Foot-and-Mouth Disease and the Mexican Cattle Industry

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Abstract

The objective of this article is to analyze the domestic and international effects of a hypothetical foot-and-mouth disease outbreak in the Mexican cattle industry. A discrete time dynamic optimization model of the Mexican cattle sector is specified, and linked to domestic and international markets. Economic consequences of foot-and-mouth disease outbreaks are simulated over time and under different scenarios. Specific findings and general policy recommendations are provided. The study reports a range of outbreaks from localized to large scale and suggests that changes in economic surplus due to foot-and-mouth disease range from a positive net gain of $0.89 to $1.6 billion to a net loss of about $67 billion, depending on the specific mitigation strategy and outbreak scenario.

Keywords: foot-and-mouth disease, welfare effects, cattle trade, cattle production, invasive species, México

JEL Codes: F14, F17, Q11, Q17, Q18.

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1. Introduction

Outbreaks of foot-and-mouth disease (FMD) are important economic events, distorting trade patterns world-wide. The effects of FMD (for example, trade bans, productivity losses, and inventory depopulation) can be extremely detrimental to a country, threatening food supplies, security, and safety (FAO, 2006).[1] In 1946, México suffered an FMD outbreak that lasted for 7 years and resulted in large losses in inventory with costs estimated over $250 million (SAGARPA, 2004).[2] More recently, an FMD outbreak in the United Kingdom (UK) in 2001 caused losses of between $3.6 to $11.6 billion (Mathews and Buzby, 2001), with around 4 million animals being slaughtered. Losses from FMD outbreaks are not exclusive to producers. Consumers can also be affected through market responses, and tourism can suffer because of travelling restrictions (Blake et al., 2002).

Country specific characteristics, such as dependence on exports or imports, livestock inventories and management, disease-control policies, consumer demographics and reaction, and value of livestock, make it difficult to extrapolate the impacts of FMD in one country to another (Schoenbaum and Disney, 2003). This observation is supported through research findings reported by Zhao, Wahl and Marsh (2006), Rich and Winter-Nelson (2007), and Paarlberg et al. (2008). An important outcome of the current research is to uncover country specific observations for México and more general economic observations. Because limited research exists for livestock for México, a better understanding of economic consequences of FMD is

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[1] Depopulation refers to the culling of infected herds.

[2] All values used are in US dollars unless otherwise noted. The $250 million in 1954 is equivalent to approximately $2 billion in 2010 (Bureau of Labor Statistics, 2010).

needed and necessary to prescribe effective policy recommendations for industry and policy makers.

The objective of this study is to analyze the economic consequences on trade (domestic and international) of a hypothetical FMD outbreak in the Mexican cattle industry. The unique characteristics of the Mexican cattle industry, such as the differentiated production practices across regions and low exports, make it particularly interesting, since most studies on the effects of FMD relate to countries with high exports. Economic consequences of a hypothetical FMD outbreak are simulated under different mitigation scenarios. These results can provide guidance for selecting different management policies. Because of the transboundary nature of FMD, it is important for policy makers in México and other North American countries to understand the potential impacts of an FMD outbreak and the consequences of the different mitigation policies. To the best of our knowledge, this is the first study to formally analyze the effects of a hypothetical FMD outbreak in the Mexican cattle industry.

There have been different approaches taken to analyze disease outbreaks in the cattle industry. In the past, studies were mainly static, either partial equilibrium or input-output models (Garner and Lack, 1995; Paarlberg and Lee, 1998). Given the nature of cattle cycles and biological lags in production it is important to include dynamics when analyzing disease outbreaks in cattle, which is the modeling approach of the current paper. Jarvis (1974), and Rosen, Murphy and Scheinkman (1994) emphasized the importance of incorporating dynamics and biology, specifically by analyzing the beef industry as a renewable resource. Some of the recent studies that incorporated dynamics in the analysis of the cattle industry are Chavas (2000), Aadland (2004), Zhao, Wahl and Marsh (2006), and Paarlberg et al. (2008). Other authors also recognized the importance of spatial effects, like Rich, Winter-Nelson and Brozović (2005a and

2005b), and Rich and Winter-Nelson (2007). Specifically, these latter three articles analyzed a particular area highly affected by FMD: South America, where the actions taken by one country have a high impact in neighboring countries. In the current article, we recognize spatially different regions across México characterized by different cattle feeding regimes.

Estimates of the effects of an FMD outbreak vary by country and study. Some of the results from the studies for the United States follow. Zhao, Wahl and Marsh (2006) found that a depopulation rate of 60 to 70 percent with total welfare loss of $34 to $50 billion corresponded to a reasonable level of traceability for the United States. Their results indicated that it is beneficial to increase surveillance to minimize the costs associated with an FMD outbreak. Paarlberg et al. (2008) analyzed the effects of a hypothetical FMD outbreak on the US agricultural sector across different livestock species. They assumed that all agricultural sectors will recover after 16 quarters, with total losses to livestock related industries of $2.8 to $4.1 billion. A recent study on hypothetical FMD outbreaks in Kansas, suggests welfare losses ranging from $1 to 50 billion (NBAF, 2010) depending on the scenario. Schoenbaum and Disney (2003) suggested that the best mitigation strategy depends on the speed of the spread of the virus and the demographics of the population. Wilson and Antón (2006) concluded that it is optimal and less restrictive to apply mitigation strategies first and then apply a small tariff if necessary. Elbakidze et al. (2009) investigated the economic effectiveness of several strategies in the United States. They considered different disease introduction points that reflect the Texas High Plains cattle industry. Results from this study showed that early detection of the disease is the most effective strategy to minimize the cost of the FMD outbreak. Elbakidze et al. (2009) also provided an in-depth review on the economics of FMD control strategies literature.

South America, Australia and Canada have also been studied in the context of FMD. Results from the following studies show how differences between countries have profound impact in the specific effects of the disease. Rich and Winter-Nelson (2007) analyzed South America, which has regions where FMD is endemic. They demonstrated the benefits using mitigation policies differentiated by region. Their results suggested that animal removal policies have the largest net present value over a 5 year period, but in the short term vaccination policies are more effective. Tozer, Marsh and Perevodchikov (2010) analyzed Australia, which is the sixth largest producer and the second largest exporter of beef. Their results suggested that changes in economic surplus due to FMD range from a positive net gain of $309 million Australian dollars to a net loss of $18.3 billion Australian dollars, with the impact on producers and consumers varying depending on the degree of outbreak and control levels. Perevodchikov and Marsh (2010) analyzed the effect of an FMD outbreak on the Canadian cattle industry. They found negative net welfare changes of $6.4 to $23.3 billion Canadian dollars, depending on the specific depopulation scenarios. Their results showed that total welfare losses from an outbreak decrease as depopulation rate increases.

This article complements the literature by analyzing the effects of a hypothetical FMD outbreak in the Mexican cattle industry. We develop a discrete time optimization model for the Mexican cattle sector that incorporates dynamic market (domestic and international) and livestock inventory effects. Pasture and feeding systems are constructed for four different regions and are integrated into the model. This model allows us to simulate the effects of different mitigation strategies for FMD and economic assumptions (i.e., consumer and trade shocks), including producer and consumer responses and consequences (i.e., welfare effects). The economic model is not limited to FMD. It can be extended to analyze outbreaks for diseases outbreaks in México such as Bovine Spongiform Encephalopathy or "mad-cow disease". Furthermore, we provide a framework for analysis that can be applied to other countries, diseases and livestock industries, even though our conclusions and results are specific for México and FMD in cattle.

The rest of the article proceeds as follows. The next section provides some background on FMD and the Mexican cattle industry. We follow with the development of the theoretical framework, proceeded by the empirical application and data used for the analysis. Results are then presented and the article ends with some brief concluding remarks.

2. Background

Foot-and-mouth disease is a viral disease that affects cloven-hoofed ruminants, it is severe and highly contagious (APHIS, 2007). Some of the symptoms of FMD are: fever, blister-like lesions, and erosions on the tongue, lips, mouth, teats and hooves (APHIS, 2007). It is transmitted by respiratory aerosols and contact with infected animals (Center for Food Security and Public Health, 2007). FMD severely affects meat and dairy production, and trade status (Mathews and Buzby, 2001). Furthermore, consumption of milk or dairy products from infected animals could infect humans (Mathews and Buzby, 2001; SAGARPA, 2004). That said, most infected animals recover, and consumption of meat from infected animals is not considered a health hazard (Mathews and Buzby, 2001).

México has been FMD free since 1954, when the last outbreak, from 1946 to 1954, was eradicated with a cost of $250 million, or approximately $2 billion in 2010 dollars (Bureau of Labor Statistics, 2010), with over a million animals being slaughtered (SAGARPA, 2004). In 1947 the Mexican-American commission for FMD eradication was created and in 1952 the Mexican-American commission for FMD prevention was created. The Mexican policy for dealing with an FMD outbreak is similar to the policy in the United States. The policy consists of completely removing animals from the herd, which involves depopulation of affected herds, cleaning and sanitation of exposed premises, quarantining susceptible herds that could have been in contact with the infected herd, and depopulation of dangerous susceptible herds (SAGARPA 2004). The Secretariat of Agriculture, Livestock, Rural Development, Fisheries, and Food (SAGARPA) has developed several eradication and prevention programs for different diseases including FMD.

In 2005, the Mexican cattle industry produced almost 9 million calves (Cunningham, 2006), while the total inventory was estimated in 31 million head (Luna Martínez and Albarrán Díaz, 2006).[3] The Mexican cattle industry is highly differentiated by production region. The different production regions have different agro-climatic characteristics, management practices and the cattle have different genetics and biological productivity (Cunningham, 2006; Peel, Johnson and Mathews, 2010). Most cattle are pasture-fed for regional consumption, with an increase in feedlot-finishing in recent years. Improvement in infrastructure and growing demand for grain-fed beef has increased trade among production regions and the establishment of feedlots. These new dynamics increase the potential for spreading the FMD virus through all production regions if there is an outbreak in any one region.

FMD affects all stages in the cattle production: breeding, feeding and marketing. Hence, it is important to understand the particular characteristics of the Mexican cattle industry to be able to model each stage and obtain an accurate analysis of the effects of FMD on the Mexican cattle industry. Production in the Mexican cattle industry can be divided in two stages: breeding and feeding. The following description of the Mexican cattle industry is derived from Peel,

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[3] The value of the cattle sector in México represented around 1.5 percent of Mexico's GDP from 2002 to 2005 (Banco de México, 2008).

Johnson and Mathews (2010), Peel (2002), Cunningham (2006), and Cunningham and Peel (2006). In the breeding stage, calves are weaned after 7 to 10 months. At this point producers decide to keep some of the calves for breeding and send the rest to the feeding stage. About half of the female offspring are retained for breeding and half are sent to the feeding stage.

The feeding stage is usually divided into stocker and finishing systems. Stocker programs are further divided into intensive stocker and extensive stocker programs. The intensive stocker program is more expensive and lasts a shorter period of time than the extensive stocker program. On average, the intensive stocker program costs $0.30 per head per day with a daily weight gain of 2.1 pounds and lasts on average 120 days, depending on the production region. The extensive stocker program on average costs less than $0.01 per head per day, with a daily weight gain of 0.65 pounds, and lasts an average 373 days, depending on the region. Approximately two thirds of the cattle going to stocker programs go into intensive stocker programs and one third into extensive stocker programs.

The finishing stage is further divided into four different systems (Cunningham, 2006; Peel, Johnson and Mathews, 2010): feedlots for Northern-style meat; feedlots for Mexican style meat; supplemented grass finished; and grass finished.[4] The majority of the cattle (about two thirds) go into the grass finishing systems. Grass finishing systems are the least expensive ($0.02 per head per day) and require the longest amount of time (480 days), with an average daily weight gain of 0.57 pounds. Feedlots for Northern-style meat are similar to US feedlots and are the most expensive ($1.54 per head per day) with an average daily weight gain of 3.15 pounds over 132 days. Approximately 15 percent of cattle go into this finishing system. Cattle fed for Mexican-style meat (approximately 24 percent of cattle) go into similar feedlots as Northern-style meat, but for fewer days (114 days on average, depending on the region). The

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[4] Northern style meat is high quality meat, very similar to meat consumed in the United States (Cunningham, 2006).

supplemented grass finishing program consists of grass finishing with grain supplementation. This program is less expensive than feedlot finishing ($1.40 per head per day on average), lasts about 110 days (depending on the region), with an average daily weight gain of 1.81 pounds. A very small percentage of cattle go into this program (Cunningham, 2006).

The Mexican cattle industry's main exports consist of male and female calves to the United States. Approximately 15 percent of the weaned calves are exported to the United States. Specifically, in 2005 México exported about 1 million male calves and 56,000 female calves to the United States (Luna Martínez and Albarrán Díaz, 2006). On the import side, México is not a significant importer of live cattle. When imports of live cattle occur, these are mainly cull cows from the United States.

Traditionally, Mexican beef exports have been negligible (about 3 million pounds per year in the 1990s), but after the BSE incidents in the United States and Canada, beef exports increased dramatically, to about 13 million pounds per year (Luna Martínez and Albarrán Díaz, 2006). In total, México is a net importer of beef, mainly from the United States and Canada. In 2005 México produced about 3.4 billion pounds of beef and imported about 511 million pounds of beef (Luna Martínez and Albarrán Díaz, 2006). Per capita beef consumption in México was fairly stable between 2000 and 2005, with an average of 35 to 37 pounds per year (Luna Martínez and Albarrán Díaz, 2006), for a total of 3.7 billion pounds of beef in 2005 (Cunningham, 2006).[5]

3. Model Framework

In this section we construct an application of a hypothetical FMD outbreak in the Mexican cattle industry. The breeding and inventory model approach follows Jarvis (1974) and Aadland (2004). The empirical model is a discrete time dynamic optimization model of the Mexican

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[5] Population in México was 103 million in 2002 and 105 million in 2005 (Luna Martínez and Albarrán Díaz, 2006).

cattle production and feeding sectors, which is linked to domestic and international markets. The invasive species component of the model follows a standard S-I-R (susceptible-infectious-removed) model of FMD dissemination (Miller, 1979; Rich and Winter-Nelson, 2007).[6] The model components are summarized below, and the reader is directed to Zhao, Wahl and Marsh (2006) for more details.

Various assumptions implemented in the empirical model are discussed ahead. The base year for the FMD outbreak simulation is assumed to be 2002. This year was chosen to remove the trade distortions caused by the BSE incidents in Canada and the United States in 2003. The relevant parameters of the model are presented in table 1 and the starting values and inventories are presented in table 2.

3.1 Breeding Herd

An annual system can describe accurately the breeding system, given the annual reproductive cycle of cattle. Breeding herd inventories are defined as:

$$K_{t+1}^{j+1} = \left(1-\delta^{j}\right)\left(K_{t}^{j} - KC_{t}^{j} + M_{t}^{j} - E_{t}^{j}\right) \tag{1}$$

$$B_t = \sum_{j=m}^{s} K_t^j \tag{2}$$

$$K_{t+1}^{0} = 0.5\theta B_t \tag{3}$$

$$Moff_{t+1}^{0} = 0.5\theta B_t \tag{4}$$

Breeding stock is differentiated by age, *j*, and time, *t*, indices. *K*, *M* and *E* represent the number of domestic, imported and exported females for breeding, respectively; *KC* corresponds to the number of culled breeding females; δ refers to the death rate; *B* is the total number of female breeding animals; *m* represents the age at which a female can start reproduction; and *s* the age at

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[6] For more information on dissemination of FMD see Miller (1979), Berentsen, Dijkhuizen, and Oskam (1992), and Mahul and Durand (2000).

which a female is culled from the herd. Equations 3 and 4 refer to the female (K_{t+1}^{0}), and male ($Moff_{t+1}^{0}$) offspring, respectively, where θ corresponds to the weaning rate.

Following Aadland (2004), a heifer becomes productive at age 2, and the productive life ends at age 10. As mentioned in the description of the Mexican cattle industry, calves that are not retained for breeding will be kept in the breeding system for approximately one year. Thus, we specify additional inventories to track the number of female (Fyg_t), and male (Myg_t) yearlings:

$$Fyg_t = \left(1 - \delta^0\right) KC_{t-1}^{0} \tag{5}$$

$$Myg_t = \left(1 - \delta^0\right) Moff_{t-1} \tag{6}$$

The birth rate ($\theta = 0.5975$) and death rate ($\delta^0 = \delta^1 = 0.0675$, $\delta^{j>1} = 0.0325$) parameters, and the starting breeding inventories were obtained from Cunningham (2006). It should be noted that the birth rate in México is low relative to the US birth rate of 0.85 (Zhao, Wahl and Marsh, 2006).

3.2 Feeding Component

The feeding component of the model provides a connection between breeding decisions and meat demand. The cattle feeding problem is to choose the number of days on feed that maximizes profits. The feeder price derived from the feeder's profit maximization arise in the breeder's first order conditions to determine the market value for feeders and the capital value of breeding animals (Zhao, Wahl and Marsh, 2006).

Based on the structure of the Mexican cattle industry, at the feeding stage we model the intensive stocker, extensive stocker, grass finishing and feedlot finishing programs. Specifically, we model four programs: intensive stocker followed by grass finishing (45 percent of cattle), intensive stocker followed by feedlot finishing (18 percent of cattle), extensive stocker followed by grass finishing (26 percent of cattle) and extensive stocker followed by feedlot finishing (11 percent of cattle). It is assumed that all calves not kept for breeding or exported will go through one of these four programs before going to slaughter and producing meat.

The framework for the pasture and feedlot components are based on the Australian pasture model (SCARM, 1990) and the US Beef National Research Council's (NRC, 2000) Nutrient Requirements of Beef Cattle. The Australian framework was used for pasture-based systems as the NRC (2000) does not consider cattle on pasture in the nutrient requirements and growth models. The growth parameters and feed quality parameters from these models were adjusted to achieve the desired growth rates and days on feed for México described previously. These assumptions and models are consistent with previous research in the beef and grazing sectors of México, see for example Díaz-Solis et al. (2003) and Reynoso-Campos et al. (2004). For a complete model of each feeding system see Zhao, Wahl and Marsh (2006), and Tozer, Marsh and Perevodchikov (2010).

Empirical specification of the feeding system is based on information from Peel (2002), Cunningham (2006), and Cunningham and Peel (2006) described in the Mexican cattle industry section. The average finishing cost (*AFC*) is calculated as the sum of the cost per pound of feed intake multiplied by the daily intake for animals in each system. In the extensive stocker system pasture costs are assumed to be \$0.005 per pound of intake and in the intensive stocker costs are assumed to be \$0.035 per pound. These costs are higher due to higher quality pasture production and the costs associated with this type of pasture production system. Feedlot ration costs are assumed to be \$0.05 per pound of intake. These costs yield daily costs approximately equal to those of Cunningham (2006) with allowance made for inflation over that period. Similarly, the finishing carcass weight (*FW*) for each system varies with the system. In the intensive grass finished system the final carcass weight is 420 pounds, the extensive grass finished system weight is 320 pounds, and the carcass weight of cattle form the feedlot systems are 550 pounds.

3.3 Domestic Markets

The domestic market is delineated by fed and non-fed beef. Total supply of fed meat (*FMS*) is calculated as the number of feeders ready for slaughter (including live imports, *SrM*) multiplied by their finishing weight, *FW*. The total supply of non-fed meat (*NFS*) is calculated as the number of culled breeding animals plus imports of culled cows (*CwM*) multiplied by the average slaughter weight (*ASW* = 475 pounds per head).

$$FMS_t = \left(1-\delta^1\right)FW_{t-1}\left(Fyg_{t-1} + Myg_{t-1} + SrM_t\right) \tag{7}$$

$$NFS_t = ASW * \left(\left(\sum_{j=1}^{m}\left(1-\delta^j\right)KC_{t-1}^{j}\right) + CwM\right) \tag{8}$$

The data used to model the domestic market are described as follows. Total domestic demand for meat was calculated as per capita beef consumption multiplied by population. Annual data from 1980 to 2003 prior to the BSE incidents in Canada and the United States were used in the model. Gross domestic product (GDP) is used as a proxy for income. Domestic price and GDP are deflated using the consumer price index (CPI) for México. Data for per capita beef consumption and domestic price were taken from Clark (2006). Population data were obtained from the US Census Bureau (US Census Bureau, 2008). GDP data are from México's National Institute for Statistics, Geography and Informatics (INEGI, 2008). CPI data were obtained though the Bank of México (Banco de México, 2008). Domestic demand for fed meat was estimated in log-log form using ordinary least squares (OLS) in Stata (version 9.2). The price elasticity of demand obtained from the estimation is -0.91. Demand elasticity estimates for México range from -0.55 to -1.1 in the literature (Golan, Perloff and Shen, 2001; Dong, Gould and Kaiser, 2004; Clark, 2006).

The demand equation for non-fed meat is given by:

$$SV_t = C_1 \left(NFS_t / ASW \right)^{-2}, \tag{9}$$

where *SV* is the salvage value of culled breeding animals and C_1 is a constant term. Demand for non-fed beef is usually less elastic (Zhao, Wahl and Marsh, 2006), thus, we use -0.5 as the non-fed price elasticity of demand.

3.4 Profit

Profit (π_t in equation 10 ahead) is calculated as the sum of revenues from fed meat (*Rfm*) and non-fed meat (*Rnfm*) minus the feeding cost (*FC*), total breeding cost (*TBC*) and inventory adjustment cost, plus the breeding export price (*BrExP*) multiplied by the female yearling exports (*BrEx*) plus the male yearling exports (*MEx*) minus the breeder imports (*BrM*). A marginal adjustment cost (*MAC*) is calibrated to increase at the rate of $0.001 per head when the change in the breeding stock increases by one. The revenue from fed meat (equation 11) consists of the market price at the optimal slaughter weight multiplied by the total supply of fed meat. The revenue from non-fed meat (equation 12) represents the salvage value times the total non-fed meat supply divided by the average slaughter weight. The feeding cost (equation 13) denotes the average feeding cost (*AFC*) in the last period multiplied by the number of feeders. The total breeding cost (equation 14) represents the average breeding cost (*ABC*) multiplied by the total number of breeding animals. The *ABC* is $200 per year (Cunningham, 2006).

$$\begin{aligned} \pi_t = {} & Rfm_t + Rnfm_t - FC_t - TBC_t - \frac{1}{2} MAC * \left(\sum_j KR_t^j - \sum_j KR_{t-1}^j \right)^2 \\ & + BrExP_t * \left(BrEx_t + MEx_t - BrM_t \right) \end{aligned} \tag{10}$$

$$Rfm_t = PMeat_t * FMS_t \tag{11}$$

$$Rnfm_t = SV_t * NFS_t / ASW \tag{12}$$

$$FC_t = AFC_{t-1} * \left(Fyg_{t-1} + Myg_{t-1}\right) \tag{13}$$

$$TBC_t = ABC * \sum_{j=1}^{m} KR_{t-1}^{j} \tag{14}$$

4.5 International Markets

International markets are incorporated into the model to capture the full effects on trade of an FMD outbreak. For the international beef markets, we consider exports to the United States and imports from the United States and Canada. Beef exports from México to the United States account for 80 to 99 percent of total beef exports from 1995 to 2003 (Global Trade Atlas). Beef imports from Canada and the United States represent 81 to 99 percent of México's total beef imports from 1995 to 2003 (Global Trade Atlas).[7] Demand equations were estimated in log-log form using OLS in Stata (version 9.2) to obtain the corresponding elasticities.

Data for the estimation were obtained from various sources. Monthly quantities exported and imported from January 1995 to November 2003 were obtained from the Global Trade Atlas. Domestic price in México is sourced from the National System on Information and Market Integration (SNIIM, 2008). Domestic price in México was deflated using México's CPI for the import demand equations from the United States and Canada, and the US CPI for the export demand equation to the United States. CPI data for México were obtained through Banco de México (2008), and for the United States through the Bureau of Labor Statistics (2008). Data on exchange rate to transform price in the export demand equation to the United States to dollars were obtained from the Pacific Exchange Rate Service, Sauder School of Business, University of British Columbia. Data on GDP for México and the United States were obtained through INEGI (2008) and Bureau of Economic Analysis (BEA, 2008), respectively. GDP for México and the United States was also deflated using the corresponding CPI.

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[7] Live exports to the United States are treated as exogenous flows, and added to domestic supply immediately after the outbreak is announced and until the trade ban is lifted.

The estimated export demand elasticity for the United States is -0.58. The assumed supply elasticities from the United States and Canada are 0.05 and 1.2, respectively. The specific export demand and supply elasticities included in the model are constant elasticity equations given in equations 15 and 16. The market clearing condition is given in equation 17.

$$D_t^i = \alpha_i \left(P_t^i\right)^{ed_i}, \; i = \text{México and United States} \tag{15}$$

$$S_t^j = \beta_j \left(P_t^j\right)^{md_i}, \; j = \text{United States and Canada} \tag{16}$$

$$\sum_i D_t^i = \sum_j S_t^j + DS_t, \tag{17}$$

where α and β are constants calibrated to match the quantities and prices in year 2002, D and S represent the demand and supply quantities, P represents the corresponding price and DS represents domestic supply.

3.6 Hypothetical FMD Outbreak

Following Schoenbaum and Disney (2003), a 2 percent death rate in infected adult cattle, a 20 percent death rate in calves, and no other changes in productivity parameters due to the hypothetical FMD outbreak are assumed. The dynamics of the dissemination process are nested in weekly intervals with the annual time units of the economic model. Cattle are classified in six states: susceptible, latent infectious, second week infectious, third week infectious, immune and dead.

After successful contact with infected animals, cattle become infectious for three weeks, where the average incubation period for FMD is three to eight days. During this period the animal can spread the virus without showing any symptoms, this stage is the latent infectious stage, which corresponds to the first week. After the first week, or incubation period, most animals will display foot and mouth lesions. Animals become immune after recovery, and while most of these animals still carry the virus, infection caused by contact with carriers is rare.

Data on dissemination rates for FMD are estimated based on results by Schoenbaum and Disney (2003). We assume that a herd makes 3.5 direct contacts with other herds per week, on average, with 80 percent effectiveness in transmitting the disease. The number of indirect contacts per week is assumed to be 35, with 50 percent being effective. One infectious herd can infect approximately 20 other herds per week. This dissemination rate is used for the first two weeks after the FMD outbreak is introduced. During this time there are no signs of the FMD outbreak visible to producers and government. Producers notice the outbreak after the second week. Mitigation strategies like movement control and quarantine measures are incorporated into the model at this stage. Starting at the third week, it is assumed that the dissemination rate decreases by half each week until the sixth week, when it reaches 2.5 percent, then, a dissemination rate of 0.7 percent after the seventh week is assumed.

4. Scenarios and Results

Scenarios are simulated and reported across depopulation levels and the duration of trade bans. The different depopulation levels correspond to varying levels of traceability, with higher depopulation rates correlated to higher levels of traceability. It was assumed that only infected herds are depopulated, with 90 percent of the infected herds in the second and third infection weeks depopulated in the fourth week. Domestic demand decreased by 5 percent over the duration of the outbreak. All beef exports and live cattle exports stop for one or two years, and there is no recurrence of FMD after eradication. The different scenarios of the empirical model were optimized using GAMS (version 22.7.2).

The analysis proceeded in several steps. First, the model was calibrated using above discussed parameters and validated to the trade conditions for México in 2002. This year was chosen to avoid the trade distortions caused by the BSE incidents in Canada and the United

States in 2003. Hence, the results are conditional on the historical patterns from México in production, consumption, and trade. In other words, after the trade ban is lifted market factors rely on elasticities that embody historical information from before the outbreak. Second, the different FMD scenarios were simulated and compared to the baseline outcomes. In this manner changes in producer and consumer welfare changes can be calculated. Eight scenarios were analyzed, the first seven corresponded from 30 to 90 percent (in increments of 10 percent) identification and depopulation rate of latent infectious herds.[8] Lower culling rates allow the disease to spread more than in higher depopulation rate scenarios, and it is related to traceability. As the industry is able to increase surveillance and information infrastructure, depopulation rates can increase. The last scenario corresponded to a localized outbreak, culling 50,000 head with a 100 percent depopulation rate.[9] It is assumed that trade bans for FMD where either one or two years in length. Thus, the FMD outbreak is equivalent to a one time shock to inventories with no recurrent events.

4.1 Results

Results are presented in tables 3 (one-year trade ban) and 4 (two-year trade ban). Each depopulation rate corresponds to a different percent loss in the total inventory and set of economic consequences. The first observation is that the length of trade ban has little effect on changes in consumer and producer surplus. This is because México is a small player in the international cattle trade and net importer of beef. Hence, we focus on table 3 with a one-year trade ban. The second observation is that the change in total surplus (consumer plus producer) decreases with increased culling of latent infectious stock. The largest loss occurs when only

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[8] As suggested by a reviewer, an alternative to this approach could be to complete more sensitivity analysis on specific parameters of the model. This is interesting and important, but outside the scope of the current study, and could be examined in a future study.

[9] The infection rate was adjusted to achieve the 50,000 head cull.

depopulating 30 percent of the latent infected herd ($66 billion). This is because lower culling rates allow the disease to spread more than in higher depopulation rate scenarios, which is consistent with Zhao, Wahl and Marsh (2006) and NBAF (2010). Change in consumer surplus is negative except for the localized outbreak (see also Paarlberg et al., 2008 and NBAF, 2010). Changes in producer surplus transition from negative to positive values when more than 60 percent of the latent infected stock is depopulated. The third observation is that the localized impact is positive, but small ($890 million in total, $280 million in producer surplus and $630 million in consumer surplus).

Government costs included in the assessment and reported in table 3 are cleanup and indemnity. It is assumed that disposal and disinfection costs are $48/head, and indemnification costs are $250/head (Schoenbaum and Disney, 2003). These costs are negative and range from $9 billion for 30 percent depopulation to $10 million for a localized outbreak.

Figure 1 represents the effect of a hypothetical FMD outbreak on beef market prices for a one-year trade ban.[10] The scenarios depicted in the figure are base, 60, 90 and 100 (localized outbreak) per cent depopulation rates. A higher price effect is observed given a larger reduction in cattle inventories (and lower depopulation rates). Even though demand decreases with the outbreak, the decrease in supply is larger, causing a higher increase in price (figure 2). After one year international markets reopen and demand increases, but as supply is slower to recover, we observe another price increase. As herds recover and cattle inventories increase, price decreases until it reaches equilibrium.

Turning to a more detailed discussion of specific scenarios (summarizing tables 3 and 4), we notice that for the 40 and 50 percent depopulation rate producers lose approximately $3.15 to $5.43 billion, while consumers lose $21.13 to $47.85 billion with total surplus loss of $29.77 to

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[10] Figures for a two-year ban are very similar and thus, omitted.

$60.51 billion as the consequence of an FMD outbreak, depending on the specific depopulation rate and duration of trade ban. These scenarios represent approximately 52 to 83 percent loss of total inventories, respectively for 50 and 40 percent depopulation rates.

At depopulation rates of 60 percent or higher producer surplus is positive. In these scenarios the increase in price combined with a relatively modest decrease in supply generated large changes in surpluses for producers. Scenarios 4 and 5 correspond to a more reasonable level of traceability, with a depopulation rate of 60 and 70 percent, which translates into a 34 to 23 percent depopulation of total inventories, respectively. The gain to producers is $1.74 to $2.39 billion, which is insufficient to offset the loss to consumers of $9.62 to $14.32 billion, for a total surplus loss of $9.68 to $16.14 billion, depending on the specific scenario and trade ban duration. Scenario 5 (70 percent depopulation rate) represents the largest gain to producers, although not the lowest loss in total surplus.

Scenarios 6 and 7 represent depopulation rates of 80 and 90 percent, corresponding to 16.35 and 11.45 percent loss of total inventories. These two scenarios correspond to a quite optimistic level of traceability. Our results show that the gain to producers could be $1.71 to $2.18 billion, while losses to consumers are expected to be $4.42 to $6.96 billion, for a total surplus loss of $3.91 to $6.50 billion, depending on the specific scenario and trade ban duration.

Finally, scenario 8 represents a localized outbreak in which depopulation is 100 percent (50,000 head). Given the high level of control in this scenario herd losses are minimized for producers, and since prices slightly decrease both producers and consumers gain. Results show surplus gains of $160 to $280 million for producers, $0.63 to $1.45 billion for consumers, and $0.89 to $1.6 billion in total, depending on the duration of the trade ban.

Figures 3 to 5 present the patterns of changes in total, consumer and producer surplus over time for the 60, 90 and 100 percent depopulation scenarios, with a one-year trade ban in place. Price effects combined with herd dynamics drive surplus changes. For depopulation rates of 60 percent and above producers experience surplus gains due to price increases and herd losses less than 34 percent. Consumers suffer greater losses due to higher prices, driving total surplus changes. However, the last scenario of 100 percent depopulation rate (localized outbreak) represents a slight decrease in price, which translates into small gain for producers and for consumers. The changes in surplus last until prices and herd size stabilize, after about eight years.

5. Discussion

Several policy implications are immediately evident. In contrast to Australia, where the duration of trade restrictions dramatically impact economic consequences (Tozer, Marsh and Perevodchikov, 2010), the key difference in México is that domestic supply of beef is relatively unaffected by trade restrictions. This is because México is a net importer of beef and exports of live cattle are not large (approximately 15 percent of the weaned calves are exported to the United States). As a result, prices increase and consumers in México are nearly always worse off.

We also observe that the scenarios with lower depopulation rates represent higher losses in herd size. Lower culling rates allow the disease to spread more than in higher depopulation rate scenarios. Thus, to control the disease more cattle have to be culled in total with the lower depopulation rates. As the industry is able to increase surveillance and information infrastructure, depopulation rates can increase, decreasing outbreak costs for both consumers and producers. This finding is similar to Zhao, Wahl and Marsh (2006), NBAF (2010) and Perevodchikov and Marsh (2010). Schoenbaum and Disney (2003) also mentioned the importance of the speed of the spread of the virus to select the best mitigation strategy. Consequently, targeting depopulation rates of 60 percent or higher are recommended for México, to minimize losses due to wider spread of the virus.

Depending on the specific scenario, the time required for price to return to equilibrium changes. As the depopulation rate increased the price after the introduction of the FMD outbreak decreased, and the number of time periods until prices revert back to equilibrium decreases as well. The number of time periods to return to equilibrium is based on historical information. However, under most scenarios it takes approximately eight years after the FMD outbreak to revert to equilibrium. This may be in part due to the cattle cycle, since breeding animals are productive for about 8 years, the time they stay in the herd. Other factors include biological constraints, such as birth rate, and the time taken to finish cattle for slaughter.

The time to return to equilibrium could be adjusted by government intervention or industry innovations. For example, the government could implement a policy to increase the birth rate of cows, by providing information such as improved reproduction and calf management practices. Another option could be to subsidize producers to raise other types of cattle with higher birth rates. A third option could be to increase imports of breeding stock to help re-build the inventories faster.

It is interesting to compare our results with the outcome of the 1946 FMD outbreak in México. The 1946 FMD outbreak in México lasted for 7 years, over a million animals were slaughtered, 52 million vaccinations were produced and applied, with estimated costs of $250 million or about $2 billion in 2010 dollars (Shahan, 1952; SAGARPA, 2004). During the outbreak, the Mexican authorities received resources (monetary and human expertise) from the United States and Canada (Shahan, 1952). Our results suggest that with a feasible depopulation rate of the latent infectious herds of 60 to 70 percent, we expect total welfare losses of $9.68 to $16.14 billion, and a 23.32 to 33.89 percent loss in total inventories, corresponding to 8 to 12 million animals relative to 2002 inventories. Some of the differences between the 1946 FMD outbreak and our simulation scenarios are the size of the herd, and meat production in México. Beef production in México has tripled from 1972 to 2006 (Luna Martínez and Albarrán Díaz, 2006). Infrastructure and interdependence of the different regions has also improved. However, the main difference arises in the types of costs being considered. In contrast to the costs reported for the 1946 outbreak, we calculate and report welfare effects.

6. Conclusions

This study analyzes a relevant policy issue for the Mexican cattle industry: the effects on trade (domestic and international) of a hypothetical FMD outbreak in the Mexican cattle industry. The unique characteristics of the Mexican cattle industry, such as the differentiated production practices across regions and low exports, make it particularly important, since most studies on the effects of FMD relate to countries with high exports. A discrete time dynamic optimization model of the Mexican cattle sector is specified, and linked to domestic and international markets. Economic consequences of foot-and-mouth disease outbreaks are simulated under selected scenarios. We provide a framework for analysis that can be applied to other countries, diseases and industries, even though our conclusions and results are specific for México and FMD.

Specific findings and general policy recommendations are provided. FMD outbreaks range from localized (positive net gain of $0.89 to $1.60 billion) to large scale (net loss of about $67 billion). Government costs (cleanup and indemnity) range from $9 billion (widespread outbreak) to $10 million (localized outbreak). The results suggest that after a hypothetical FMD outbreak consumers are expected to lose the most, while producers could lose or gain.

Depending on the scenario considered, the expected loss in consumers' surplus is \$4.42 to \$55.46 billion, the expected loss in producers' surplus (scenarios 1 to 3) is \$1.73 to \$5.43 billion, while the expected gain in producers' surplus (scenarios 4 to 7) is \$1.71 to \$2.39 billion. The percentage of total inventory depopulated ranges from approximately 11 to 87 percent. The upshot is that consumers burden most of the outbreak cost. Even though producers also bear part of the outbreak costs, they can recover some of those costs through the increase in price due to reduced supply. The localized outbreak (scenario 8) is different. In such case, both producers and consumers experience surplus gains. The duration of the trade ban had a small impact on welfare effects, given that México exports little beef and has a large consumption base.

More generally speaking, we find that welfare losses decrease rapidly as the depopulation rate of infected cattle increases, however, at a decreasing rate. These results imply that it is beneficial to increase surveillance and information infrastructure, which is consistent with the previous literature. The increasing trend toward intensive feedlot operations could increase the likelihood of FMD spread should an outbreak occur. Market disruptions including price shifts and the time to revert to equilibrium is different in México because of lower birth rates and extended feeding periods. To overcome this limitation government and industry could team up to increase birth rate of cows by improving reproduction and calf management practices, raising cattle with higher birth rates or increasing imports of breeding stock.

The focus of the majority of previous studies corresponds to countries highly dependent on exports. Our results show that even in countries where exports do not represent a significant part of the industry, the effects of invasive species outbreaks can be detrimental to the industry. Finally, the optimal disease control scenario will depend on the point where marginal benefit equals marginal cost. Hence, it is important to consider the cost of implementing the necessary measures. To provide significant conclusions and valid policy recommendations requires accurate estimates of the cost of implementing the different traceability and depopulation rates.

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Table 1: Parameter Description and Values

Parameter	Description	Value	Units
Breeding			
δ^j	Death rate for age $j>1$	0.0325[a]	percentage
δ^j	Death rate for age $j=0,1$	0.0675[a]	percentage
θ	Birth rate	0.5975[a]	percentage
ABC	Average maintenance cost	200[a]	\$/year
MAC	Marginal adjustment cost coefficient	0.001[b]	\$/head
β	Time rate of preference	0.95[b]	percentage
r	Interest rate	0.09[b]	percentage
Demand, Supply and Market Equilibrium			
ASW	Average slaughter weight	475.15[a]	pounds/head
ER	Exchange rate MXN-\$	9.66[c]	MXN/\$
Demand Elasticities (DE)			
MEX	México domestic DE for beef	-0.91[d]	
US	US DE for Mexican beef	-0.5797[d]	
Supply Elasticities (SE)			
CAN	CAN SE for Mexican beef market	1.20[e]	
US	US SE for Mexican beef market	0.05[e]	
Constants			
α_{MEX}	MEX demand equation	5100[f]	
α_{US}	US demand equation	7[f]	
β_{CAN}	CAN supply equation	135[f]	
β_{US}	US supply equation	590[f]	
C_1	Demand equation for non-fed meat	64770[f]	

Sources: [a] Cunningham (2006); [b] Zhao, Wahl, and Marsh (2006); [c] Pacific Exchange Rate Service; [d] estimated values; [e] assumed values; [f] calibrated values for 2002.

Table 2: Starting Values and Inventories[a]

Parameter	Description	Starting Value	Units
Pmeat	Meat price in México	1.40	\$/pound
SV	Salvage value	500	\$/head
Moff	Male calves	4.49	million head
Myg	Male yearlings	3.65	million head
Fyg	Female yearlings	2.17	million head
K^0	Females kept for breeding of age $j = 0$	2.18	million head
K^1	Females kept for breeding of age $j = 1$	2.00	million head
K^2	Females kept for breeding of age $j = 2$	1.85	million head
K^3	Females kept for breeding of age $j = 3$	1.79	million head
K^4	Females kept for breeding of age $j = 4$	1.73	million head
K^5	Females kept for breeding of age $j = 5$	1.67	million head
K^6	Females kept for breeding of age $j = 6$	1.61	million head
K^7	Females kept for breeding of age $j = 7$	1.51	million head
K^8	Females kept for breeding of age $j = 8$	1.49	million head
K^9	Females kept for breeding of age $j = 9$	1.43	million head
K^{10}	Females kept for breeding of age $j = 10$	0.00	million head
KC^0	Culled females of age $j = 0$	2.31	million head
KC^{10}	Culled females of age $j = 10$	1.39	million head
SrM	Live bovine imports for slaughter	0.1505	million head
BrM	Breeder imports	0.0391	million head
CwM	Culled cows imports	0.0166	million head
BrEx	Female yearling exports	0.078	million head
MEx	Male yearling exports	0.541	million head

[a] Calibrated values for 2002.

Table 3: Welfare Changes after an FMD Outbreak, with a one-year trade ban

Scenario	Depopulation Rate[a]	Loss (million head)[b]	Loss (percentage)[b]	Government Costs ($ billion)	Change in Consumer Surplus ($ billion)	Change in Producer Surplus ($ billion)	Change in Total Surplus ($ billion)
1	30%	30.71	87.02%	-9.15	-55.46	-1.73	-66.34
2	40%	29.13	82.54%	-8.68	-47.85	-3.90	-60.43
3	50%	18.44	52.25%	-5.50	-21.29	-3.99	-30.78
4	60%	11.96	33.89%	-3.56	-14.32	1.74	-16.14
5	70%	8.23	23.32%	-2.45	-9.91	2.39	-9.97
6	80%	5.77	16.35%	-1.72	-6.96	2.18	-6.50
7	90%	4.04	11.45%	-1.20	-4.72	1.79	-4.13
8	100%	0.05	0.14%	-0.01	0.63	0.28	0.89

[a] Refers to latent infectious herds; [b] refers to total inventory.

Table 4: Welfare Changes after an FMD Outbreak, with a two-year trade ban

Scenario	Depopulation Rate[a]	Loss (million head)[b]	Loss (percentage)[b]	Government Costs ($ billion)	Change in Consumer Surplus ($ billion)	Change in Producer Surplus ($ billion)	Change in Total Surplus ($ billion)
1	30%	30.71	87.02%	-9.15	-53.87	-3.49	-66.51
2	40%	29.13	82.54%	-8.68	-46.40	-5.43	-60.51
3	50%	18.44	52.25%	-5.50	-21.13	-3.15	-29.77
4	60%	11.96	33.89%	-3.56	-14.06	1.89	-15.73
5	70%	8.23	23.32%	-2.45	-9.62	2.39	-9.68
6	80%	5.77	16.35%	-1.72	-6.61	2.13	-6.20
7	90%	4.04	11.45%	-1.20	-4.42	1.71	-3.91
8	100%	0.05	0.14%	-0.01	1.45	0.16	1.60

[a] Refers to latent infectious herds; [b] refers to total inventory.

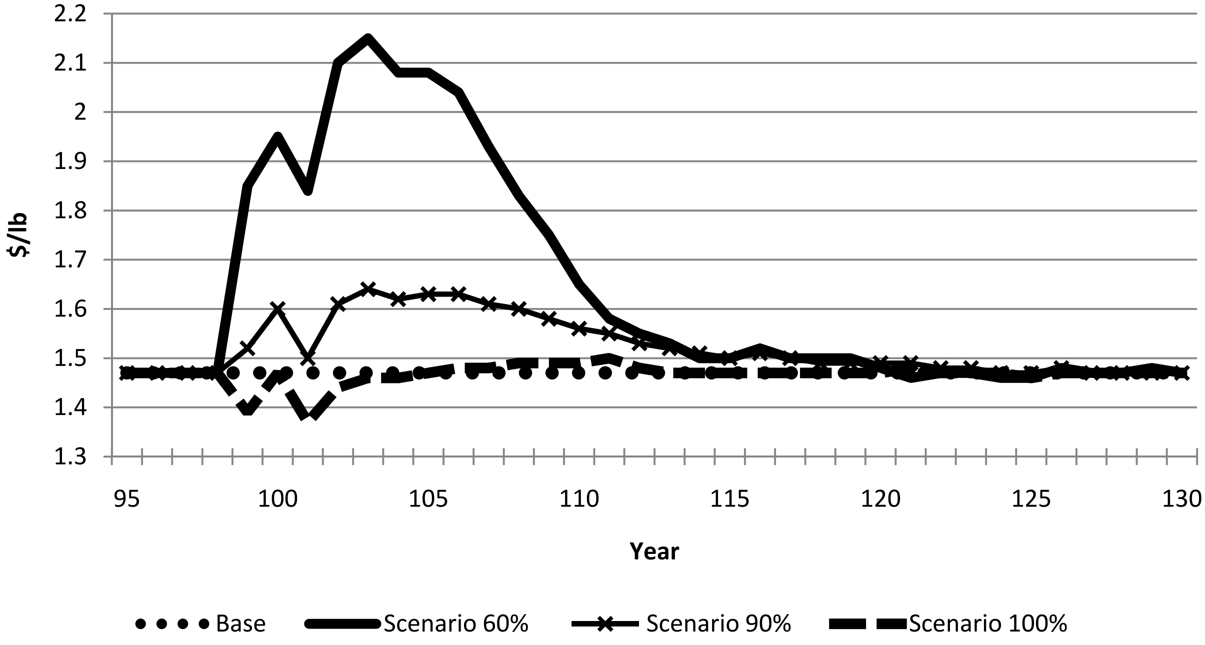

Figure 1: FMD Outbreak Effect on Market Price, with a one-year trade ban

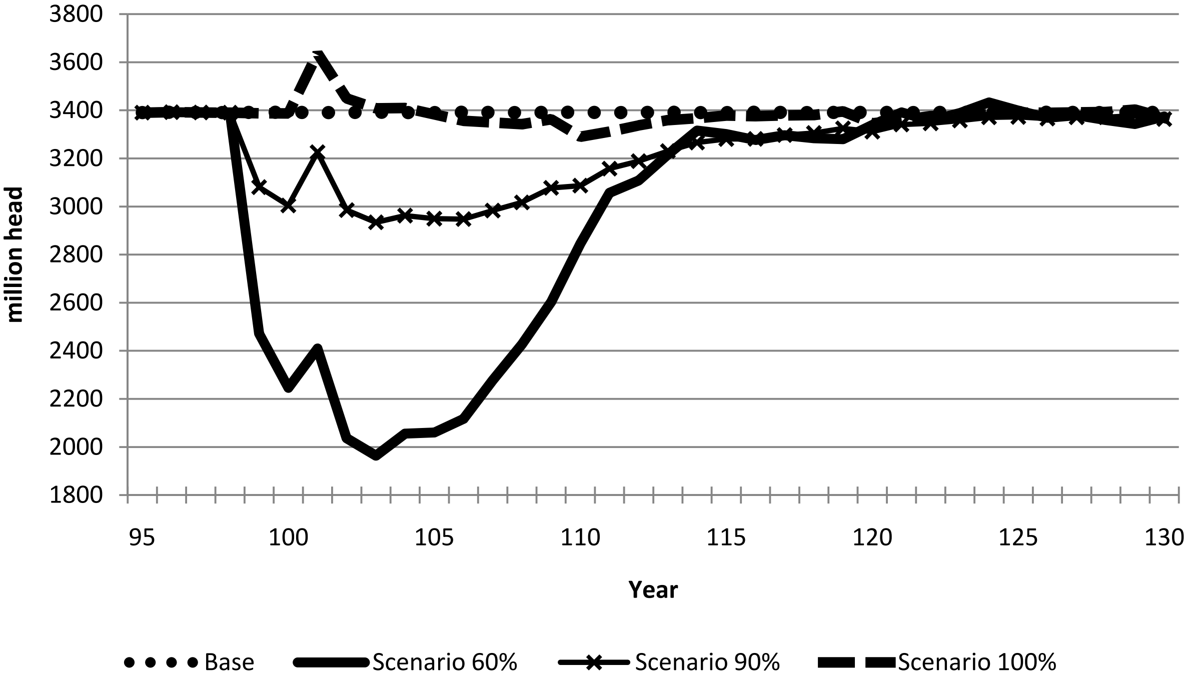

Figure 2: FMD Outbreak Effect on Herd Size, with a one-year trade ban

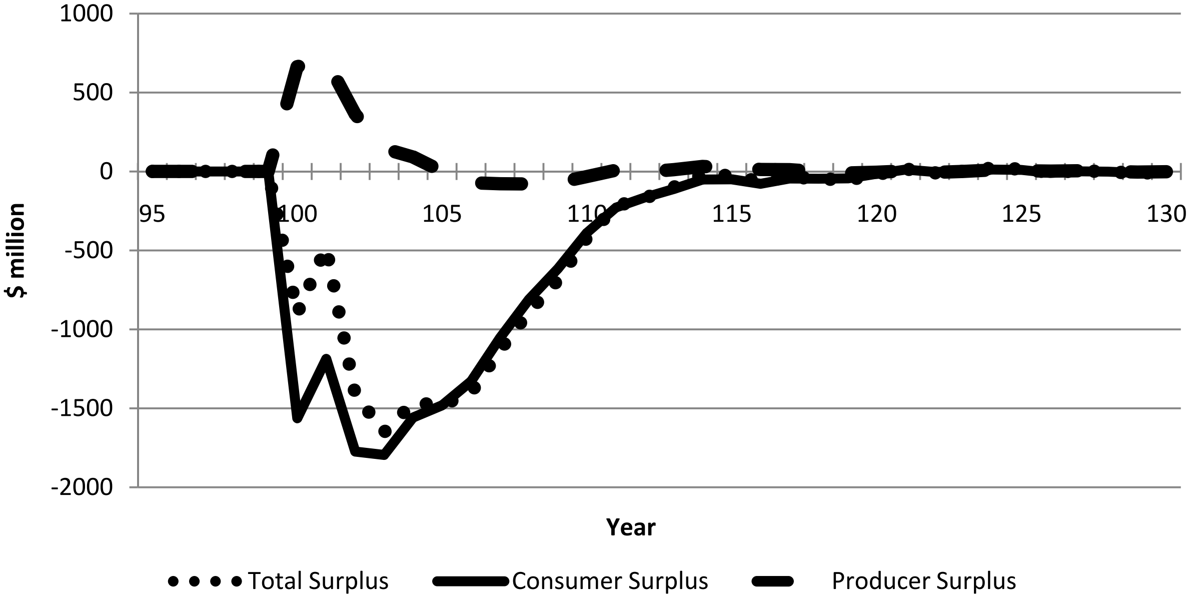

Figure 3: Total, Consumer and Producer Economic Surplus, for the 60 percent depopulation scenario with a one-year trade ban

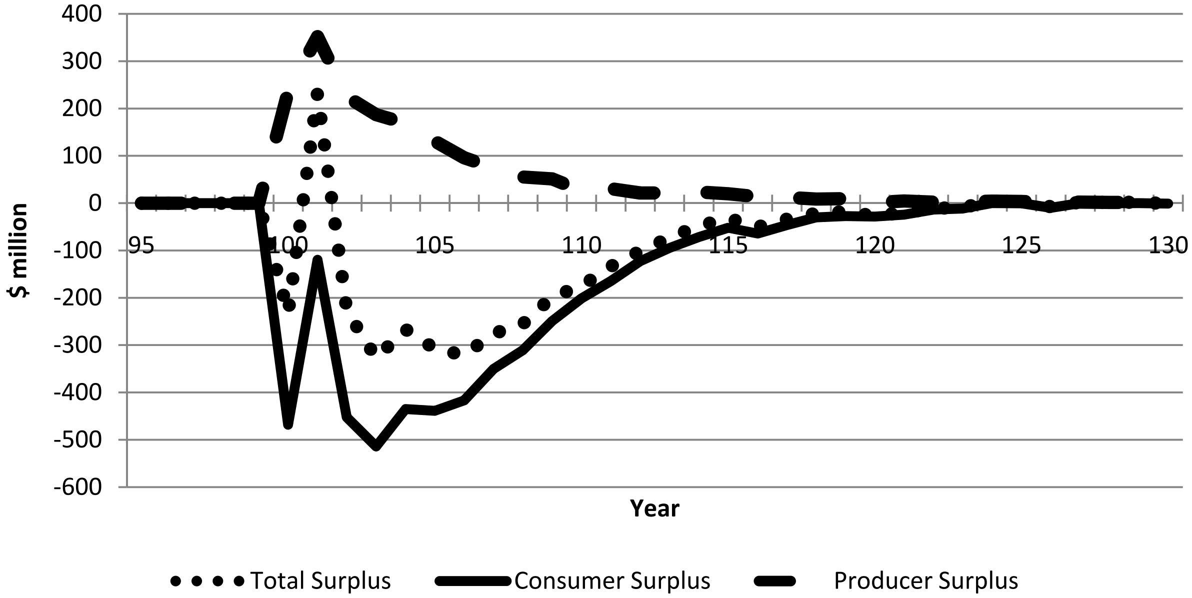

Figure 4: Total, Consumer and Producer Economic Surplus, for the 90 percent depopulation scenario with a one-year trade ban

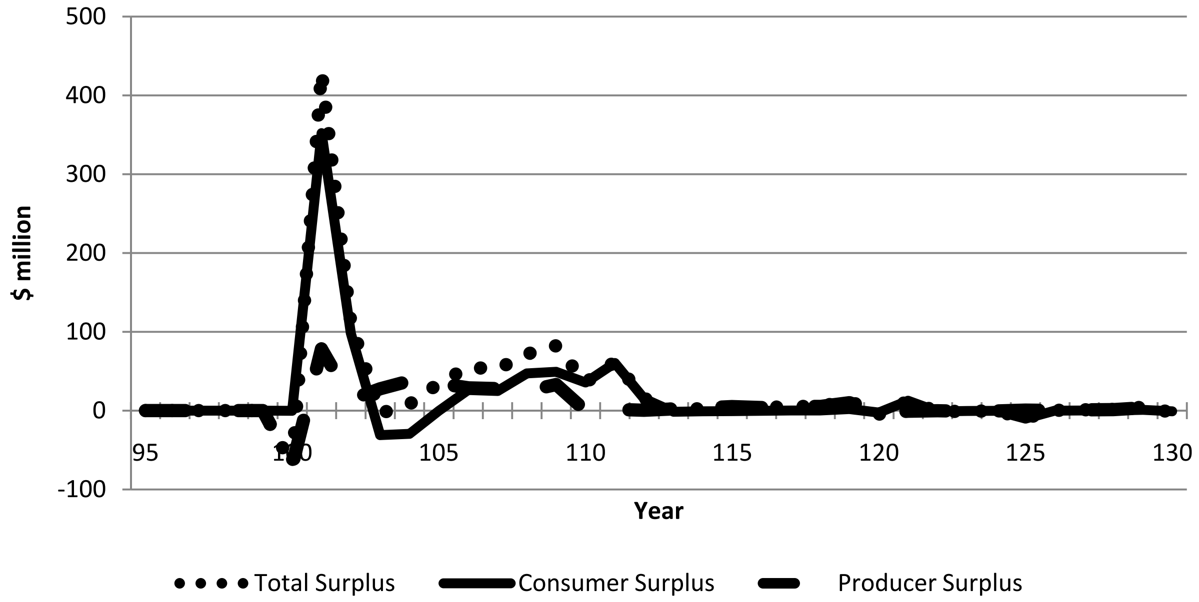

Figure 5: Total, Consumer and Producer Economic Surplus, for the 100 percent depopulation scenario (localized outbreak) with a one-year trade ban