THE ECONOMIC IMPACTS OF A FOOT-AND-MOUTH DISEASE OUTBREAK: A REGIONAL ANALYSIS

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Abstract

Contagious animal diseases like foot-and-mouth disease (FMD) are often referred to as economic diseases because of the magnitude of economic harm they can cause to producers and to local communities. This study demonstrates the local economic impact of a hypothetical FMD outbreak in southwest Kansas, an area with high density of cattle feeding. The expected (most probable) economic impact of the disease hinges heavily on where the incidence of the disease occurs. If the disease were to occur in a cow-calf herd in the region economic impact is expected to be relatively small compared to if it were introduced simultaneously in five large feedlots in southwest Kansas. Disease surveillance, management strategies, mitigation investment, and overall diligence clearly need to be much greater in concentrated cattle feeding and processing areas at the large feeding operations in the region.

Introduction

Concerns about invasive species and foreign animal diseases have escalated substantially in recent years. Terrorist attacks on the U.S. in September 2001 greatly increased awareness of vulnerability of U.S. agriculture to bioterrorism. In response to these concerns, President Bush signed into law the *Public Health Security and Bioterrorism Preparedness and Response Act of 2002*. The purpose of this Act is to "To improve the ability of the United States to prevent, prepare for, and respond to bioterrorism and other public health emergencies" (107th Congress, 2002).

Discovery of an infected dairy cow with bovine spongiform encephalopathy (BSE) in the U.S. in December 2003 and the subsequent loss of world markets for U.S. produced beef demonstrate the economic impact animal health can have on the livestock and related industries. The BSE incident resulted in immediate closure of major U.S. beef export markets (Japan, Korea, Mexico, and Canada). The U.S. exported over one million metric tons of beef in 2003 compared to only 200,000 metric tons in 2004 following discovery of the BSE infected animal in Washington State (USDA, FAS). Coffey et al. (2005) estimated that the U.S. beef industry losses resulting from export restrictions during 2004, ranged from $3.2 billion to $4.7 billion.

The United Kingdom experienced a severe foot-and-mouth disease (FMD) outbreak in 2001. On February 20, 2001 FMD was confirmed in Great Britain. Subsequent epidemiological analysis determined that at least 57 premises were infected by the time the first case was identified (Scudamore, 2002). By September 30, 2001 when the outbreak was eradicated, 221 days later, 2,026 cases of FMD had been confirmed; over six million animals were destroyed and the disease spread to Ireland, France, and the Netherlands. Thompson et al. (2002) estimated losses from FMD in the UK at £5.8 to £6.3 billion ($10.7 to $11.7 billion U.S.). This FMD outbreak in the United Kingdom demonstrates the need to understand probable economic impacts of a highly contagious disease to develop effective public policy.

The objective of this research is to determine the economic implications of a hypothetical FMD outbreak in a specific local region in Southwest Kansas under three different disease introduction scenarios. These scenarios include disease introduction at a single cow-calf operation, introduction at a single medium-sized feedlot (feedlot with between 10,000-30,000 head of cattle one-time feeding capacity), and introduction simultaneously at five large feedlots (feedlots with greater than 40,000 head one-time feeding capacity). The first two scenarios would be indicative of a likely small-scale outbreak (though there is some probability of the outbreak being large). Whereas, the latter scenario represents what could characterize a purposeful simultaneous introduction of the disease and would have a much greater probability of a larger outbreak.

An epidemiological disease spread model is used to determine the probable spread of a hypothetical FMD outbreak in southwest Kansas, an area selected because of its relatively high concentration of large cattle feeding operations as well as other livestock enterprises and a large beef processing presence. Results from the disease spread model are integrated into an economic framework to determine the regional economic impacts. Results from this study can be used to assess what economic impacts would be if such an event occurred in a local region and in implementing future invasive species and foreign animal disease management policies.

Overview of Foot-and-Mouth Disease

Foot-and-Mouth Disease (FMD) is a highly contagious viral disease of cloven-hoofed domestic and wild animals, such as cattle, bison, pigs, sheep, goats, and deer. Because FMD is highly contagious, it is arguably one of the most important livestock diseases in terms of economic impact throughout the world.

The FMD virus is hearty in that it can survive for long periods in uncooked processed meats, frozen products (i.e., semen, meat, and bones), milk and dairy products (even when pasteurized), and fomites (i.e., clothing, shoes, hides, etc.) and over a broad range of climates and regions. Such regions that have recently battled FMD range from arid regions in Africa (such as Botswana) to tropical regions in South America (such as Brazil). FMD is currently present in parts of South America, Europe, Asia, and Africa. In the U.S., FMD was first discovered in 1870. Since the initial outbreak, there have been eight additional outbreaks with the last being a mild epidemic in California in 1929. In 1914, the U.S. had its most devastating FMD outbreak, which began in Michigan and spread to the Chicago stockyards by 1915. Overall, FMD had spread to 22 states and 172,000 cattle, hogs, sheep, and goats were destroyed during the eradication program (McCauley, et al., 1979).

Transmission of the virus primarily occurs via direct or indirect contact, animate vectors (e.g., humans), inanimate vectors (e.g., vehicles), and air (over land or across bodies of water. Animals exposed to the virus will typically develop signs of FMD within two to five days. FMD is typically not fatal in livestock, though mortality in animals less than one year of age is significantly more probable. The main impact of FMD on infected livestock is reduced productivity.

If FMD is discovered, aggressive quarantines, substantial restrictions on animal movement, and stamping-out of exposed animals are strategies enacted to attempt to rapidly arrest and eradicate the disease. Furthermore, vaccination strategies may be employed in addition to intensive disinfection programs to try to contain the disease. Depending upon the expected economic impact of the disease, the type of emergency response and disease management strategy may differ. That is, if economic impacts of the incidence of the disease differ substantially, the optimum management strategy may differ depending upon where the disease might occur even within the same region. The point is that we must understand the probable economic impact of the disease by different scenarios of introduction to help assure that the costs associated with disease mitigation, if it is discovered do not further contribute to the likely adverse economic costs of the disease outbreak.

The Office International des Epizooties (OIE), the most widely accepted world animal health organization, ensures transparency on the global incidence of animal diseases. Because of the highly contagious nature and large economic impact of FMD throughout the world, "FMD is the first disease on the OIE List A and was the first disease for which the OIE established an official list of free countries and zones" (OIE website). A country having FMD-free status has an enormous trade advantage. Countries that are FMD-free, as designated by the OIE, can restrict meat imports from countries that are not FMD-free, with trade limited to certain types of meat (e.g., processed meat).

Methodology

Epidemiological Analysis

Epidemiology deals with the incidence, distribution, and control of diseases in populations. Empirical epidemiological models are commonly used to assess potential disease outbreaks through the use of simulations. A commonly used empirical model is the state-transition model. In state-transition models, a unit is classified into one of several possible health states (i.e., susceptible, infected, immune, or removed). The transition (or pathways) between states depends on an array of factors with various vectors of disease transmissions (e.g., direct and indirect contacts) and probabilities associated with such transmissions. Most probabilities in a state-transition model are obtained from past outbreaks, field studies, and/or expert opinion.

The epidemiological disease spread model used in this study is the North American Animal Disease Spread Model (NAADSM) which was originally developed by the Animal Plant Health Inspection Service of the U.S. Department of Agriculture. Several recent studies including Lee, Setizinger, and Paarlberg (2006), Pendell (2006), and Reeves et al., (2006) have used the NAADSM to analyze impacts of FMD outbreaks. The NAADSM is a spatial, stochastic, state-transition simulation model that simulates animal disease spread. The NAADSM is a flexible tool that allows for simulating temporal and spatial spread of FMD at the herd level (Hill and Reeves, 2006).

This study evaluates contagious animal disease spread for three different introductions of a hypothetical FMD outbreak: 1) introduction at a cow-calf herd, 2) introduction in a medium-sized feedlot, and 3) introduction at five large feedlots. In the five large feedlots scenario, FMD is hypothetically introduced simultaneously in five large feedlots in southwest Kansas. Such a scenario might represent the case where FMD is intentionally introduced. In the other two scenarios, one cow-calf herd and one medium-sized feedlot, the index case (i.e., initial case) is hypothetically introduced in one randomly chosen cow-calf herd and one randomly chosen medium-sized feedlot herd in southwest Kansas. For each scenario, the NAADSM model is simulated with 1,000 iterations creating a distribution of probable disease spreads and durations. We use the expected value from these simulations for each scenario in our economic models.

Southwest Kansas was selected as the study area because it is one of the most intensively populated beef cattle feeding and beef processing regions in the nation. As a result, the local economy in this area is highly dependent on the industry which amplifies the importance of the economic impact of such a disease outbreak. In early 2005, of the 6.6 million head of cattle in Kansas, 2 million head were located in the 14-county geographic area analyzed in this study (USDA, NASS). In 2003, Kansas was the leading state in the U.S. in the number of cattle slaughtered (7.4 million head). Further, Kansas imported 4.58 million head of cattle in 2003. If a FMD outbreak occurred in Kansas, a six-mile radius quarantine area surrounding the infected premise would be instituted by the Kansas Department of Health and Environment. Within the quarantine area, in an area 1.5 miles surrounding the infected premise called an exposed zone, all animals would be destroyed. In addition, all animal in-shipments would be stopped at the border and in-state animal movements would be halted (Kansas Department of Health and Environment, 2006). In the epidemiological model used in this study, FMD that might jump outside of the 14-county southwest Kansas area being studied is censored. Despite quarantines and other disease management controls, the disease would have a probability of jumping outside of the southwest Kansas area. However, our economic impact analysis is focused on the local area where we know specific details about operation type, size, and location and can thus identify with the actual number of animals and operations likely to be affected if FMD occurred. As such we can better determine local economic impacts by focusing on a single region.

A FMD outbreak in Kansas coupled with Kansas's emergency guidelines and policies would affect Kansas producers differently than producers outside the state. Therefore, this study presents the economic framework by separating Kansas producers from the rest of U.S. producers. The results from the animal disease spread model, including total number of fed cattle, feeder cattle, dairy cattle, and market hogs that would need to be destroyed to contain the disease, are integrated into an economic framework.

Economic Analysis

Economic analyses play a crucial role in assessing alternative policies regarding management of potential contagious animal diseases. Models that integrate epidemiology and economics are gaining prevalence in the literature. Rich, Miller, and Winter-Nelson (2005) present an overview of five types of economic models used in conjunction with epidemiological modeling. These five types of economic models include: i) benefit-cost analysis; ii) linear programming; iii) input-output; iv) partial equilibrium analysis; and v) computable general equilibrium.

This study employs both partial equilibrium analysis and input-output approaches. There are several studies that have used a partial equilibrium analysis. Berentsen, Dijkhuizen, and Oskam (1992) and Mangen, Burell, and Mourits (2004) which used single-sector models to examine alternate FMD control measures in the Netherlands. Paarlberg, Lee, and Seitzinger (2002) modeled the U.S. agricultural sector with three market levels to quantify the economic impacts of a FMD outbreak in the U.S. Schoenbaum and Disney (2003) used a multi-sector model to compute welfare impacts of alternate FMD control scenarios in the U.S.

Input-Output (I-O) methods are another popular economic tool used in modeling animal disease outbreaks. Three studies that have used the I-O framework to examine FMD outbreaks in Australia, California, and France are by Garner and Lack (1995), Ekboir (1999), and Mahul and Durand (2000), respectively. Caskie, Davis, and Moss (1999) analyzed impacts of BSE in Northern Ireland using I-O models.

Partial Equilibrium Analysis

The structural model used in this study develops a set of supply and demand equations that provides horizontal and vertical linkages between different marketing levels. The model permits variable input proportions by using quantity transmission elasticities that allow for variable input proportions (Brester, Marsh, and Atwood, 2004).

This structural model of the U.S. beef, pork, and poultry industries consists of four marketing levels for beef within the farm-retail marketing chain, three marketing levels for pork, and two levels for poultry. The four marketing levels within the beef sector that are modeled are retail, wholesale (beef processors), slaughter (fed cattle), and farm (cow-calf). Because the pork industry is more vertically integrated compared to the beef industry, there are only three marketing levels within the pork sector (i.e., retail, wholesale, and slaughter). The poultry marketing chain is highly integrated and has only two marketing levels, retail and wholesale.

Because one of the main issues surrounding FMD is the United States ability to trade with other countries, trade of beef at the farm, slaughter, and wholesale-levels and of pork at the slaughter and wholesale-levels is also incorporated into the structural model. Additionally, an outbreak in Kansas would halt all animal movement in and out and within the State. This animal movement ban and border closing is also incorporated into the structural model by disaggregating Kansas from the rest of the United States. The basic structure of the model is presented in the Appendix. Details of the model are presented in (Pendell, 2006).

A frequently used tool to estimate impacts of exogenous shocks to markets is the equilibrium displacement model (EDM). An EDM is a linear approximation to unknown supply and demand functions. The magnitude of deviations from the initial equilibrium and the degree of non-linearity of true supply and demand functions will determine the model's accuracy. If deviations from initial equilibrium are relatively small, then the linear approximation of the unknown supply and demand curves are a relatively accurate measure of the true supply and demand functions (Wohlgenant, 1993). Welfare measures from the equilibrium displacement model are incorporated into the input-output analysis to estimate the regional economic impact.

Input-Output Analysis

The input-output (I-O) model constructed for this analysis is a multiregional model (Miller and Blair, 1985; Miller, 1998). Given the concentration of cattle production and processing in the southwest Kansas region, much of near-term impact will be concentrated within the region. However, the overall control strategy will affect the entire state of Kansas as livestock will not be permitted to move in either direction across state borders.

The I-O construction followed procedures generally employed in standard core-periphery models (e.g., Holland and Hughes, 1992; Kilkenny, 1993, 1995; Kilkenny and Rose, 1995; Holland, Weber and Waters, 1996). With the regions specified as the 14-county southwestern Kansas economy, and the 91-county rest of Kansas economy, separate I-O models were built for each region plus the combined region using the IMPLAN modeling system (MIG, 1999). One general enhancement incorporated into this research was the use of IMPLAN's new national trade flow model (Lindall, Olson and Alward, 2005) to estimate the multiregional trade flows in this fully-developed social accounting matrix (SAM) framework.

Formally, the derivation of the model follows the I-O balance equation given by:

(1) $X + y = x$,

where X is a matrix of inter-industry (including households) and inter-regional (domestic trade) transactions. The X matrix consists of four principal sub-matrices denoted by subscripts i and j referring to regions 1 and 2, respectively. Sub-matrices X_{11} and X_{22} on the main diagonal represent intra-regional inter-industry transactions while off-diagonal sub-matrices X_{12} and X_{21} represent inter-regional trade transactions. Each sub-matrix consists of $m + n + o$ rows and columns where m is the number of industries, n is the number of factor sectors, and o is the number of household sectors. The row and column dimensions of the X matrix are $(m + n + o) \times 2$.

The y is a vector of final demand (government consumption, investment, foreign exports) transactions. The y vector consists of two principal sub-vectors denoted by subscripts i and j referring to regions 1 and 2, respectively. Sub-vector y_1 consists of final demand transactions for region 1 while sub-vector y_2 consists of final demand transactions for region 2. The row dimension for each sub-vector is $(m+n+o)$ as denoted for matrix *X*. The row dimension for vector *y* is $(m+n+o)\times 2$.

The *x* is a vector of total outlays (industry outlays, factor outlays, household outlays). The *x* vector consists of two principal sub-vectors denoted by subscripts *i* and *j* referring to regions 1 and 2, respectively. Sub-vector x_1 consists of total outlays for region 1 while sub-vector x_2 consists of total outlays for region 2. The row dimension for each sub-vector is $(m+n+o)$ as denoted for matrix *X*. The row dimension for vector *x* is $(m+n+o)\times 2$.

Assuming inputs are proportional to total outlays, a direct requirements matrix *A* can be derived:

(2) $A = X(x)^{-1}$,

where $(x)^{-1}$ is a diagonal matrix formed from the *x* vector denoted above. Elements are the reciprocal of the total outlay transactions of vector *x*. *A* is the matrix of input coefficients, i.e., "direct coefficients," denoting the proportion of input per unit of total outlay. Matrix *A* has the same dimensions as matrix *X*.

By substitution, the standard behavioral model for the inter-industrial multiplier analysis can be written as:

(3) $Ax + y = x$.

Rearranging equation (3) in terms of *y* yields:

(4) $y = x - Ax$.

Solving equation (4) for *x*, the outputs of the production sectors equal:

(5) $y = x(I - A)x$, and

(6) $(I - A)^{-1} y = x$.

Where I is the identity matrix and $(I - A)^{-1}$ is the multiregional multiplier matrix and exogenous changes are introduced through a vector represented by y.

Results

As seen in Figure 1, the cumulative expected number of animals that would be destroyed if a FMD outbreak occurs differs substantially by scenario. Two things, 1) number of animals infected and 2) length of disease outbreak, are among the most important epidemiological outputs. For example, if the index case for a FMD outbreak that begins within a cow-calf herd, an expected approximately 126,000 head of livestock are destroyed and the disease outbreak would last 29 days in length. If the index case for a FMD outbreak begins within a medium-sized feedlot, the expected number of livestock destroyed would be 407,000 head and the disease would endure for 39 days. For FMD that is simultaneously introduced at five large feedlots an expected 1.68 million head of animals would be destroyed in southwest Kansas and the outbreak would last 89 days.

Mean estimates for changes in producer surplus associated with the different scenarios at each market level are presented in Table 1. In general, as the number of animals present at the premise of the index case increases, producer surplus losses associated with a FMD outbreak become larger. Total producer surplus (retail, wholesale, slaughter, and farm) for the beef industry declines by $43.2 million when the index case is a single cow-calf herd. When the initial case of FMD occurs in a medium-sized feedlot, total producer surplus losses for the beef industry are $166.5 million. Total producer surplus declines by $728.5 million if FMD is introduced in five large feedlots.

The 14-county southwestern Kansas regional economy is dominated by livestock production and processing. As seen in Table 2, the overall economy generated about $12.8 billion (2004$) in total economic activity in 2004. That level of economic activity supported an estimated 92,000 jobs and was sufficient to support nearly $5 billion in all types of income associated with regional production (value-added). Manufacturing activity is, by far, the dominant economic sector, with meatpacking accounting for the majority of productive value (83% of manufacturing). Other major sectors include agriculture with about $2.6 billion worth of economic activity, combined services ($1.8 billion), government and other manufacturing (about $900 million each). Major employers include combined services, government, manufacturing, agriculture, and trade, each supporting about 11,000 to 15,000 jobs in the region.

Attesting to the dominance of livestock production and processing in the region, the three sectors – grain farming, cattle ranching and farming, and animal slaughter, accounted for over 50 percent of the value of all regional economic activity. In addition, these combined sectors provided about a quarter of employment and total income associated with regional production.

The regional impacts of various outbreak scenarios are shown in Tables 3 and 4. Presentation of the results follows the standard information available in IMPLAN SAM models. The top one-third of the Tables show the value of productive activity (output) using a 14-sector aggregation scheme. While most sectors are highly aggregated, those assumed most impacted by a disease outbreak (grain farming, cattle ranching and farming, animal production-except cattle and poultry (i.e., swine production), meatpacking, and truck transportation) are broken out in detail. The middle third of the table shows three value-added (income) categories, and the lower third shows households by income group.

The value of the direct impacts for cattle, hogs, and meatpacking are taken directly from the partial equilibrium analysis. Estimates associated with grain farming and truck transportation were estimated based on familiarity with the region and the overall value of production in the livestock and meatpacking sectors.

The vector of direct impacts assumed to accrue to southwestern Kansas is shown for the three FMD incidence scenarios in Table 3. In the large feedlot outbreak scenario, the output impacts to the region prior to recovery were estimated to be over $685 million with approximately 64 and 16 percent of the impacts coming from cattle ranching and farming and animal slaughtering, respectively (Table 3). As seen in Table 4, the total output impacts to the rest of Kansas for the same scenario were estimated to be about an additional $260 million. In the rest of the state, cattle ranching and farming bears the largest brunt of the FMD outbreak with $110.9 million (Table 4). Other sectors that are significantly impacted include animal slaughtering, rest of manufacturing, finance, insurance, real estate, and services.

The combined overall impact for the State of Kansas can be obtained by summing the values in Tables 3 and 4. When considering the combined output impacts for all 105 counties in Kansas, the total estimated economic impact would reach nearly $1 billion in productive activity in the five large feedlot outbreak scenario.

SAM accounts also permit the estimation of impacts accruing to value-added (all types of income associated with production) and to households (primarily labor income). Continuing with the five large feedlots scenario, nearly $150 million in total value-added would be lost to southwestern Kansas with an additional $76 million loss to the rest of Kansas. Residents of the region would see a direct decline of approximately $110 million in household income. As the impacts emanate throughout the rest of Kansas, the total impact to value-added reaches about $220 million and total household income declines by about $175 million.

Corresponding impacts in the other scenarios are substantially smaller, but not trivial. A FMD outbreak in a single medium-sized feedlot could result in approximately $200 million decline in total economic activity. Even a relatively small outbreak in a single cow-calf herd would tally about $35 million in lost output to Kansas.

Conclusions

Most previous research on FMD has drawn the same general conclusion; a FMD outbreak has severe economic implications. This study estimated the economic impact of a FMD outbreak in southwestern Kansas under three different disease introduction scenarios. The scenarios included introduction of FMD at a cow-calf operation, a medium-sized feedlot, and simultaneously at five large feedlots. The different scenarios were used to demonstrate how the incidence of such a disease would have widely different epidemiological and economic implications. As such, diligence in managing, having contingency plans in place, investment in disease control strategies, and for ways to deal with the disease if it were to occur are much different depending upon the nature of the disease incidence or outbreak.

If the disease was introduced in a single cow herd, with rapid detection and ability to arrest the disease quickly and restore normal cattle and meat movement in the region in a relatively short time frame, local economic damages would be modest. That is, total economic impact (production activity, value-added, and household income) on the local southwest Kansas economy would be a loss of about $35 million. However, in contrast, if the disease were introduced in five large feedlots, the total economic impact in the area would approach a $1 billion loss.

Clearly, if the disease hit several large feedlots at once, the economic loss would very substantial for the local community. This indicates that diligent animal health surveillance programs and policies and industry management strategies to ensure against FMD introduction in large feedlots is critical. Given the amount of traffic into large feedlots every day and the number of cattle coming into such facilities for finishing on a regular basis, introduction and spread of a contagious disease to other premises is not only easier, but probable. The aggressiveness and amount of resources that would be worth committing to a FMD incident if it were to occur in this region depends on the nature of the incident. If the incident occurred in large feedlots, a considerable amount of resource commitment to control the disease appears to be a prudent investment.

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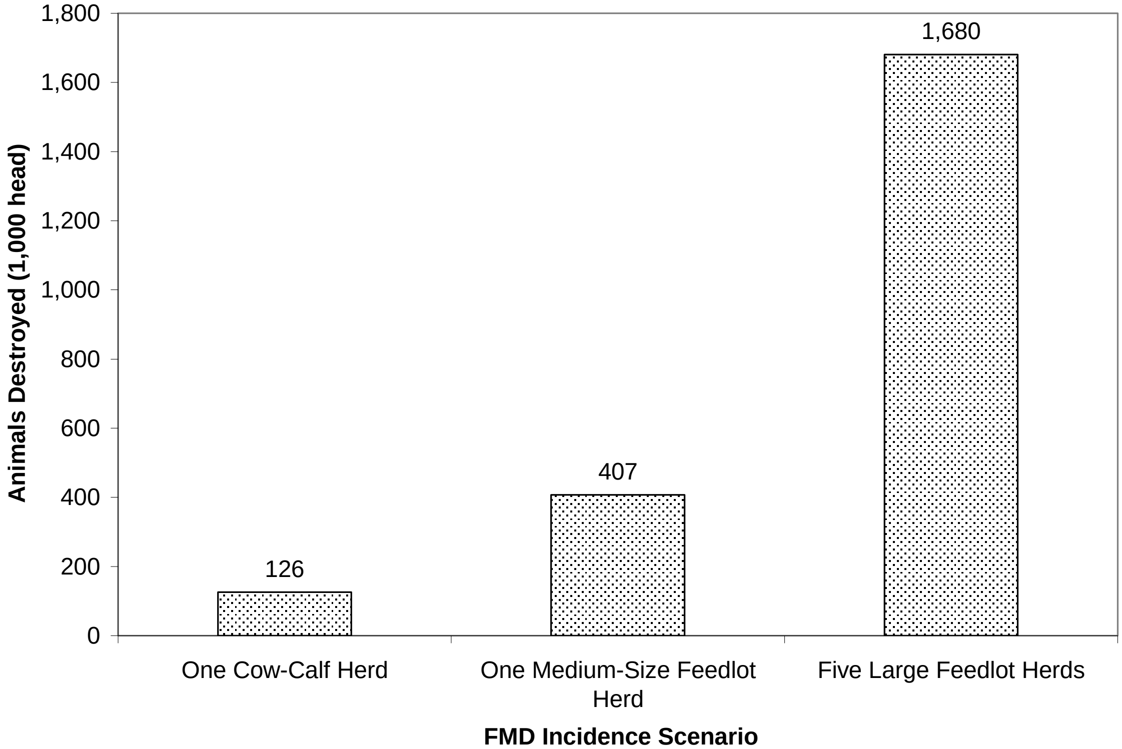

Figure 1. Cumulative Expected Number of Destroyed Animals for Different Scenarios of Hypothetical FMD Incidence

Table 1. Changes in Producer Surplus for Each Market Level Associated with Three Different Hypothetical FMD Incidence Scenarios($ millions)

	Hypothetical FMD Incidence Scenario		
	Five Large Feedlot Herds	One Feedlot Herd	One Cow-Calf Herd
Beef Producer Surplus:			
Retail Level	-63.57	-17.39	-6.97
Wholesale Level	-134.87	-33.08	-10.90
Other States Slaughter (Fed Cattle) Level	-50.15	-16.82	-9.34
Kansas Slaughter (Fed Cattle) Level	-374.93	-72.97	-6.99
Other States Farm (Feeder Cattle) Level	-95.44	-24.20	-8.67
Kansas Farm (Feeder Cattle) Level	-9.51	-2.01	-0.37
Total Beef Industry Producer Surplus	-728.48	-166.47	-43.24
Pork Producer Surplus:			
Retail Level	22.64	6.34	2.84
Wholesale Level	3.90	1.11	0.61
Other States Slaughter (Hog) Level	4.88	1.14	0.22
Kansas Slaughter (Hog) Level	-5.10	-1.12	0.00
Total Pork Industry Producer Surplus	26.32	7.47	3.67
Pork Poultry Surplus:			
Retail Level	66.87	18.74	8.40
Wholesale Level	22.86	6.41	2.87
Total Poultry Industry Producer Surplus	89.74	25.15	11.27
Total Meat Industry Producer Surplus	*-612.43*	*-133.86*	*-28.30*

Table 2. Economic Value of Livestock Production and Processing in 14-County Region in Southwest Kansas where Hypothetical FMD Incidents are Simulated, (2004$ millions)

Industry	Industry Output[1]	Employ-Ment	Labor Income[1,2]	Total Value Added[1,2]
Ag, Forestry, Fish & Hunting	2,568.176	13,407	312.538	785.504
Grain Farming[3]	554.220	4,083	78.159	343.543
Cattle Farming and Ranching[3]	1,724.033	6,125	133.162	285.761
Mining	621.273	3,076	158.651	403.767
Utilities	211.364	502	39.877	129.219
Construction	377.149	4,248	131.708	156.159
Manufacturing	5,101.099	13,394	766.290	915.965
Animal- Except Poultry- Slaughtering[3]	4,221.908	11,677	459.541	512.658
Wholesale Trade	306.666	2,754	115.228	209.625
Transportation & Warehousing	404.678	3,517	129.949	172.792
Retail Trade	444.619	8,781	173.242	269.241
Information	173.680	863	37.413	73.556
Finance & Insurance	264.461	2,092	76.892	185.828
Real Estate & Rental	144.257	1,308	34.531	91.238
Professional- Scientific & Tech. Services	154.329	1,814	69.195	85.129
Management of Companies	32.100	269	12.284	16.772
Administrative & Waste Services	102.196	2,126	34.176	46.170
Educational Services	9.892	218	4.378	6.212
Health & Social Services	369.762	6,675	184.560	216.952
Arts- Entertainment & Recreation	30.588	1,160	9.180	14.815
Accommodation & Food Services	169.091	4,190	50.711	75.471
Other services	336.407	6,177	107.506	182.907
Government & Non-NAICs	945.643	15,700	515.134	836.364
Totals	**12,767.428**	**92,272**	**2,963.442**	**4,873.687**

[1] Millions of dollars.
[2] Labor income combines employee compensation and proprietary income. Value added combines labor income with other property income and indirect business taxes.
[3] Sectors are broken out to highlight, but not double counted in the totals.

Table 3. Estimated Direct and Total Impact to Southwest Kansas Region Associated with Alternative Hypothetical FMD Outbreak Scenarios, (2004$ millions)

		Direct Impact			Total Impact		
	Description	**Five Large Feedlot Herds**	**One Feedlot Herd**	**One Cow-Calf Herd**	**Five Large Feedlot Herds**	**One Feedlot Herd**	**One Cow-Calf Herd**
14-County Southwest Kansas (Region A)	**Grain Farming**	-4.330	-1.055	-0.334	-5.202	-1.231	-0.359
	Cattle Ranching and Farming	-346.000	-65.874	-6.324	-435.920	-85.170	-10.446
	Animal Production - except cattle and poultry	-4.590	-1.008	0.000	-5.624	-1.261	-0.082
	Rest of Agriculture	0.000	0.000	0.000	-1.563	-0.314	-0.043
	Mining	0.000	0.000	0.000	-0.023	-0.005	-0.001
	Construction	0.000	0.000	0.000	-1.610	-0.322	-0.045
	Animal - except poultry - slaughtering	-105.740	-25.935	-8.547	-107.966	-26.456	-8.697
	Rest of Manufacturing	0.000	0.000	0.000	-15.736	-3.101	-0.378
	Truck Transportation	-2.040	-0.424	-0.072	-8.175	-1.696	-0.297
	Rest of TCPU	0.000	0.000	0.000	-17.242	-3.487	-0.535
	Wholesale and Retail Trade	0.000	0.000	0.000	-23.568	-4.826	-0.801
	Finance Insurance Real Estate	0.000	0.000	0.000	-25.642	-5.201	-0.816
	Services	0.000	0.000	0.000	-33.724	-6.879	-1.117
	Government	0.000	0.000	0.000	-3.660	-0.734	-0.107
	SUM	-462.700	-94.296	-15.277	-685.655	-140.682	-23.724
	Employee Compensation	0.000	0.000	0.000	-75.897	-15.700	-2.733
	Proprietor Income	0.000	0.000	0.000	-13.502	-2.731	-0.416
	Other Property Type Income	0.000	0.000	0.000	-56.589	-11.372	-1.715
	SUM	0.000	0.000	0.000	-145.988	-29.802	-4.864
	Households LT10k	0.000	0.000	0.000	-1.046	-0.214	-0.035
	Households 10-15k	0.000	0.000	0.000	-1.780	-0.364	-0.060
	Households 15-25k	0.000	0.000	0.000	-7.783	-1.593	-0.263
	Households 25-35k	0.000	0.000	0.000	-11.082	-2.268	-0.374
	Households 35-50k	0.000	0.000	0.000	-20.638	-4.224	-0.698
	Households 50-75k	0.000	0.000	0.000	-32.515	-6.654	-1.098
	Households 75-100k	0.000	0.000	0.000	-16.115	-3.297	-0.544
	Households 100-150k	0.000	0.000	0.000	-11.050	-2.261	-0.373
	Households 150k+	0.000	0.000	0.000	-8.142	-1.666	-0.275
	SUM	0.000	0.000	0.000	-110.151	-22.542	-3.721

Table 4. Estimated Direct and Total Impact to Rest of Kansas Associated with Alternative Hypothetical FMD Outbreak Scenarios, (2004$ millions)

		Direct Impact			Total Impact		
	Description	Five Large Feedlot Herds	One Feedlot Herd	One Cow-Calf Herd	Five Large Feedlot Herds	One Feedlot Herd	One Cow-Calf Herd
91-County Rest of Kansas (Region B)	**Grain Farming**	-4.330	-1.055	-0.334	-6.900	-1.582	-0.410
	Cattle Ranching and Farming	-38.440	-9.106	-1.035	-110.883	-25.350	-4.749
	Animal Production - except cattle and poultry	-0.510	-0.112	0.000	-4.719	-1.141	-0.334
	Rest of Agriculture	0.000	0.000	0.000	-4.574	-0.941	-0.137
	Mining	0.000	0.000	0.000	-0.220	-0.046	-0.008
	Construction	0.000	0.000	0.000	-0.740	-0.166	-0.032
	Animal - except poultry - slaughtering	-26.430	-6.484	-2.137	-26.673	-6.541	-2.153
	Rest of Manufacturing	0.000	0.000	0.000	-23.924	-5.086	-0.846
	Truck Transportation	-0.510	-0.106	-0.018	-3.171	-0.699	-0.139
	Rest of TCPU	0.000	0.000	0.000	-11.314	-2.508	-0.484
	Wholesale and Retail Trade	0.000	0.000	0.000	-13.650	-3.062	-0.618
	Finance Insurance Real Estate	0.000	0.000	0.000	-23.065	-5.177	-1.029
	Services	0.000	0.000	0.000	-28.711	-6.404	-1.269
	Government	0.000	0.000	0.000	-1.550	-0.349	-0.069
	SUM	-70.220	-16.863	-3.524	-260.095	-59.053	-12.277
	Employee Compensation	0.000	0.000	0.000	-36.248	-8.143	-1.670
	Proprietor Income	0.000	0.000	0.000	-5.795	-1.285	-0.255
	Other Property Type Income	0.000	0.000	0.000	-33.719	-7.569	-1.498
	SUM	0.000	0.000	0.000	-75.762	-16.998	-3.423
	Households LT10k	0.000	0.000	0.000	-0.539	-0.121	-0.024
	Households 10-15k	0.000	0.000	0.000	-1.007	-0.226	-0.046
	Households 15-25k	0.000	0.000	0.000	-3.438	-0.771	-0.155
	Households 25-35k	0.000	0.000	0.000	-5.250	-1.178	-0.237
	Households 35-50k	0.000	0.000	0.000	-9.587	-2.151	-0.434
	Households 50-75k	0.000	0.000	0.000	-17.824	-3.998	-0.806
	Households 75-100k	0.000	0.000	0.000	-10.888	-2.442	-0.492
	Households 100-150k	0.000	0.000	0.000	-9.534	-2.139	-0.431
	Households 150k+	0.000	0.000	0.000	-7.054	-1.582	-0.319
	SUM	0.000	0.000	0.000	-65.121	-14.609	-2.945

Appendix

The following is the structural model that was used to conduct the *Partial Equilibrium Analysis* (details of the model parameters are presented in Pendell, 2006).

Beef Sector:

Retail

1) U.S. retail beef demand: $Q_B^r = f_1(P_{BUS}^r, P_{KUS}^r, P_{YUS}^r, Z_{BUS}^r)$
2) U.S. retail beef supply: $Q_B^r = f_2(P_{BUS}^r, Q_B^w, W_{BUS}^r)$

Wholesale

3) U.S. wholesale beef demand: $Q_{BUS}^{wd} = f_3(P_{BUS}^w, Q_B^r, Z_{BUS}^w)$
4) Export wholesale beef demand: $Q_{BE}^w = f_4(P_{BE}^w, Z_{BE}^w)$
5) U.S. wholesale beef supply: $Q_{BUS}^{ws} = f_5(P_{BUS}^w, Q_B^s, W_{BUS}^w)$
6) Import wholesale beef supply: $Q_{BI}^w = f_6(P_{BI}^w, W_{BI}^w)$
7) Total wholesale beef demand: $Q_B^w = Q_{BUS}^{wd} + Q_{BE}^w$
8) Total wholesale beef supply $Q_B^w = Q_{BUS}^{ws} + Q_{BI}^w$

Slaughter

9) Total fed cattle demand: $Q_B^s = f_7(P_{BUS}^s, Q_B^w, Z_{BUS}^s)$
10) KS fed cattle supply: $Q_{BKS}^s = f_8(P_{BKS}^s, Q_B^f, W_{BKS}^s, N_B^s)$
11) Other States fed cattle supply: $Q_{BO}^s = f_9(P_{BUS}^s, Q_B^f, W_{BO}^s)$
12) Total U.S. fed cattle supply: $Q_{BUS}^s = Q_{BKS}^s + Q_{BO}^s$
13) Import fed cattle supply: $Q_{BI}^s = f_{10}(P_{BI}^s, W_{BI}^s)$
14) Total fed cattle supply: $Q_B^s = Q_{BUS}^s + Q_{BI}^s$
15) KS fed cattle inventory: $N_B^s = f_{11}(F_B^s)$

Farm

16) Total feeder cattle demand: $Q_B^f = f_{12}(P_{BUS}^f, Q_B^s, Z_B^f)$
17) KS feeder cattle supply: $Q_{BKS}^f = f_{13}(P_{BKS}^f, W_{BKS}^f, N_B^f)$
18) Other States feeder cattle supply: $Q_{BO}^f = f_{14}(P_{BUS}^f, W_{BO}^f)$
19) Total U.S. feeder cattle supply: $Q_{BUS}^f = Q_{BKS}^f + Q_{BO}^f$
20) Import feeder cattle supply: $Q_{BI}^f = f_{15}(P_{BI}^f, W_{BO}^f)$
21) Total feeder cattle supply: $Q_B^f = Q_{BKS}^f + Q_{BO}^f$
22) KS feeder cattle inventory: $N_B^f = f_{16}(F_B^f)$

Price Relationships

23) Kansas and Other States slaughter prices: $P^{s}_{BKS} = P^{s}_{BO} + S^{s}_{B}$

24) Kansas and Other States feeder prices: $P^{f}_{BKS} = P^{f}_{BO} + S^{f}_{B}$

Pork Sector:

Retail

25) U.S. retail pork demand: $Q^{r}_{K} = f_{17}(P^{r}_{BUS}, P^{r}_{KUS}, P^{r}_{YUS}, Z^{r}_{KUS})$

26) U.S. retail pork supply: $Q^{r}_{K} = f_{18}(P^{r}_{KUS}, Q^{w}_{K}, W^{r}_{KUS})$

Wholesale

27) U.S. wholesale pork demand: $Q^{wd}_{KUS} = f_{19}(P^{w}_{KUS}, Q^{r}_{K}, Z^{w}_{KUS})$

28) Export wholesale pork demand: $Q^{w}_{KE} = f_{20}(P^{w}_{KE,} Z^{w}_{KE})$

29) U.S. wholesale pork supply: $Q^{ws}_{KUS} = f_{21}(P^{w}_{KUS}, Q^{s}_{K}, W^{w}_{KUS})$

30) Import wholesale pork supply: $Q^{w}_{KI} = f_{22}(P^{w}_{KI}, W^{w}_{KI})$

31) Total wholesale pork demand: $Q^{w}_{K} = Q^{wd}_{KUS} + Q^{w}_{KE}$

32) Total wholesale pork supply: $Q^{w}_{K} = Q^{ws}_{KUS} + Q^{w}_{KI}$

Slaughter

33) Total market hog demand: $Q^{s}_{K} = f_{23}(P^{s}_{KUS}, Q^{w}_{K}, Z^{s}_{KUS})$

34) KS market hog supply: $Q^{s}_{KKS} = f_{24}(P^{s}_{KKS}, W^{s}_{KKS})$

35) Other States market hog supply: $Q^{s}_{KO} = f_{25}(P^{s}_{KUS}, W^{s}_{KO}, N^{s}_{K})$

36) Total U.S. market hog supply: $Q^{s}_{KUS} = Q^{s}_{KKS} + Q^{s}_{KO}$

37) Import market hog supply: $Q^{s}_{KI} = f_{26}(P^{s}_{KI}, W^{s}_{KI})$

38) Total supply of market hog: $Q^{s}_{K} = Q^{s}_{KUS} + Q^{s}_{KI}$

39) KS market hog inventory: $N^{s}_{K} = f_{27}(F^{s}_{K})$

Price Relationships

40) Kansas and Other States slaughter prices: $P^{s}_{KKS} = P^{s}_{KO} + S^{s}_{K}$

Poultry Sector:

Retail

41) U.S. retail poultry demand: $Q^{r}_{Y} = f_{28}(P^{r}_{BUS}, P^{r}_{KUS}, P^{r}_{YUS}, Z^{r}_{YUS})$

42) U.S. retail poultry supply: $Q^{r}_{Y} = f_{29}(P^{r}_{YUS}, Q^{w}_{Y}, W^{r}_{YUS})$

Wholesale

43) U.S. wholesale poultry demand: $Q^{w}_{Y} = f_{30}(P^{w}_{YUS}, Q^{r}_{Y}, Z^{w}_{YUS})$

44) U.S. wholesale poultry supply: $Q^{w}_{Y} = f_{31}(P^{w}_{YUS}, W^{w}_{YUS})$

where the variables P_i^j and Q_i^j indicate price and quantity for at the *j*th marketing level for commodity *i*, respectively. Superscript *r* denotes retail, *w* denotes wholesale, *s* denotes slaughter, and *f* denotes farm-level, respectively, while subscripts *B*, *K*, and *Y* denotes the beef, pork, and poultry sectors, respectively. Additional subscripts, *US* (United States), *KS* (Kansas), *OS* (Other States – United States excluding Kansas), *E* (Export), and *I* (Import) represent locations. The variables, z_i^j and w_i^j, are elements of the demand and supply shifters (*Z* and *W*) which represent the exogenous cost shocks from the initial equilibrium as a result of FMD. These shifts are determined from the epidemiological model. Cattle and hog inventories (N_i^j) are reduced by the amount of cattle and hogs that are destroyed due to FMD (i.e., denoted by F_i^j). The variable, F_i^j, is the number of animal destroyed, determined by the epidemiological model, divided by the original number of *i*th commodity for the *j*th marketing level.