Modeling the Economic Impact of Foot-and-Mouth Disease in the United States Using the Paarlberg Quarterly Economic Model

Dawit Assefa, Ann Hillberg Seitzinger, Melissa Schoenbaum

USDA–APHIS–VS–STAS–CEAH
Fort Collins, Colorado
Dawit.G.Assefa@aphis.usda.gov,
Ann.S.Seitzinger@aphis.usda.gov,
Melissa.Schoenbaum@aphis.usda.gov,

ABSTRACT

The U.S. Department of Agriculture–Animal and Plant Health Inspection Service–Veterinary Services–Center for Epidemiology and Animal Health addresses questions related to minimizing the consequences of animal disease outbreaks while protecting the nation's livestock, food, and the environment. That includes modeling the economic impact of potential disease outbreaks using the Paarlberg model. The Paarlberg model is a quarterly economic model that allows analysts to simulate the potential economic impact of different types of disease spread across a number of different industries and commodities. Analysts are able to apply "shocks" reflecting how different industries and trade partners are affected by a specific disease spread scenario and estimate the market impacts. The model produces large data sets that need to be analyzed and summarized. To do so, we used a data visualization software called Tableau. Tableau allows us to handle, analyze, and visualize large amounts of data in an efficient manner. We create dashboards that allow analysts and decision-makers alike to understand trends and patterns from model runs.

ABOUT THE AUTHORS

Dawit Assefa is Program Analyst with the USDA-APHIS-VS-CEAH-Monitoring and Modeling unit. He received a BA in Economics and an MS in computer information systems from Colorado State University with an emphasis on business intelligence. He serves as the unit's specialist in data visualization, validation and cleaning functions using a multitude of software.

Ann Hillberg Seitzinger is a supervisory agricultural economist with the Center for Epidemiology and Animal Health (CEAH) in Fort Collins, Colorado. CEAH belongs to USDA–APHIS's Veterinary Services. She received a Ph.D. in agricultural economics with specialties in international agricultural trade and policy from Purdue University..

Melissa Schoenbaum is a biological scientist with the CEAH Monitoring and Modeling Unit. She received a B.S. degree in biological sciences from East Texas State University and an M.S. degree in computer information technology, with a database emphasis, from Regis University. She serves as the modeling team's data management specialist and is the technical liaison with developers during software development projects.

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BUILDING AN ECONOMIC MODEL SCENARIO FROM A SIMULATED ANIMAL DISEASE OUTBREAK

Epidemiological and economic modeling are effective tools in understanding the complexities in modern agriculture. Economic modeling has the capability to simulate multifaceted and complex issues. Predicting how markets, prices, and demand will change under specific circumstances is a large task. The communication of these results is just as important and complex. The use of data visualization lessens the burden of communicating intricate details and patterns to stakeholders and decision-makers.

Before looking at the economic consequences of an animal disease outbreak, it is important to know the epidemiological impacts of the outbreak. We used parameters for the epidemiological model taken from a previous study that was modified to be appropriate for ModSim World. The original research question explored several disease-control strategies that have not been applied in previous real-life situations to determine if they were economically feasible (Delgado et al., 2015). We simulated highly contagious foot-and-mouth disease (FMD) using the Animal Disease Spread Model (ADSM).

ADSM is a stochastic state-transition model and provides a flexible susceptible/latent/infected/removed (SLIR) framework for users to simulate disease progression and spread by contact or air. ADSM has the ability to simulate a

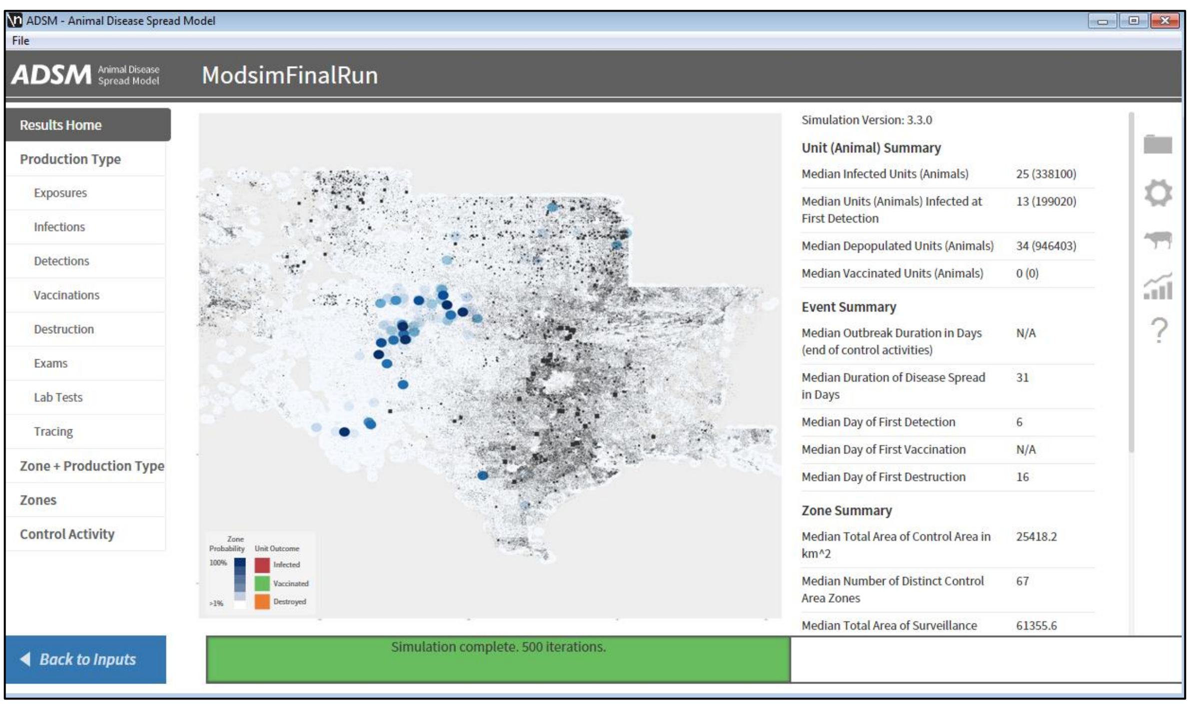

Figure 1

number of highly contagious animal diseases. ADSM also provides options to introduce various measures to control the disease outbreak, such as vaccination and depopulation.

For this particular scenario, the population of animals included cattle, swine, sheep, and goats, as those animals are the species susceptible to FMD. This is important in the economic evaluation, as these are the animals that are removed from the population due to control response activities. We simulated the outbreak through 500 iterations in order to account for the inherent variability in biological processes that are designed into the parameterization of ADSM.

We inserted the results described above from the ADSM component of the model into the quarterly model of U.S. agriculture as percentage changes, and executed the model for 16 quarters to determine the economic impacts of the FMD outbreak. The quarterly agricultural sector model solves for the percentage changes in the endogenous variables. We applied these percentage changes to a baseline formed by the observed data for the first quarter of 2014 through the fourth quarter of 2017.

ABOUT THE PAARLBERG MODEL

The model and application assume price-taking economic decision-makers who maximize well-defined objective functions. Price taking is the economic theory that those in the market will accept the prevailing prices that the market offers. Utility maximization for consumers gives a set of per capita demand functions. Producers (firms or farms) choose inputs and products that maximize profits using three types of inputs. One type, which includes fuel and electricity, is mobile among production activities and is in perfectly elastic supply. A second input type consists of sector-specific physical and human capital, and the fourth input is land, which is mobile across crop production. Total consumption of final goods (beef, pork, poultry meat, lamb and sheep meat, eggs, milk, wheat, coarse grains, rice, and soybean oil) in the U.S. economy in the current quarter depends on population and per capita consumption during the quarter. Wheat and coarse grains are included, since they are also used for feed. Soybean oil is included because its joint product, soybean meal, is a major feedstuff. We modeled rice because its production area interacts with crops used for animal feed. We incorporated health-shock parameters which allow variations in the level of consumer perception of health risks, this affects how consumers perceive the news of an animal disease in a given industry.

Most of the data required for the model consist of quarterly supply, use, and price figures for the years 2014 to 2017. These values set the baseline to which the percentage changes are applied. With some exceptions, the data are reported in the Livestock Marketing Information Center (LMIC) database. The LMIC database does not include some data for crops and trade. Quarterly supply, use, and price data for coarse grains, wheat, rice, and the soybean complex come from situation reports prepared by the Economic Research Service of the U.S. Department of Agriculture (USDA–ERS, Outlook series). In some cases, we summed or averaged monthly data to generate quarterly data.

Four sets of parameters drive the model: the livestock feed-balance calculator, the revenue shares for all agricultural industries, elasticities used in the model solution, and disease-related parameters used to manipulate disease scenarios. We constructed the numerical model so that the user can alter the parameter values. This is useful because there is variation in the literature for many parameter values. The first three sets of parameters discussed here are based on estimates in the literature, tempered in some cases by additional expert opinion. The shocks put into this framework of parameters come from the ADSM model. An example of the last parameter would be a production shock that is calculated from the ADSM model outputs multiply by a disease-related parameter to determine an impact on prices.

Data visualization of results

Tableau is one data visualization software application used at USDA–APHIS–VS–CEAH. The data visualization options within Tableau allow our team to present critical facts, patterns, and discoveries to management and stakeholders in an efficient and interactive manner. For this example, after running the Paarlberg model and obtaining the results, we imported outputs from the Excel files into Tableau. Tableau is able to interface with the output files without changing the contents of the original files.

In Tableau, we computed and visualized summary statistics from the key variables in the economic model outputs. These figures include exports of products, imports of products, retail prices that consumers pay at the grocery store, and returns to capital and management. Using the epidemiological outputs from ADSM, the median number of days for a disease outbreak was 34, affecting a median number of 42 premises per iteration. We then worked closely with our economists and epidemiologists to understand the impacts shown in the results. The visualizations included in the following figures are examples of the standard outputs our economists expect to review as part of their analysis. Along with creating standard outputs, we work through specific questions that our economist and epidemiologist had to characterize the overall impact of a FMD outbreak. Working beyond standard visualizations creates an opportunity to find patterns and critical information that will ultimately help with the final analysis. Details are provided in each section to give further explanation of each concept

PAARLBERG SIMULATION

All shocks applied to the model were done by percentage change, meaning we increase or decrease the magnitude of the shock by some percent. The shocks applied in the simulation affected multiple commodities and industries. Within different commodities and industries, we shocked specific livestock based on animals affected by FMD and our epidemiological control strategy, which was depopulation. There were also shocks applied to demand for products, and overall trade capabilities of the United States to showcase what the market reaction might be to a large-scale FMD outbreak. The trade shocks applied can be seen in Figure 2. During the first quarter of the model run, we shut down all international trade for 8 different commodities. We chose to simulate a complete shutdown to represent what could be a possible response from trading partners to halt all trade on these specific commodities until the outbreak had been controlled. The intensity of the shocks in subsequent quarters fell to a 50% and 25% reduction in trade as trade partners were willing to accept more and more goods.

Trade Shocks

	Quarter		
	2014		
	Q1	Q2	Q3
Cattle Exports <320Kg	-1.0000	-0.5000	-0.2500
Beef Exports.	-1.0000	-0.5000	-0.2500
Cattle Exports > 320Kg	-1.0000	-0.5000	-0.2500
Dairy Cow Export.	-1.0000	-0.5000	-0.2500
Hog Export; Feeder	-1.0000	-0.5000	-0.2500
Hog Export; Slaughter	-1.0000	-0.5000	-0.2500
Lamb & Sheep Export	-1.0000	-0.5000	-0.2500
Pork Export	-1.0000	-0.5000	-0.2500

Figure 2

EXPORTS

The graphs in Figure 3 show the movement of the export market for beef, pork, and lamb. The graphs illustrate the complete shutdown of trade and the gradual reduction in the intensity of shocks. During the quarter after the shocks were lifted, lamb and beef exports reacted similarly. Lamb exports at the beginning of 2015 showed no difference compared with the baseline model run without any shocks applied to the model. Beef showed minimal deviations from the baseline, with only a 0.1% increase of exports above the baseline. Pork exports responded differently than the beef and lamb. Exports for pork gained in the fourth quarter of 2014—9.5% above the baseline model. For the remainder of the simulation, exports were at least 1% higher than the baseline.

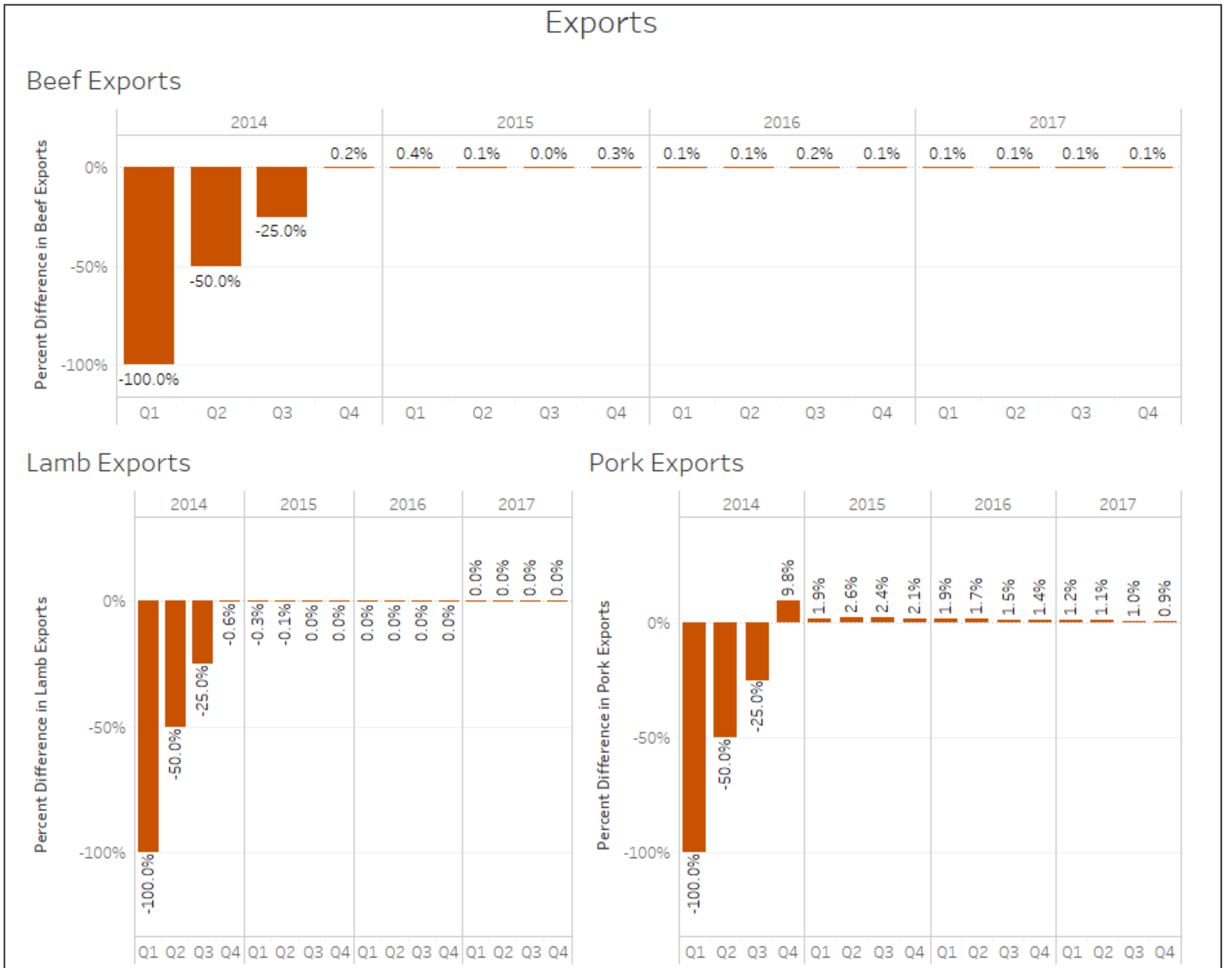

Figure 3

IMPORTS

Although we did not implement import shocks for beef, pork, or lamb, these import markets were heavily affected during the simulation, as shown in Figure 4. There were percentage decreases of beef imports during the first 2 quarters as we shocked the beef export market. Beef imports fell by 16.5% and 6.21%, likely due to larger quantities of beef remaining in the U.S. market due to a complete shutdown of exports in quarter 1 of 2014 and a 50% reduction in quarter 2. Similar effects took place in the pork import market. Although we shocked pork exports at the same rate as beef exports, pork imports fell by a more significant percentage. During the first 3 quarters of the simulation, imports fell by 56.21%, 48.20%, and 31.15% in 2014. This demonstrates how different commodities were affected by similar trade shocks. Unlike decreases in beef and pork imports, the model indicated an increase in imports for lamb during the quarters affected by shocks in 2014. Significant increases in imports for lamb were counter to what we assumed would be the response for that industry. Imports rose by 17.84%, 9.06%, and 3.74% during the first 3 quarters of 2014.

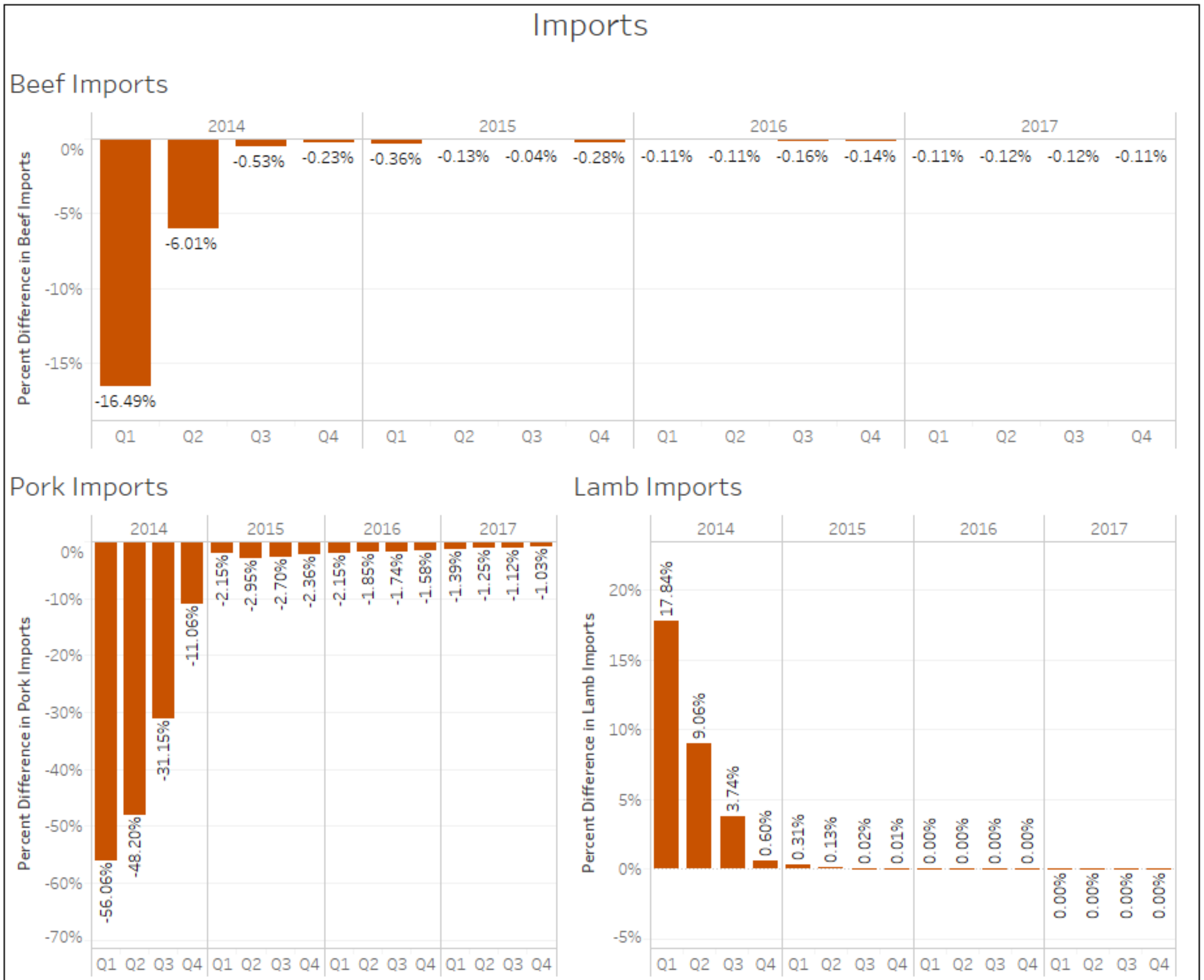

Figure 4

PRICES

With larger quantities still in the U.S. market, the fall in demand for beef and pork imports, along with the fall in consumer demand simulated, led to a reduction in beef retail prices during the same time period, as shown in Figure 4. Beef prices fell by 6.48% and 2.36% during the first 2 quarters of 2014. Pork prices fell at a slightly higher rate during the first 3 quarters of 2014. During the first quarter of 2014, prices fell by 13.52%, followed by 11.32%, 7.51%, and 2.67% during the last 3 quarters of 2014. Unlike beef prices, pork prices experienced a larger and longer price decrease throughout the simulation of the model. Lamb prices increased during the same time periods when beef and pork prices were falling, increasing by 18.37%, 9.18%, and 4.54% during the first 3 quarters of 2014

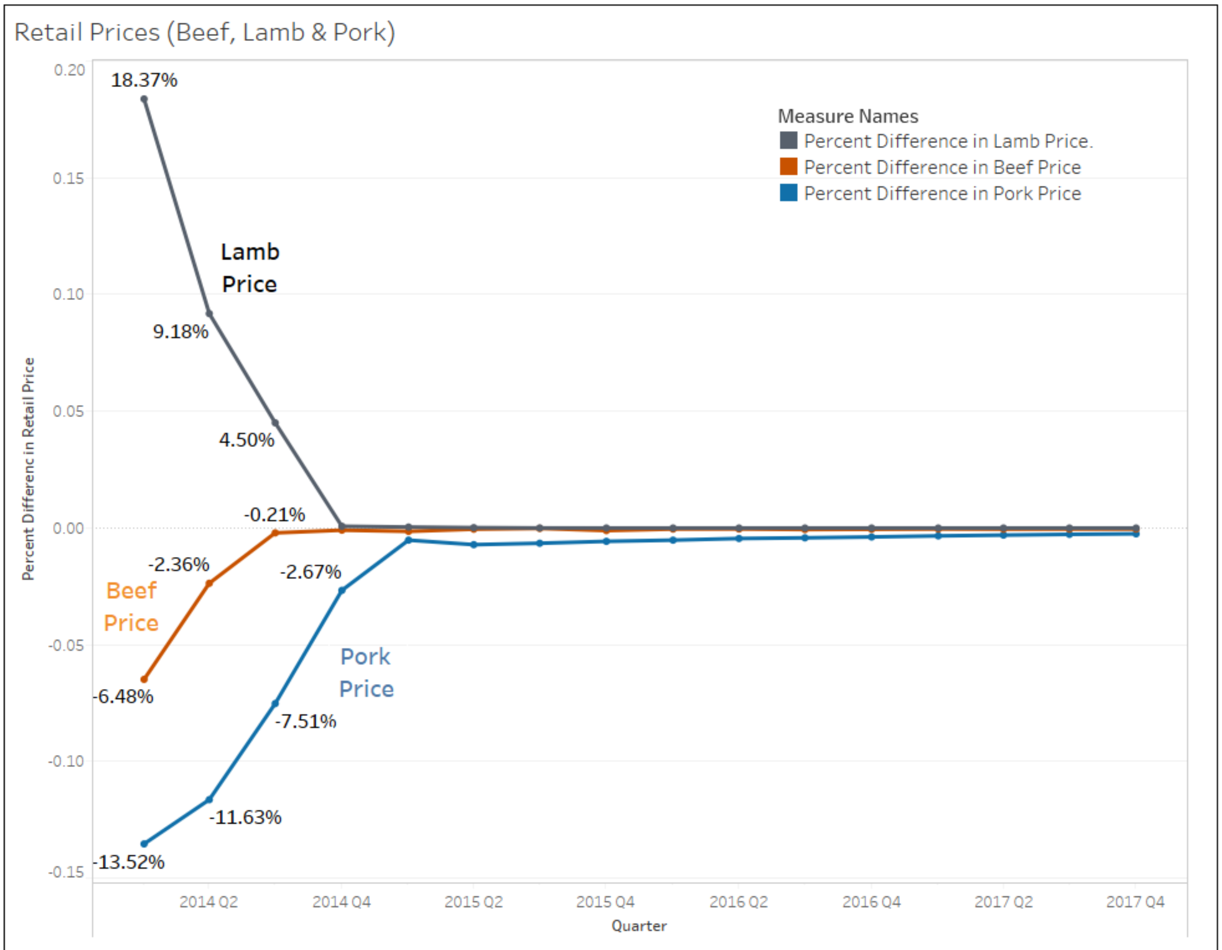

Figure 5

RETURN TO CAPITAL AND MANAGEMENT

To understand how producers are affected by the outbreak scenario, we used the measure returns to capital and management as shown in Figure 5. Returns to capital and management illustrate the welfare of producers throughout the run of the model. The measure takes into account several other model values, including price, production, demand, and the import-export markets. The model showed significant percentage decreases to beef returns to capital and management cost in the first 3 quarters of 2014; the measure fell in the last 3 quarters by 79.52%, 73.33%, and 39.44%. During the first quarter that shocks were not applied, the model showed a quick response to baseline levels. Along with a producer surplus of 2.47% in quarter 3 and 3.08% in quarter 4 of 2014. Pork producers' returns to capital and management dropped at a similar rate during the first 3 quarters of the simulation: 66.14% (quarter 1), 64.61% (quarter 2), 43.81% (quarter 3). Unlike beef, pork returns to capital and management continued to have a negative percentage change compared with the baseline until quarter 1 of 2015. For lamb producers, the model displayed a surplus of returns to capital and management of 33.60% (quarter 1), 14.82% (quarter 2), and 11.78% (quarter 3).The 3 quarters of surplus were followed by consecutive quarters of negative returns to capital and management during the fourth quarter of 2014 and the first quarter of 2015. The increase in sheep and lamb meat returns to capital and management resulted from the increase in prices during that same time span.

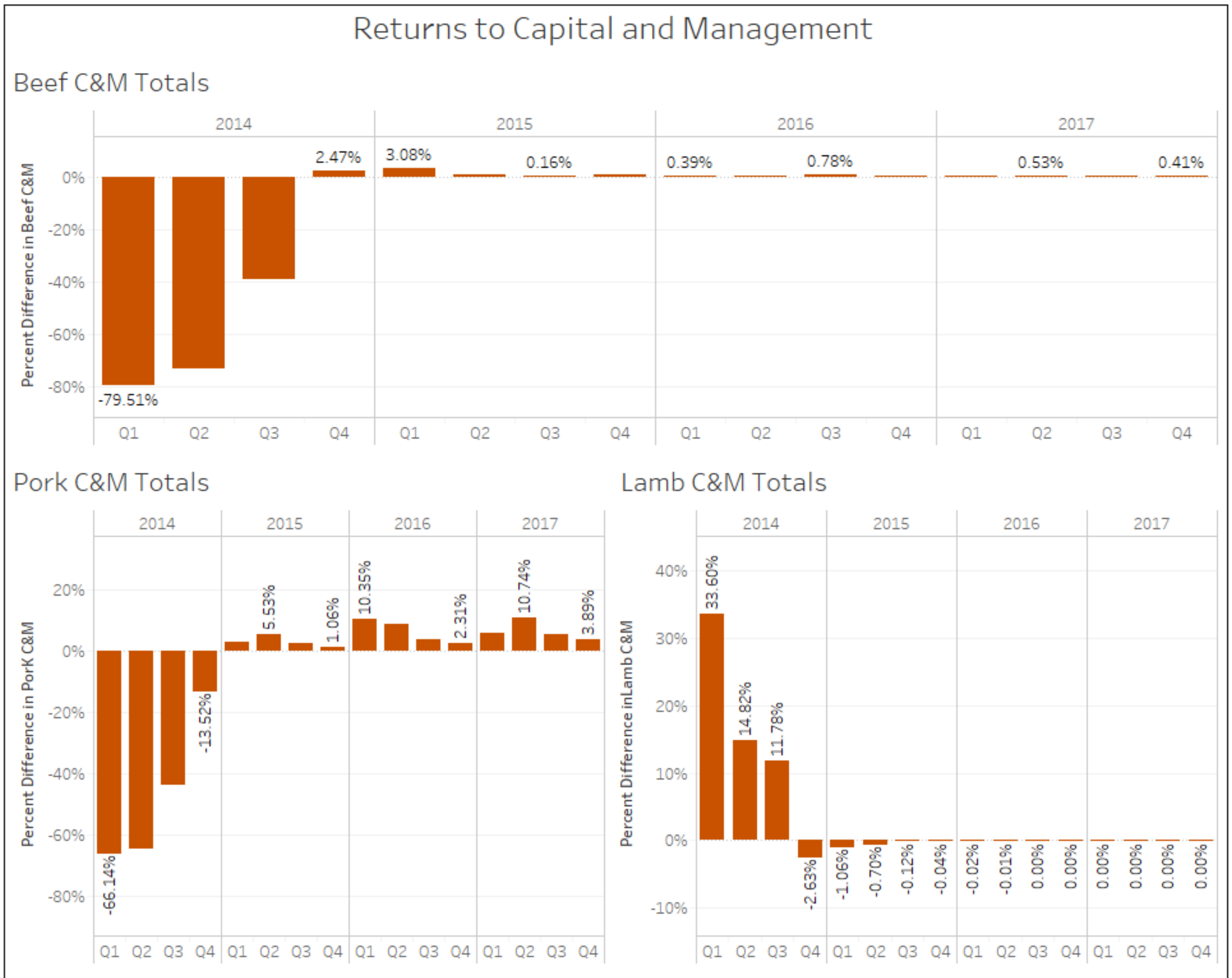

Figure 6

OPTIONS AVAILBLE BASED ON ANALYSIS

Decision-makers are presented with many options to consider from this type of scenario. There are a number of other scenarios that can be simulated in ADSM that would provide a range of epidemiological responses. Some of these scenarios could include:

- Increase passive surveillance options as to reduce the time to detection of disease, and possibly reduce the outbreak duration.
- Pre-emptive depopulating ring of herds in a zone around the infected herd. This is an aggressive strategy that creates the perception that a large amount of health animals are being killed for no reason.
- Vaccination might also be considered as an option for disease control. The use of vaccine changes a consumer's perception of the final product and causes additional problems in proving disease freedom.

There are other community solutions that could be considered. From a surplus perspective, one opportunity might be to redirect some of the excess supply into a supplement food program, such as Woman, Infants and Children (WIC). Each choice has additional economic complexities that would require separate analysis.

CONCULSION

The visualizations helps to tell the story of the outbreak. Exports stop as our trading partners are concerned with spreading an animal disease. Prices plunge as our domestic supply increases. Most imports stop as well, but not all, presenting an unexpected development in this scenario. Recovery happens, but not at the same pace for every industry.

USDA–APHIS–VS–CEAH relies on modeling and data visualization tools to provide quick answers to questions related to emergency preparedness and response. The combination of software applications, such as the Paarlberg model and Tableau, provide a powerful means to look at multifaceted questions. Planning and evaluating alternative control strategies for disease response need to take into account not only the efficacy of the strategy to prevent disease spread, but also the economic implications of the strategy on trade and consumer demand. The ability to present results in an efficient manner allows decision-makers and stakeholders to understand not only the result of our modeling but also the process we used to produce those results.

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