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The Economic Impacts of a Foot-And-Mouth Disease Outbreak: A Regional Analysis

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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 FMD outbreak in southwest Kansas. The expected economic impact of the disease hinges heavily on where the incidence of the disease occurs. Disease surveillance, management strategies, mitigation investment, and overall diligence clearly need to be much greater in concentrated cattle feeding and processing areas at large feeding operations in the region.

Key Words: foot-and-mouth disease, invasive species, livestock, regional analysis

JEL Classifications: Q11, Q13, R15

Concerns about invasive species and foreign animal diseases have escalated substantially in recent years. Terrorist attacks on the United States 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).

Discovery of an infected dairy cow with bovine spongiform encephalopathy (BSE) in the United States 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 United States exported over one million metric tons of beef in 2003 compared with only 200,000 metric tons in 2004 after discovery of the BSE-infected animal in Washington State (USDA, FAS). Coffey et al. 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 epi-

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demiological analysis determined that at least 57 premises were infected by the time the first case was identified (Scudamore). 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. estimated losses from FMD in the UK at £5.8 to £6.3 billion (US$10.7 to $11.7 billion). 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 10,000–20,000 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. The simultaneous introduction into five large feedlots could ultimately result in larger consequences due to the number of cattle that would be destroyed and the number of animate (e.g., humans) and inanimate (e.g., vehicles) vectors entering a large feedlot on a daily basis.

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

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 hardy 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 United States, 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 United States 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.).

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 used 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. In other words, we must understand the probable economic impact of the disease outbreak, including different scenarios of introduction, to help assure that the costs associated with disease mitigation 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 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 and Plant Health Inspection Service of the U.S. Department of Agriculture. Several recent studies, including Lee, Seitzinger, and Paarlberg; Pendell; and Reeves et al. 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).

The data used in the epidemiological model consists of herd location (latitude and longitude), species (cattle feedlot, cow–calf, dairy, and swine), and density. Data for the disease-spread model were obtained from two sources: (i) The Kansas Department of Health and Environment, and (ii) the USDA's National Agricultural Statistics Service (NASS).

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 simu-

Table 1. Economic Value of Livestock Production and Processing in 14-County Region in Southwest Kansas where Hypothetical FMD Incidents are Simulated (2004 Dollars, Millions)

Industry	Industry Output[a]	Employment	Labor Income[a,b]	Total Value Added[a,b]
Ag, forestry, fish & hunting	2,568.176	13,407	312.538	785.504
Grain farming[c]	554.220	4,083	78.159	343.543
Cattle farming and ranching[c]	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[c]	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[d]	945.643	15,700	515.134	836.364
Totals	12,767.428	92,272	2,963.442	4,873.687

[a] Millions of dollars.
[b] Labor income combines employee compensation and proprietary income. Value added combines labor income with other property income and indirect business taxes.
[c] Sectors are broken out to highlight, but not double counted in the totals.
[d] North American Industry Classification System.

lated 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. As seen in Table 1, the overall economy for the 14 counties in southwestern Kansas generated about $12.8 billion (2004 dollars) 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), and 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% 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.

In early 2005, of the 6.6 million head of cattle in Kansas, 2 million head were located in the 14-county geographic area (USDA, NASS). In 2003, Kansas was the leading state in the United States 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 Livestock Commissioner. 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 Animal Health Department). 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 response plan and policies would affect Kansas producers differently from 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 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 (I-O), (iv) partial equilibrium analysis, and (v) computable general equilibrium.

This study uses both partial equilibrium analysis and I-O approaches. There are several studies that have used a partial equilibrium analysis to analyze the impacts of a FMD outbreak. Berentsen, Dijkhuizen, and Oskam and Mangen, Burell, and Mourits used single-sector models to examine alternative FMD control measures in the Netherlands. Paarlberg, Lee, and Seitzinger modeled the U.S. agricultural sector with three market levels to quantify the economic impacts of a FMD outbreak in the United States. Schoenbaum and Disney (2003) used a multisector model to compute welfare impacts of alternate FMD control scenarios in the United States.

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; Ekboir; and Mahul and Durand, respectively. Caskie, Davis, and Moss 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).

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 with 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 ability of the United States 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 into and out of 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.

A frequently used tool to estimate impacts of exogenous supply and demand 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 nonlinearity 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).

Exogenous percentage changes in supply associated with a hypothetical FMD outbreak at different marketing levels within the beef and pork industries are estimated from the results obtained from the disease-spread model and incorporated into the EDM. Exogenous demand shocks (i.e., change in consumer demand) could also be incorporated into the EDM. For example, if consumers perceive that FMD is a problem in beef and pork, they might reduce beef and pork demand and increase poultry demand. Welfare measures from the equilibrium displacement model are incorporated into the I-O analysis to estimate the regional economic impact.

I-O Analysis

The I-O model constructed for this analysis is a multiregional model (Miller; Miller and Blair). 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 used in standard core–periphery models (e.g., Holland and Hughes; Holland, Weber and Waters; Kilkenny, 1993, 1995; Kilkenny and Rose). 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). One general enhancement incorporated into this research was the use of IMPLAN's new national trade flow model (Lindall, Olson, and Alward) to estimate the interregional trade flows in this fully developed social accounting matrix (SAM) framework.

The derivation of the SAM multiplier model follows Alward. The fundamental SAM accounting identity is:

$$(1) \quad X + Y = Z,$$

where X is a matrix of interindustry (including households) and interregional (domestic trade) transactions. The X matrix consists of four principal submatrices denoted by subscripts i and j referring to regions 1 and 2, respectively. In our case, region 1 is the 14-county southwestern Kansas model and region 2 is the 91-county rest-of-Kansas model. Submatrices X_{11} and X_{22} on the main diagonal represent intraregional interindustry transactions while off-diagonal submatrices X_{12} and X_{21} represent interregional trade transactions. Each submatrix 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 X, then, are the accounts endogenous to the model responding to some externally generated economic stimulus.

That stimulus comes from final demand. Y is a matrix of final demand (government consumption, investment, foreign exports) transactions. Y consists of two principal submatrices denoted by subscripts i and j referring to regions 1 and 2, respectively. Submatrix Y_{11} consists of final demand transactions for region 1 while submatrix Y_{22} consists of final demand transactions for region 2. The row and column dimensions for each submatrix are $(m + n + o)$ as denoted for matrix X. The dimensions for matrix Y are $(m + n + o) \times 2$. In our model, these are the exogenous accounts representing changes in final demand from external markets responding to news of the livestock disease outbreak.

Summing X and Y yields Z, a matrix of total outlays (industry outlays, factor outlays, household outlays). Total outlays are defined as the value of inputs to production that, in turn, equals the value of outputs from all sources of demand. Z consists of two principal submatrices denoted by subscripts i and j referring to regions 1 and 2, respectively. Submatrix Z_{11} consists of total outlays for region 1 while subvector Z_{22} consists of total outlays for region 2. The dimensions for each submatrix are $(m + n + o)$ as denoted for matrix X. The row and column dimensions for matrix Z are $(m + n + o) \times 2$. Total outlays (or output) are the combined value of both the endogenous and exogenous economic changes.

To derive the outputs for the production sectors, solve Equation (1) for X (see Alward for derivation):

$$(2) \quad (I - A)^{-1} Y = X$$

where I is the identity matrix, A is the matrix of input coefficients (i.e., direct coefficients) denoting the proportion of input per unit of total outlay, $(I - A)^{-1}$ is the multiregional multiplier matrix, and exogenous changes are introduced through matrix Y.

Having the economic multipliers for our 14-county southwestern Kansas region and our 91-county rest-of-Kansas region, we look to the partial equilibrium results for the direct economic impacts. The sectors most likely directly affected in the event of a disease outbreak would be cattle ranching and farming (including feedlot production), other animal production (except poultry and cattle [i.e., swine production]), animal slaughtering, grain farming, and transportation. The task was to translate the values from partial equilibrium analysis into direct impacts to the I-O model.

The Kansas farm and slaughter levels of producer surplus represent the value of lost cattle and swine production. Similarly, the wholesale levels of beef and pork producer surplus are the value of lost animal slaughtering. These are the values available to be distributed to all of the affected sectors both in southwestern Kansas and the rest of Kansas.

The value of cattle and swine production is first distributed to southwestern Kansas and the rest of Kansas using Kansas agricultural statistics. One of the primary inputs into cattle and swine production is the value of feed. Thus, some portion of the value of livestock production needed to be deducted from Kansas farm and slaughter sectors and applied to grain production as an estimate of the loss of demand for grain inputs. The total value attributed to grain farming was estimated by multiplying the number of cattle destroyed by a per-head added cost to the grain industry for hauling grain an additional 200 miles that otherwise would have been used in the southwest Kansas feedlots.

Similarly, the wholesale level of producer surplus represents the increment of value generated in the processing and packing activities occurring there. Some proportion of that value can be attributed to the transportation services needed to move inputs and outputs associated with this activity. Here it is assumed that about one-half percent of the total value of livestock processing is attributable to transportation inputs. These then serve as the values derived from the partial equilibrium model and distributed to affected sectors in the I-O model to estimate the total economic impacts to southwestern Kansas and the state.

Results

The expected number and standard deviation of animals that would be destroyed if a FMD outbreak occurs differ substantially by scenario at each level (Table 2). Two things, number of animals infected and length of disease outbreak, are among the most important epidemiological outputs. For example, if the index case for a FMD outbreak begins within a cow–calf herd, an expected 92,612 head of livestock in feedlots would be 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 in feedlots destroyed would be 292,425 head and the disease would endure for 39 days. For FMD that is simultaneously introduced at five large feedlots, an expected 1.20 million head of cattle in feedlots would be destroyed in southwest Kansas and the outbreak would last 89 days.

The standard deviation of the number of animals destroyed is relatively large. These large values are because in several simulations the number of animals destroyed was near zero and in others most of livestock in the region is destroyed because of widespread disease outbreak. We focus our regional economic analysis on the average number of animals destroyed. However, with the large standard deviations, analyzing the economic implications of distributions of disease impact and spread deserve additional research.

Mean estimates for changes in producer surplus associated with the different scenarios

Table 2. Summary Statistics of Destroyed Animals for Different Scenarios of Hypothetical FMD Incidence

	Mean	Std. Dev.
Number of animals destroyed (head)		
Five large feedlot herds		
Feedlot	1,200,427	1,134,904
Farm	26,113	24,870
Swine	387,415	384,553
One feedlot herd		
Feedlot	292,425	760,049
Farm	6,304	16,520
Swine	92,041	246,576
One cow–calf herd		
Feedlot	92,612	445,760
Farm	2,018	9,884
Swine	26,343	134,644
Length of outbreak (days)		
Five large feedlot herds	89	47.76
One feedlot herd	39	38.94
One cow–calf herd	29	26.28

at each market level are presented in Table 3. In addition, the 95% confidence intervals for changes in producer surplus are presented in Table 3. 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 regional impacts of various outbreak scenarios are shown in Tables 4 and 5. Presentation of the results follows the standard information available in IMPLAN SAM models. The top one-third of the tables shows the value of productive activity (output) using a 14-sector aggregation scheme. Although most sectors are highly aggregated, those assumed most affected by a disease outbreak (grain farming, cattle ranching and farming, animal production except cattle and poultry [i.e., swine production], meatpacking, and

Table 3. 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 Medium-Size Feedlot Herd	One Cow-Calf Herd
Beef producer surplus:			
retail level	−63.57	−17.39	−6.97
	(−138.25, 48.82)[a]	(−50.30, 15.14)	(−32.23, 9.97)
Wholesale level	−134.87	−33.08	−10.90
	(−154.35, −50.57)	(−50.12, −16.83)	(−29.09, −9.43)
Other states slaughter (fed cattle) level	−50.15	−16.82	−9.34
	(−132.51, 110.81)	(−54.28, 25.50)	(−39.93, 8.81)
Kansas slaughter (fed cattle) level	−374.93	−72.97	−6.99
	(−7,162.79, 6,381.24)	(−1,291.76, 1,131.37)	(−20.16, −7.86)
Other states farm (feeder cattle) level	−73.20	−24.20	−8.67
	(−94.94, −51.45)	(−31.75, −17.80)	(−18.50, −10.59)
Kansas farm (feeder cattle) level	−9.51	−2.01	−0.37
	(−16.28, −0.83)	(−1.37, −0.75)	(−0.87, −0.46)
Total beef industry producer surplus	−706.23	−166.47	−43.24
Pork producer surplus:			
Retail level	22.64	6.34	2.84
	(−6.30, 42.22)	(−2.17, 14.97)	(−1.39, 9.69)
Wholesale level	3.90	1.11	0.61
	(−4.16, 10.53)	(−1.44, 3.75)	(−1.19, 2.20)
Other states slaughter (hog) level	4.88	1.14	0.22
	(0.41, 9.40)	(−0.35, 2.78)	(−0.22, 1.85)
Kansas slaughter (hog) level	−5.10	−1.12	0.00
	(−6.23, −3.87)	(−1.32, −0.99)	(−1.28, −0.96)
Total pork industry producer surplus	26.32	7.47	3.67
Poultry producer surplus:			
Retail level	66.87	18.74	8.40
	(−56.66, 162.74)	(−19.48, 57.22)	(−12.50, 37.12)
Wholesale level	22.86	6.41	2.87
	(−19.83, 56.15)	(−6.83, 19.76)	(−4.39, 12.82)
Total poultry industry producer surplus	89.74	25.15	11.27
Total meat industry producer Surplus	−590.18	−133.86	−28.30

[a] Indicates the 95% confidence interval.

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.

In I-O analysis, the direct economic impacts are the immediate changes in the value of total final demand. Subsequent impacts to value-added or household income arise as the indirect or backward-linked sectors and institutions are affected by the direct change in final demand. Thus, in an immediate (direct) sense, all that is changing is the value of production. Impacts to labor, households, and interlinked industry sectors do not appear until the total impacts are computed. The value of the direct impacts for cattle, hogs, and meatpacking are taken directly from the

Table 4. Estimated Direct and Total Impact to Southwest Kansas Region Associated with Alternative Hypothetical FMD Outbreak Scenarios (2004 Dollars, 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

partial equilibrium analysis as described earlier. Estimates associated with grain farming and truck transportation were estimated on the basis of a consensus of experts knowledgeable with both 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 4. In the large feedlot outbreak scenario, the output impacts to the region before recovery were estimated to be over $685 million with approximately 64% and 16% of the impacts coming from cattle ranching and farming and animal slaughtering, respectively (Table 4). 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 5). Other sectors that are significantly affected 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 4 and 5. 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

Table 5. Estimated Direct and Total Impact to Rest of Kansas Associated with Alternative Hypothetical FMD Outbreak Scenarios (2004 Dollars, 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

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 an 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 were 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 be 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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References

Alward, G.S. "Deriving SAM Multiplier Models Using IMPLAN." National IMPLAN Conference: Proceedings of the Conference. Minneapolis, Minnesota, August 15–16, 1996, pp. 7–16.

Berentsen, P.B., A.A. Dijkhuizen, and A.J. Oskam. "A Dynamic Model for Cost–Benefit Analyses of Foot-and-Mouth Disease Control Strategies." *Preventive Veterinary Medicine* 12(1992):229–43.

Brester, G.W., J.M. Marsh, and J.A. Atwood. "Distributional Impacts of Country-of-Origin Labeling in the U.S. Meat Industry." *Journal of Agricultural and Resource Economics* 29(2004): 206–27.

Caskie, P., J. Davis, and J.E. Moss. "The Economic Impact of BSE: A Regional Perspective." *Applied Economics* 31(1999):1623–30.

Coffey, B., J. Mintert, J. Fox, T. Schroeder, and L. Valentin. *The Economic Impact of BSE on the Us Beef Industry: Product Value Losses, Regulatory Costs, and Consumer Reactions.* Kansas State University Agricultural Experiment Station and Cooperative Extension Service, MF-2678, April 2005.

Ekboir, J.M. "Potential Impact of Foot-and-Mouth Disease in California: The Role and Contribution of Animal Health Surveillance and Monitoring Services." Agricultural Issues Center, University of California, Davis, 1999.

Garner, M.G., and M.B. Lack. "An Evaluation of Alternate Control Strategies for Foot-and-Mouth Disease in Australia: A Regional Approach." *Preventive Veterinary Medicine* 23 (1995):9–32.

Hill, A., and A. Reeves. "North American Animal Disease Spread Model Version 3.0.X, User's Guide." United States Department of Agriculture, Animal and Plant Health Inspection Service (APHIS), August 2006.

Holland, D., and D. Hughes. "On the Estimation of Commodity and Trade Flows Between Rural and Urban Regions: A Three–Region Approach." Staff Paper No. 92-4. Dept. of Agr. Econ., Washington State University, 1992.

Holland, D., D. Hughes, B.A. Weber, and E.C. Waters. "Modeling the Economic Linkage between Core and Periphery Regions: The Portland, Oregon Trade Area." Working paper, No. 92-103, Dept. of Agr. And Resour. Econ., Oregon State University, 1992.

Kilkenny, M. "Rural/Urban Effects of Terminating Farm Policies." *American Journal of Agricultural Economics* 75(1993):968–80.

———. "Operationalising a Rural–Urban General Equilibrium Model Using a Bi-regional SAM." *Social and Demographic Accounting*, G.J.D. Hewings and M. Madden, eds., pp. 164–79. New York: Cambridge University Press, 1995.

Kilkenny, M., and A. Rose. "Interregional SAMs and Capital Accounts." *Social and Demographic Accounting*, G.J.D. Hewings and M. Madden, eds., pp. 41–59. New York: Cambridge University Press, 1995.

Lee, J.G., A.H. Seitzinger, and P.L. Paarlberg. "Comparison of Economic and Disease Criteria for Controlling Foot and Mouth Disease." Paper presented at the Western Agricultural Economics Association Meetings, Anchorage, Alaska, June 28–30, 2006.

Lindall, S., D. Olson, and G. Alward. "Multi-Regional Models: The IMPLAN National Trade Flows Model." Paper presented at the 36th Annual Meeting of the Mid-Continent Regional Science Association and the 44th Annual Meeting of the Southern Regional Science Association. Alexandria, Virginia, April 7–9, 2005.

Mahul, O., and B. Durand. "Simulated Economic Consequences of Foot-and-Mouth Disease Epidemics and Their Public Control in France." *Preventive Veterinary Medicine* 47(2000):23–38.

Mangen, M.-J.J., A.M. Burell, and M.C.M. Mourits. "Epidemiological and Economic Modeling of Classical Swine Fever: Application to the 1997/1998 Dutch Epidemic." *Agricultural Systems* 81(2004):37–54.

McCauley, E.H., N.A. Aulaqi, J.C. New, W.B. Sundquist, and W.M. Miller. "Potential Economic Impact of Foot-and-Mouth Disease in the United States." *Potential Economic Impact of Foot-and-Mouth Disease in the United States*, E.H. McCauley, N.A. Aulaqi, J.C. New, W.B. Sundquist and W.M. Miller, eds. St. Paul, MN: University of Minnesota and APHIS-USDA, 1979.

MIG, Inc. *IMPLAN Professional: User=s Guide, Analysis Guide, Data Guide*. Stillwater, MN: Minnesota IMPLAN Group, 1999.

Miller, R.E. "Regional and Interregional Input–Output Analysis." *Methods of Interregional and Regional Analysis*, W. Isard, I.J. Azis, M.P. Drennan, R.E. Miller, S. Saltzman and E. Throbecke, eds. Aldershot, UK: Ashgate, 1998.

Miller, R.E., and P.D. Blair. *Input–Output Analysis: Foundations and Extensions*. Englewood Cliffs, NJ: Prentice Hall, 1985.

North American Animal Disease Spread Model (NAADSM). Internet site: http://www.naadsm.org/ (Accessed February 2007).

Office International des Epizooties (OIE). Internet site: http://www.oie.int/eng/en_index.htm (Accessed December 2005).

Paarlberg, P.L., J.G. Lee, and A.H. Seitzinger. "Potential Revenue Impact of an Outbreak of Foot-and-Mouth Disease in the United States." *Journal of American Veterinary Medical Association* 220(2002):988–92.

Pendell, D.L. "Value of Animal Traceability Systems in Managing a Foot-and-Mouth Disease Outbreak in Southwest Kansas." Ph.D. dissertation. Kansas State University, 2006.

Reeves, A., A.D. Gil, F. Zagmutt–Vergara, A.E. Hill, B.A. Corso, and M.D. Salman. "Validation of the North American Animal Disease Spread Model Using Data from the 2001 Outbreak of Foot-and-Mouth Disease in Uruguay." *Proceedings of the 87th Annual Meeting of the Conference of Research Workers in Animal Disease*, R.P. Ellis, ed. Ames, IA: Blackwell Publishing, 2006.

Rich, K.M., G.Y. Miller, and A. Winter–Nelson. "A Review of Economic Tools for the Assessment of Animal Disease Outbreaks." *Revue Scientifique et Technique de l'Office International des Epizooties* 24(2005):833–45.

Schoenbaum, M.A., and W.T. Disney. "Modeling Alternative Mitigation Strategies for a Hypothetical Outbreak of Foot-and-Mouth Disease in the United States." *Preventive Veterinary Medicine* 58(2003):25–52.

Scudamore, J.M. *Origin of the UK Foot and Mouth Disease Epidemic in 2001*. London: Department for Environment and Food and Rural Affairs, June 2002.

Thompson, D., P. Muriel, D. Russell, P. Osborne, A. Bromley, M. Rowland, S. Creigh–Tyte, and C. Brown. "Economic Costs of the Foot and Mouth Disease Outbreak in the United Kingdom in 2001." *Revue Scientifique et Technique de l'Office International des Epizooties* 21(2002): 675–87.

U.S. Department of Agriculture, Foreign Agricultural Services (FAS). *Production, Supply and Distribution*. Internet site: http://www.fas.usda.gov/psd/intro.asp (Accessed July 2006).

U.S. Department of Agriculture, National Agricultural Statistics Services (NASS). Internet site: http://www.nass.usda.gov/index.asp (Accessed July 2006).

Wohlgenant, M.K. "Distribution of Gains from Research and Promotion in Multi-Stage Production Systems: The Case of the U.S. Beef and Pork Industries." *American Journal of Agricultural Economics* 75(1993):642–51.

107th Congress. Public Health Security and Bioterrorism Preparedness and Response Act of 2002. Public Law 107-188. June 12, 2002.

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: $Q^r_B = f_1(P^r_{BUS}, P^r_{KUS}, P^r_{YUS}, Z^r_{BUS})$
2) U.S. retail beef supply: $Q^r_B = f_2(P^r_{BUS}, Q^w_B, W^r_{BUS})$

Wholesale

3) U.S. wholesale beef demand: $Q^{wd}_{BUS} = f_3(P^w_{BUS}, Q^r_B, Z^w_{BUS})$
4) Export wholesale beef demand: $Q^w_{BE} = f_4(P^w_{BE}, Z^w_{BE})$
5) U.S. wholesale beef supply: $Q^{ws}_{BUS} = f_5(P^w_{BUS}, Q^s_B, W^w_{BUS})$
6) Import wholesale beef supply: $Q^w_{BI} = f_6(P^w_{BI}, W^w_{BI})$
7) Total wholesale beef demand: $Q^w_B = Q^{wd}_{BUS} + Q^w_{BE}$
8) Total wholesale beef supply: $Q^w_B = Q^{ws}_{BUS} + Q^w_{BI}$

Slaughter

9) Total fed cattle demand: $Q^s_B = f_7(P^s_{BUS}, Q^w_B, Z^s_{BUS})$
10) KS fed cattle supply: $Q^s_{BKS} = f_8\left(P^s_{BKS}, Q^f_B, W^s_{BKS}, N^s_B\right)$
11) Other states fed cattle supply: $Q^s_{BO} = f_9\left(P^s_{BUS}, Q^f_B, W^s_{BO}\right)$
12) Total U.S. fed cattle supply: $Q^s_{BUS} = Q^s_{BKS} + Q^s_{BO}$
13) Import fed cattle supply: $Q^s_{BI} = f_{10}(P^s_{BI}, W^s_{BI})$
14) Total fed cattle supply: $Q^s_B = Q^s_{BUS} + Q^s_{BI}$
15) KS fed cattle inventory: $N^s_B = f_{11}(F^s_B)$

Farm

16) Total feeder cattle demand: $Q^f_B = f_{12}\left(P^f_{BUS}, Q^s_B, Z^f_B\right)$
17) KS feeder cattle supply: $Q^f_{BKS} = f_{13}\left(P^f_{BKS}, W^f_{BKS}, N^f_B\right)$
18) Other states feeder cattle supply: $Q^f_{BO} = f_{14}\left(P^f_{BUS}, W^f_{BO}\right)$
19) Total U.S. feeder cattle supply: $Q^f_{BUS} = Q^f_{BKS} + Q^f_{BO}$
20) Import feeder cattle supply: $Q^f_{BI} = f_{15}\left(P^f_{BI}, W^f_{BO}\right)$
21) Total feeder cattle supply: $Q^f_B = Q^f_{BKS} + Q^f_{BO}$
22) KS feeder cattle inventory: $N^f_B = f_{16}\left(F^f_B\right)$

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: $Q^w_{KE} = f_{20}\left(P^w_{KE,} Z^w_{KE}\right)$
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: $Q^s_{KUS} = Q^s_{KKS} + Q^s_{KO}$
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^j_i and Q^j_i 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^j_i and w^j_i are elements of the demand and supply shifters (*Z* and *W*) that 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^j_i) are reduced by the amount of cattle and hogs that are destroyed due to FMD (i.e., denoted by F^j_i). The variable F^j_i 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.