km Ring Vaccination

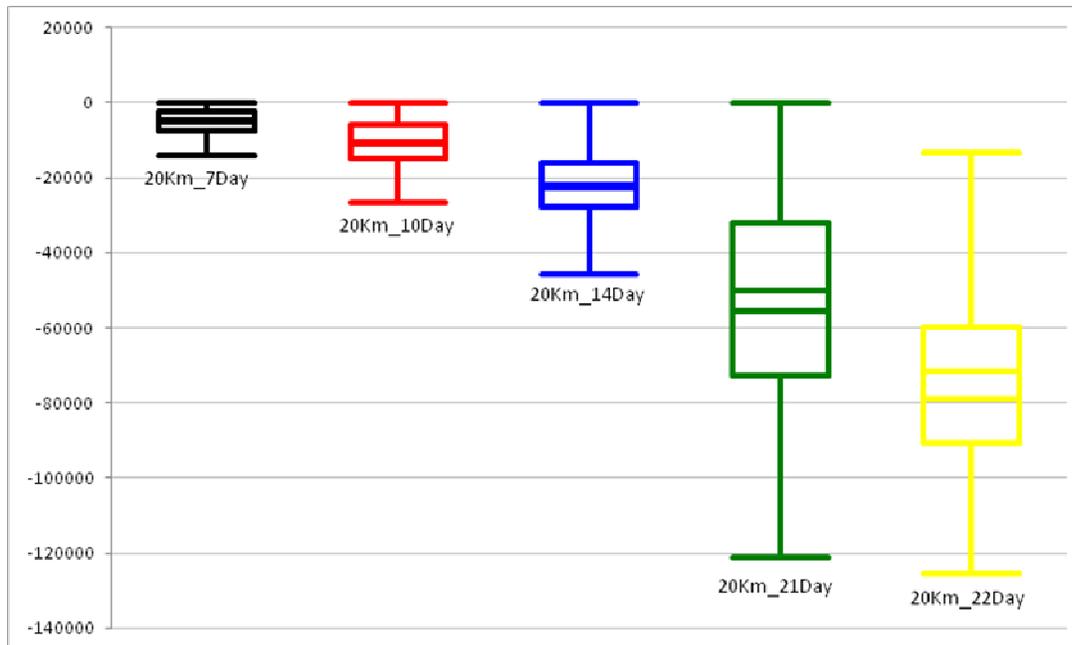


Figure 8. Box Plot of National Agricultural Surplus Loss Spread -- 20 Km Ring Vaccination

Clearly, the vaccination policy would be set without clear knowledge of how many days might expire before the disease is detected. Figure 9 shows the box plot of national agricultural surplus losses under alternative vaccination strategies across all delays in detection. While 10 km ring vaccination does not provide benefits outweighing the costs in terms of additional slaughter required (recall the "vaccinate to die" assumption) and additional costs of disease mitigation, it appears 20 km ring vaccination does provide sufficient benefits to reduce the spread of national agricultural surplus losses. Even 20 km ring vaccination does not appear to reduce the mean or median national surplus loss. Thus in this particular study, vaccination of dairy herds in a 20 km ring around infected premises is not a viable policy for slowing the spread of the disease and minimizing the mean or median national surplus losses from the disease. It may however, be a viable option for reducing the chance of an extreme disease outcome occurring.

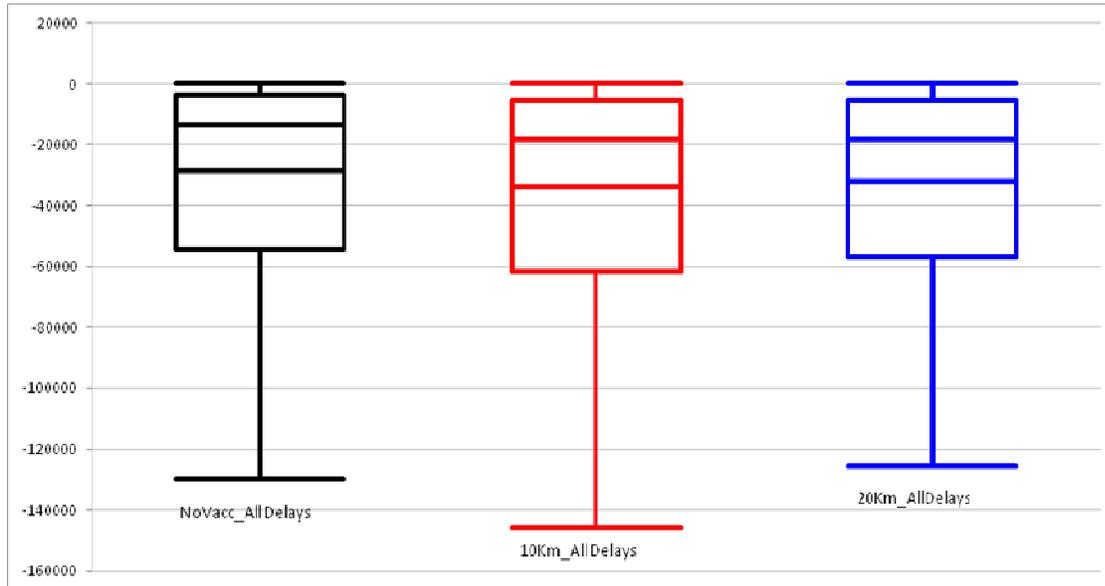


Figure 9. Box Plot of National Agricultural Surplus Loss Spread Under Alternative Vaccination

6.2. Risk Aversion Analysis

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

Vaccination has both pros and cons. First under current "vaccinate to die" strategy more slaughter is employed and second vaccination is costly in terms of supplies and man-hours. However, the goal of vaccination is to slow the spread of the disease. Thus, it should be examined as a risk reduction technique. Stochastic Efficiency with Respect to a Function (SERF) is used here. The SERF method identifies where dominance between two alternatives switches (breakeven risk aversion coefficients) given bounds on the absolute risk aversion coefficient (ARAC). SERF allows for estimation of the utility-weighted risk premiums between alternatives to provide a cardinal measure for comparing the payoffs between risky alternatives (Hardaker et al.). Figure 10 presents the SERF diagram showing that the highest expected utility is obtained from 20 Km vaccination as the ARAC rises. For vaccination, as risk aversion rises

vaccination becomes the preferred strategy. However, for risk neutral decision makers, choosing no vaccination may be a preferable strategy since vaccination does not reduce the mean or median national agricultural welfare loss.

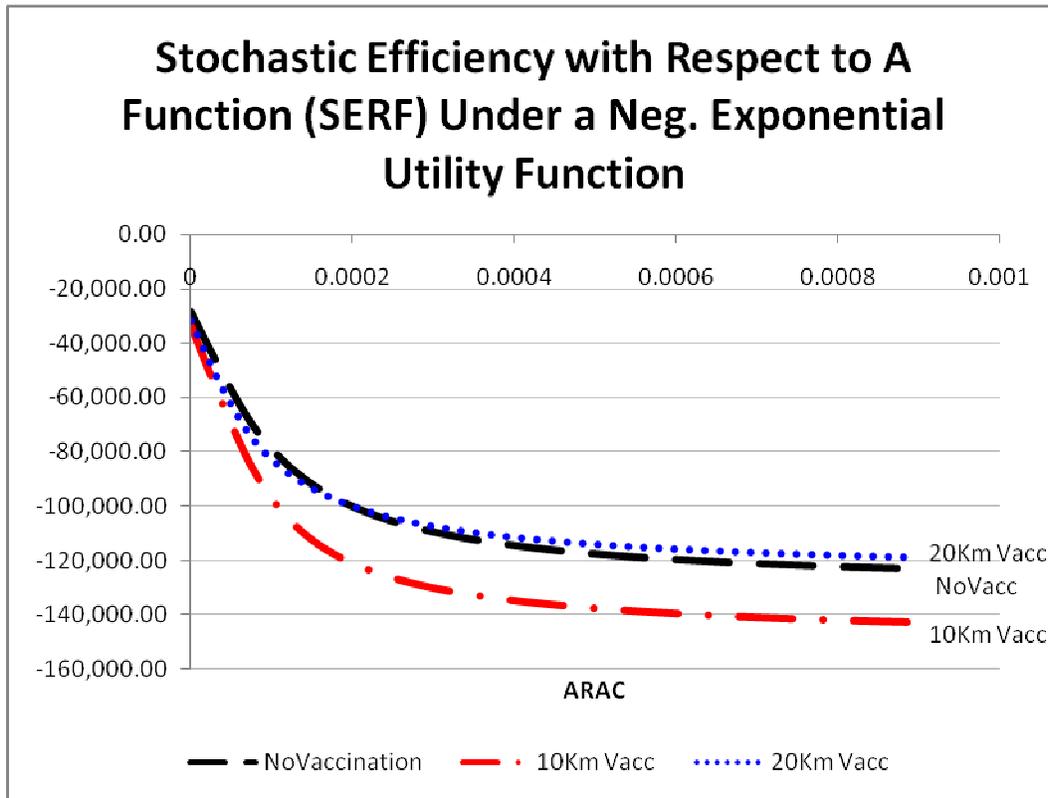


Figure 10. SERF Diagram Under Alternative Scenarios⁵

⁵ The three scenarios compared are no vaccination (NoVacc), 10 km ring vaccination (10Km Vacc) and 20 km ring vaccination (20Km Vacc) averaged across all delays in detection. The vertical axis represents the utility of loss under a negative exponential utility function. The horizontal axis represents the absolute risk aversion coefficient at which the corresponding level of loss occurs.

6.3. The Cost of an Additional Hour Delay in Detection

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

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

As an extension of the risk aversion analysis, the cost of an additional hour delay under alternative vaccination strategies can be compared as shown in Figure 11. The average cost of an additional hour of delay increases with vaccination, but 20 km ring vaccination second order stochastic dominates both 10 km ring vaccination and no vaccination. Thus even in examining results by hourly national welfare loss under late detection, vaccination is an appealing strategy for reducing the risk of greater losses

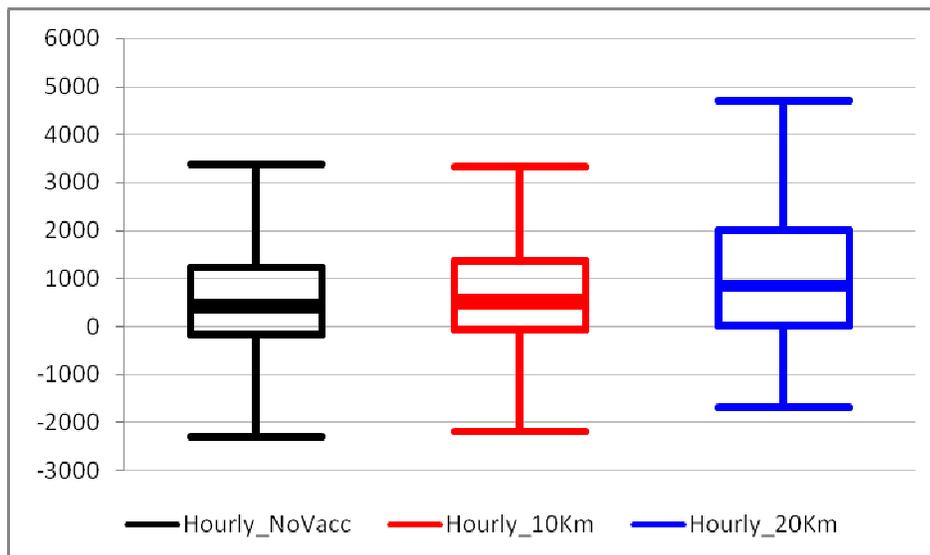


Figure 11. Box Plot of Cost per Hour of Delay between 21 and 22 Days

6.4. Price Impacts

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

1.1.8. Price Impacts for Live Animals

Recall that ASM is acting almost as a short run equilibrium model where price and quantity changes are a reflection of the animal disease shock but herd adjustments are not allowed. There are two sources of movement in live animal prices. The first is obviously the shift in supply resulting from massive slaughter of animals in California, dairy calves in particular. The second, forces driving quantity demanded and supplied in other regions such as a greater surplus of grain available for feeding and increased domestic meat prices due to international trade restrictions. These two forces will be moving against each other, and the direction of the price change expected will depend on the relative sizes of these shifting factors. Table 11 provides results across all vaccination levels for beef animals.

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

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

Table 11. Mean Prices of Live Cattle Under Alternative Days of Detection⁶

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

California is not a major producer of hogs and pigs, ranking 29th in the nation (USDA-NASS, 2009). However, international trade restrictions without the use of zoning implies that pork will also be a restricted commodity. The US is a major exporter of pork, so a block of pork exports means lower demand for hogs for slaughter and feeder pigs. Price changes in these commodities reflect these adjustments. California is ranked third in sheep and goat production, but with no trade impacts and relatively small quantity impacts in the region in question there is not enough market forces being brought to bear in order to shift lamb or mutton prices. Table 12 provides results across all vaccination levels for hogs and sheep.

Table 12. Mean Prices of Live Hogs and Sheep Under Alternative Days of Detection

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

⁶ Variables are delays in detection averaged across all vaccination scenarios.

Although poultry production is not affected by FMD directly, chicken and turkey serve as a substitute for beef and a complement for pork (Davis et al.). Thus demand effects will be moving in opposite directions as a result of an FMD outbreak. The direction of the price change will depend on which is larger. The change in the price of chicken and turkey will determine the changes in the price of broilers, turkeys and eggs. The next section provides an overview of these results. Table 13 provides the prices changes in eggs, broilers and turkeys.

Table 13. Mean Prices of Eggs and Live Poultry Under Alternative Days of Detection

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

1.1.9. Price Impacts for Meat and Livestock Products Excluding Dairy

A key assumption that is worth stating again is that domestic meat consumption is not reduced due to "fear factors" about meat safety. Rather, price changes are driven by supply shifts in live animals and international trade impacts. Table 14 provides prices for beef, pork and poultry over all vaccination scenarios. For beef, changes in national supply were apparently small enough to not affect price in the earlier days to detection but does increase price under the latest detection scenarios. Pork price however, most likely due to the international trade impacts, is reduced. Chicken and turkey prices are increased under early detection scenarios; however, under 22 day detection chicken price decreases below the pre-disease base and under 21 and 22 day detection turkey price decreases below the pre-disease base. This may be reflective of the role of poultry as a substitute for beef. One other commodity price that could be mentioned here is the price of wool. As the number of sheep is reduced, the supply of wool available will decrease and consequently the price of wool is increased as shown in Table 15.

Table 14. Mean Prices of Beef, Pork and Poultry Under Alternative Days to Detection

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

Table 15. Mean Price of Wool Under Alternative Days to Detection

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

1.1.10. Price Impacts for Dairy Products

Perhaps one of the most important price impact categories to discuss under this particular set of scenarios is the impact on the prices of dairy products. Table 16 shows prices under the base and each delay in detection averaged across all vaccination strategies. The first column is the price per cwt of milk at the farm. The remaining columns are prices of processed milk products. Note that price impacts do not reflect international trade restrictions as long as products are pasteurized. The pasteurization process has been found to kill the FMD virus (Thurmond and Perez). Furthermore, there is little international trade in dairy products.

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

Table 16. Mean Price of Dairy Products Under Alternative Days to Detection

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

1.1.11. Price Impacts for Feed Grains

A final price impact category that usually receives little attention is feed grains. Feed grain price changes are the result of changes in demand for feed grains when livestock operations are subject to a disease outbreak. Slaughter in California means a reduction in the demand for feed grain in that region, which in turn results in additional supply for other regions. This is reflected in the decrease in feed grain prices shown in Table 17.

Table 17. Mean Price of Feed Grains Under Alternative Days to Detection

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

1.1.12. Summary of Price Changes

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

6.5. Regional Livestock Producer Surplus Impacts

Ranking scenarios based on losses to national economic wellbeing includes the sum of changes in consumer, producer and processor surplus. However, simply looking at national agricultural surplus may over or under estimate impacts to regional livestock producers who are expected to be the hardest hit by the outbreak. This section will break down livestock producer surplus impacts by ASM region, a map of which are shown in Figure 12.

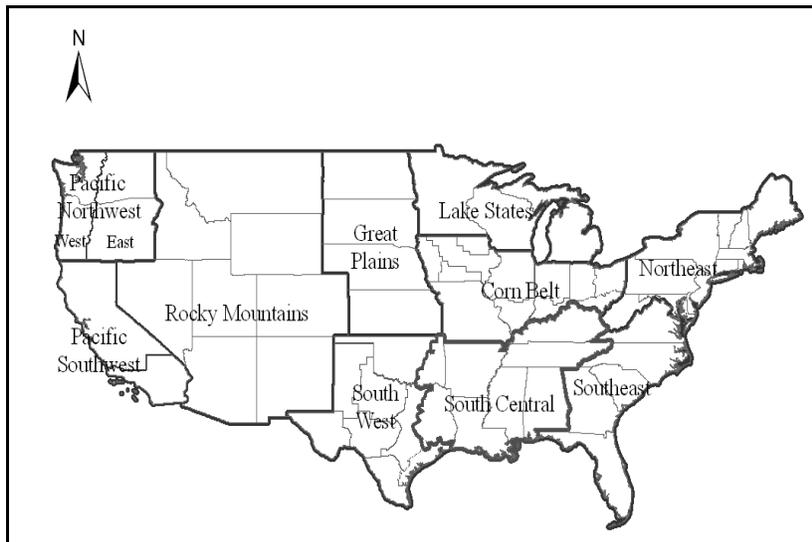


Figure 12. ASM Regions and Sub-regions

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

1.1.13. Total US Livestock Producer Surplus Changes

When looking at the change in producer surplus in the nation as a whole, the median loss from a no disease base is \$15.8 billion as shown in Table 18. **Summary Statistics for Total Livestock Producers' Surplus Changes Relative to the Base.** Comparing across delays in detection for all vaccination types, early detection still second order stochastic dominates late detection. This implies that producers should have an incentive to participate in earlier detection if it is clear the losses that could be sustained from later detection. Comparing across different vaccination strategies, a different ranking is discovered. Producers prefer that vaccination not be used during the outbreak, followed by 20 km ring vaccination. Only under the latest detection scenario, when risk aversion is increasing does 20 km ring vaccination become preferred to no vaccination. This is not unreasonable from a producer standpoint given the additional slaughter inherent in the use of vaccination. Examining the producer surplus loss in the nation as a whole may underestimate the producer impacts in the infected region, so the remainder of this section will examine the producer impacts region by region.

Table 18. Summary Statistics for Total Livestock Producers' Surplus Changes Relative to the Base Scenario⁷

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

⁷ Variables are the total US economic surplus change averaged across alternative vaccination strategies for delays in detection.

1.1.14. Pacific Southwest (PSW)

Starting with the region of outbreak it can reasonably be expected that producers' wellbeing in this region will fall more than in any other region. As expected the median change in national producer surplus from the no-disease base is \$16.5 billion as shown in Table 19. This is the largest loss region in the simulated outbreak under all scenarios. Comparing this to the total US producer surplus change, not examining this region individually would underestimate the loss producers would face. Rankings of strategies remain the same. Early detection is always preferred to later detection and no vaccination is the preferred strategy unless detection occurs late and decision makers are more risk averse.

Table 19. Summary Statistics for California (Pacific Southwest) Livestock Producers' Surplus Changes Relative to the Base Scenario

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

1.1.15. Dairy Producing Regions

As stated earlier, California is the top dairy producing state in the US followed by Wisconsin (which resides in the Lake States region), New York, Pennsylvania (which are both in the Northeast region), and Idaho (which is in the Rocky Mountains region). Given the decrease in dairy coming from California as a result of the outbreak, there is a strong potential that producers in these regions could gain as a result of higher dairy prices. As shown in Table 20, under all delays in detection and vaccination strategies, the producers in the Lake States (LS) and Northeast (NE) regions gain from the outbreak. Producer surplus gains in the LS region ranged from a median \$35 million under the earliest detection scenario to \$372 million under the latest detection scenario, in which dairy prices are highest.

Results in the Rocky Mountain (RM) region were more mixed. Median producers surplus in the RM region falls under early detection at 7 days by \$35 million; however, it should be noted that

some of the cattle production in California is shipped to Idaho to be fed out. Starting with detection at 10 days though, simulations indicate producers begin to gain in median surplus. This gain ranges from \$7.6 million at 10 days to \$469 million at 22 days.

Table 20. Summary Statistics for Other Dairy Producing Regions Livestock Producers' Surplus Changes Relative to the Base Scenario⁸

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

1.1.16. Other Livestock and Grain Production Regions

Regions that are major producers of cattle largely realized gains from the disease outbreak. This includes the Great Plains (GP) region that realized gains in median producer surplus ranging from \$282 million under 14 day delay in detection to \$320 million under 22 day detection--the region also had gains at 7, 10 and 21 days delay. This region houses a thriving cow/calf and

⁸ Here the Lake States region is abbreviated LS, the Northeastern region is abbreviated NE and the Rocky Mountain region is abbreviated RM.

cattle feeding industry as well as grain production. Producers in that region stand to benefit from lower grain prices for cattle and increased prices for fed cattle resulting from the outbreak. Results are shown in Table 21.

Table 21. Summary Statistics for Great Plains Region Livestock Producers' Surplus Changes Relative to the Base Scenario

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

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

Table 22. Summary Statistics for Southwest Region Livestock Producers' Surplus Changes Relative to the Base Scenario

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

The Corn Belt (CB) is where the majority of the hog production in the US occurs. As such, this region experiences losses in median producer surplus ranging from \$4.7 million at 22 days delay

in detection to \$28.5 million at 7 days delay in detection. These losses will most likely occur as a result of the trade restriction moving the price of hogs and pork down, although it may be partially offset by the decrease in the price paid for feed corn. Results are shown in Table 23.

Table 23. Summary Statistics for Corn Belt Region Livestock Producers' Surplus Changes Relative to the Base Scenario

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

Producers in the South Central region of the US lose in median surplus under these simulated outbreaks except for under a 21 day delay in detection. This may be due to the mixed production in that region, with losses resulting from cow/calf production impacts. Results are shown in Table 24.

Table 24. Summary Statistics for South Central Region Livestock Producers' Surplus Changes Relative to the Base Scenario

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

The Southeast region covering Florida, Georgia, North and South Carolina and Virginia will have producers gaining in median wellbeing by a small amount under each scenario except for the 7 day delay in detection as shown in Table 25. These results, like the South Central region may be mixed due to the mix of livestock producer types in the region. Florida, in particular is a large

cattle production state but North Carolina is a large hog production state. Thus the impact on this region will vary depending on the size of the outbreak. At only a 7 day delay in detection, the trade impact to hog production appears to be outweighing the impact to cattle and poultry producers.

Table 25. Summary Statistics for Southeast Region Livestock Producers' Surplus Changes Relative to the Base Scenario

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

6.6. Trade Impact Analysis

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

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

Second, trade analysis was not taken out into future years since trade restrictions remain in place at some level 2-5 years into the future. This only looks at year 0, the year of the outbreak. In particular, for the use of vaccination trade will be restricted longer since the US would have a

"FMD Free with Vaccination" status for several years. This may warrant allowing the ASM model to find a dynamic equilibrium since longer term trade restrictions may alter the livestock industry in the US. The future years of the restrictions would need to be considered to truly assess the disease outbreak with full trade impacts. The limitations described in this section could be explored in a separate extension of the study.

7. Conclusions and Implications

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

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

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

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

In terms of limitations, there is still much work that could be done for animal disease modeling. In particular the approach and analysis in this study could be improved by considering several factors. First, the international trade assumptions could be improved. The assumption is that the disease is confined to California but that all US opportunities to export were lost. However a zoning policy might be able to be employed to reduce international trade losses. In particular, the pork trade would not be as affected if zoning were put into place. The assumption that livestock and livestock product exports are reduced to autarky levels is a worst case scenario that would be more applicable to a multi-region outbreak rather than a regionalized outbreak. Second, only the short run aspects of the outbreak were examined. Essentially, the "year 0" or the year of the outbreak were examined without looking the 5-10 years into the future to determine when or if the livestock sector would recover from the outbreak. This long run analysis would particularly be important given international trade impacts and the time it will take to regain market share after export restrictions are put in place by our current export partners.

In terms of further work, what is clear is that the threat of animal disease--FMD in particular--is very real to the US agricultural sector and there is still much work to be done to assess vulnerability and outbreak related strategies would be over the short and long run. Further aspects not discussed in this study, but that could be examined in the future, are the implications this would have on tourism and commercial traffic important to the California economy. Furthermore, the costs of human suffering and lost wages from movement restriction policies could be explored. Also the results could be extended by explorations of the balance between ex ante investment and ex post response. In order to have early detection, investment would need to be made in diagnostics equipment and personnel in laboratories as well as the possibility of a random, mandatory testing procedure in vulnerable regions. Although these issues are not specifically modeled in this dissertation, the results presented here provide motivation for the further examination of balance issues.

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9. Appendix: Integrated Epidemic/Economic Modeling

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

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

9.1. General Framework

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

1. Define Scenarios
2. Make appropriate adjustments in epidemic model to reflect economic questions
3. Make necessary conversions for the epidemic model output to become the economic model input and make appropriate adjustments in the economic model
4. Provide a feedback loop from the economic model to better inform the epidemic model and or modify the control strategies

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

9.1.1. Defining Scenarios

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

9.1.2. Epidemic Modeling

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

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

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

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

The second state goes by many terms ("latent", "sub-clinically infectious", "incubating" are used in the models discussed here), but is usually the state in which the susceptible animal has contracted the disease but has not yet shown any clinical signs. For many diseases animals in

this state can still "shed" the disease, meaning other susceptible animals can contract it. Day one of the disease episode is assumed to be the day the first animal enters this state.

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

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

This study will utilize the integration of the DADS model (Bates, Thurmond and Carpenter with the Agricultural Sector Model (ASM) (Adams et al.) to assess economic impacts in studies completed under the National Center for Foreign Animal and Zoonotic Disease Defense (FAZDD). They are discussed in detail below.

9.1.2.1. The Davis Animal Disease Simulation (DADS) Model

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

9.1.3. Economic Modeling

The third stage is the bridging of the epidemic and economic models and the disease related adjustments in the economic model. There are many factors that may determine which kind of

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

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

9.1.3.1. FASOM

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

9.1.3.1.1. Overview of the ASM Structure

The Agricultural Sector Model contains budgets for beef, dairy, hogs, sheep, broilers, turkeys, egg layers and horses although the last category is treated in a very cursory fashion. Within the

beef and hog operations a number of intermediate budgets are represented to separate out important stages of production.

- Beef: Beef animals generate fed and non fed beef with intermediate outputs of heifer and steer calves, heifer and steer yearlings and cull cows. We model production at the cow-calf, stocker and feedlot stages plus an infusion of calves and cull cows from the dairy herd. Specifically we represent cow/calf operations, steer and heifer calves in stocker operations, steer and heifer yearlings in stocker operations, beef yearlings in feedlots, and beef calves in feedlots.
- Dairy: Dairy animals generate milk and calves with intermediate outputs of cull cows.
- Hogs: Hogs generate fed hogs with intermediate outputs of feeder pigs and cull sows. We model production at the (1) farrowing, (2) finishing and (3) farrow to finish stages.
- Sheep: Sheep generate wool, lamb and cull ewes.
- Turkeys: Turkeys generate turkeys.
- Broilers: Broilers generate broilers.
- Egg Production: Hens generate eggs. A single laying hen on average produces 257 eggs or just over 21 dozen per year.
- Horses and Mules: Horses and mules produce horses and mules.

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

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

In implementing an animal disease, the focus will be on reducing the production of outputs and increasing other costs. This will imitate a “disease shock” on the region of interest. Budgets in ASM are normalized to a one animal basis. This means epidemic data in terms of head slaughtered, vaccination, or restricted must also be normalized. Intuitively, the impact of the disease is spread evenly across an entire region such that the average productivity per animal in the region is reduced and the average cost of production per animal is increased. To see how an animal disease shock is imposed in the overall conceptual structure, refer to Figure 13. Because of the supply and demand relationships in the model, an animal disease shock impact assessment can occur both upstream and downstream of the actual livestock production budgets.

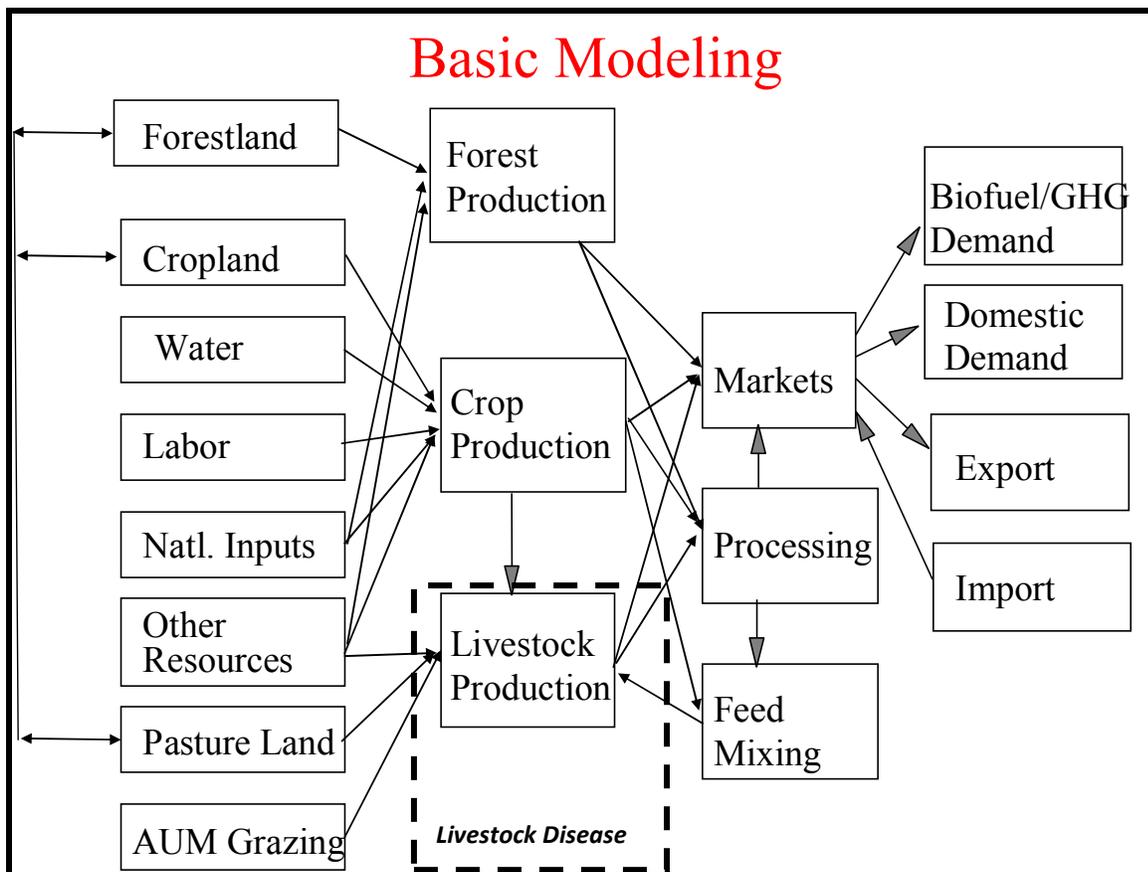


Figure 13. Basic FASOM Modeling Structure and Disease Shock Imposition (adapted from Adams et al.)

9.1.3.1.2. Geographic Representation

ASM is built on a county level, results are reported on either a sub-regional basis or are aggregated to a regional basis. The full ASM runs over 11 regions and 66 sub-regions. The 66 sub-regions consist of one sub-region for each continental US state except for further breakdowns in California, Illinois, Indiana, Iowa, Ohio, Oregon, Oklahoma, Texas and Washington. These states have sub-state production regions based on differences in production conditions.

In addition to the trade of goods within the US regions and sub-regions, FASOM also allows trade flow with 37 international regions listed below. Figure 14 gives a map of these regions. Within the model, animal products the US imports are eggs, wool, non-fed beef, fed beef, pork, secondary dairy products (i.e. butter, cheese, dry milk), and some live cattle. The US exports of animal products are eggs, fed beef, wool, pork, secondary dairy products, chicken and turkey.

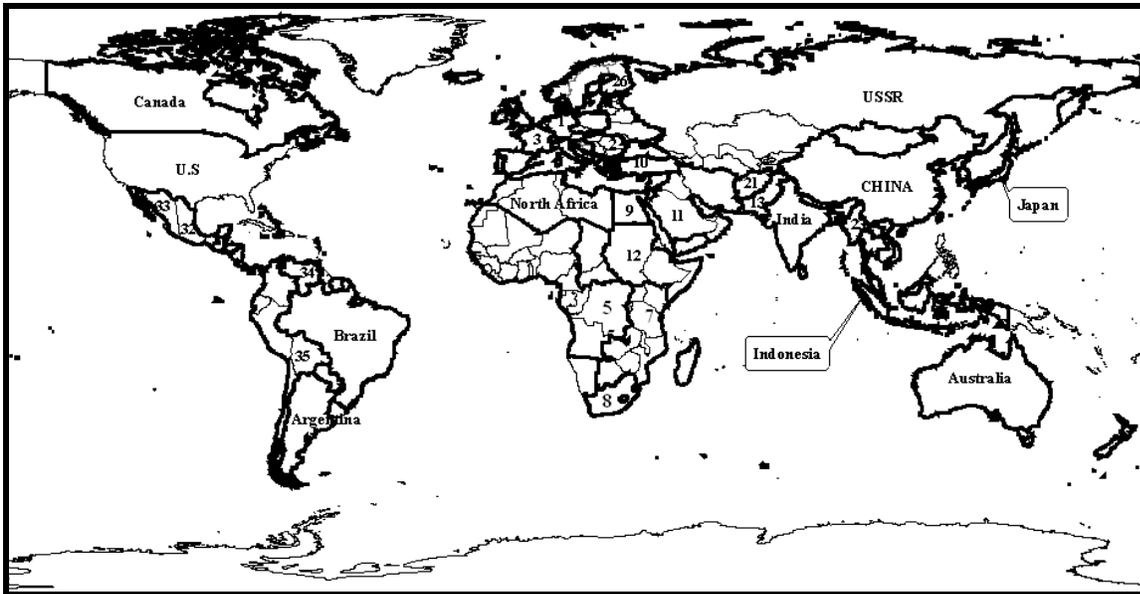


Figure 14. International Market Regions in ASM

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

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

9.1.3.1.3. Modeling the Market

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

- regional product supply,
- national raw product demand,
- regional or national processed commodity demand,
- regional or national supply of processed commodities,
- regional or national (depending on commodity) export demand
- regional or national (depending on commodity) import supply,
- regional feed supply and demand,
- regional direct livestock demand,
- international transport perfectly elastic supply and
- country-specific excess demand and supply of rice, sorghum, corn, soybeans and the 5 types of wheat

9.1.3.1.4. Using FASOM to Model Animal Disease

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

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