Economic Impacts of Potential Foot and Mouth Disease Agroterrorism in the USA: A General Equilibrium Analysis

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Abstract

The foot and mouth disease (FMD) virus has high agro-terrorism potential because it is contagious, can be easily transmitted via inanimate objects and can be spread by wind. An outbreak of FMD in developed countries results in massive slaughtering of animals (for disease control) and disruptions in meat supply chains and trade, with potentially large economic losses. Although the United States has been FMD-free since 1929, the potential of FMD as a deliberate terror weapon calls for estimates of the physical and economic damage that could result from an outbreak. This paper estimates the economic impacts of three alternative scenarios of potential FMD attacks using a computable general equilibrium (CGE) model of the US economy. The three scenarios range from a small outbreak successfully contained within a state to a large multi-state attack resulting in slaughtering of 30 percent of the national livestock. Overall, the value of total output losses in our simulations range between $37 billion (0.15% of 2006 baseline economic output) and $228 billion (0.92%). Major impacts stem from the supply constraint on livestock due to massive animal slaughtering. As expected, the economic losses are heavily concentrated in agriculture and food manufacturing sectors, with losses ranging from $23 billion to $61 billion in the two industries.

Introduction

Agroterrorism is “the deliberate introduction of a disease agent, either against livestock or into the food chain for purposes of undermining stability and/or generating fear” [1]. Agriculture is particularly vulnerable because an agroterrorism attack can be executed with relatively little technology and at low costs [2]. Further, protecting potential targets of agroterrorism is costly because agricultural activities are widely dispersed and have extensive linkages with the rest of the economy. As such, an agroterrorism event can disrupt the economy by contaminating livestock, crops, or other targets in the food supply chain.

Agroterrorism is a type of bioterrorism but is not classified as a weapon of mass destruction (WMD) because it does not involve direct attacks on the human population [1]. However, the economic impacts of a bioterrorist attack on agriculture would not be confined to farms and can be consequential. An agroterrorism attack may also involve significant human health risks depending on the pathogens used and food targets. In addition, a deliberate introduction of livestock or crop pathogens and food contamination is expected to cost society much more than a natural outbreak since it is likely to increase fear.

The United Nations Office International des Epizooties (OIE) produces a list of pathogens. Many of these pathogens are considered to be severe threats because they are highly transmittable and may potentially have serious socioeconomic and/or public health consequences. The foot-and-mouth disease (FMD) virus is listed by the OIE and is regarded as one of the greatest potential agroterrorism threats [3,4]. The FMD virus can be easily weaponized and is highly contagious. The FMD virus can be transmitted via inanimate objects such as animal byproducts, water and straw, and can spread up to 100 kilometers by wind [4,5]. FMD affects cloven-hoofed animals such as cattle, swine, sheep, goats, and deer, though it is rarely fatal to adult animals. The virus may be disseminated through the introduction of infected raw or processed meat to points in the animal supply chain [6]. Although the FMD virus does not affect humans, the meats from infected animals are not used for food because the virus can spread rapidly through the meat processing supply chain. In addition, the virus can persist in human nasal passages for up to 36 hours and on shoes for 9 to 14 weeks [7]. Thus, an outbreak of FMD in developed countries results in massive slaughtering of animals (for disease control) and disruptions in meat supply chains and trade with potentially large economic losses.

The United States (US), Canada and Mexico have been FMD-free since 1929, 1952 and 1953, respectively [7]. The United Kingdom (UK) which also had been FMD-free since 1967 experienced a large outbreak in 2001 that lasted for 8 months. The cost of the outbreak to the UK economy, including agriculture and tourism losses, has been estimated at about $11 billion [7,8], and almost 7 million animals or about 12% of all livestock were slaughtered. Another outbreak in 2007 was quickly contained due to measures put in place after the 2001 event. Still, many countries extended or imposed a ban on imports of beef from the UK following the 2007 outbreak.

In this paper we estimate the impacts on the US economy of a potential FMD outbreak caused by a hypothetical agroterrorism event. We use a 57-sector computable general equilibrium (CGE) model to analyze several different scenarios of the severity of the attack and public response. This paper contributes to the ongoing need for information on the range of potential economic consequences associated with various terrorist risks. It also helps to evaluate the resilience of the economy, and the relative cost-effectiveness of alternative options to prevent, prepare and respond to such events.

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We estimate the economic impacts of three alternative scenarios of potential FMD attacks, ranging from a small outbreak successfully contained within a state to a large multi-state attack resulting in slaughtering of 30 percent of the national livestock. Overall, the estimated value of total output losses range between $37 billion (0.15% of 2006 baseline output) and $228 billion (0.92%). Major impacts stem from the supply constraint on livestock due to massive animal slaughtering. As expected, the output losses are heavily concentrated in agriculture and food manufacturing sectors, with losses ranging from $23 billion to $61 billion in the two industries. The estimated impacts can be described as the short- to medium-run economic effects of an FMD outbreak due to an agroterrorism event. These impacts abstract from the recovery of the affected agricultural sectors and other long-run implications for the economy, which are beyond the scope of the current study.

The next section briefly introduces the characteristics of our CGE model and discusses how we model the shocks, responses, and remediation activities within the CGE modeling framework. In the following section, we present three scenarios of potential FMD attacks and estimates of the direct impacts. Section IV presents individual and combined estimates of economic losses for the three scenarios. The paper ends with a brief summary and suggestions for future research.

**CGE Analysis of Potential FMD Outbreak in the United States**

Several studies have evaluated the potential economy-wide impacts of FMD outbreaks in the US. The most common approach is input-output (I-O) modeling. This methodology involves two main steps. First, the estimated direct impacts of an event are converted into final demand expenditure changes. Second, these changes in final expenditures are imposed on the I-O model to calculate the total (direct plus indirect) effects on the economy [9-11]. Although it reflects the structure of an economy and the interaction among various sectors, the I-O approach leaves out crucial price-related adjustments that may be important in determining the economic impacts of shocks. Paarlberg et al. [12] employed a more flexible framework by combining a model of FMD disease spread with a partial equilibrium model of the US agricultural market and its dependent sectors to evaluate three scenarios of an FMD outbreak. Similarly, Hagerman et al. [13] simulated an outbreak in the California dairy industry, which produces 22% of the US milk supply, and evaluated control strategies such as alternative detection and vaccination approaches.

This study employs a computable general equilibrium model which overcomes most of the limitations of the I-O framework by allowing for endogenous, non-linear price-driven changes in the economy. The CGE approach represents the state of the art approach to impact and remediation activities within the CGE modeling framework. In the following section, we present three scenarios of potential FMD attacks and estimates of the direct impacts. Section IV presents individual and combined estimates of economic losses for the three scenarios. The paper ends with a brief summary and suggestions for future research.

**Model description**

CGE models are comprehensive multi-market models of an economy based on the behavioral responses of individual producers and consumers within the constraints of labor, capital and natural resources. CGE models maintain most of the advantageous features of input-output (I-O) models (e.g., full accounting of all inputs, multi-sector detail, ability to measure interdependence) while overcoming many of their limitations (e.g., absence of behavioral content, linearity, lack of substitution, absence of prices). CGE models have many valuable attributes that make them well-suited to the analysis of terrorist attacks [19] and are increasingly being used to analyze these and related issues [15,22]. In short, they have the ability to incorporate estimates of direct effects and to translate them into economy-wide (general equilibrium) effects through the interaction of producers and consumers in various markets in response to the constraints imposed by the attack. The behavioral, market-oriented, and flexible basis of CGE models gives them an edge in modeling most types of resilience [23]. Commodity and input substitutions are readily captured in firms’ production functions and households’ expenditure systems, as is import substitution, in response to price adjustments. Excess capacity and relocation can be modeled by relaxing relevant constraints in the system of equations. Several other resilience adjustments can be incorporated through changes in parameters (e.g., adaptive input/ import substitution, adaptive conservation) or side-calculations (e.g., production rescheduling).

The CGE model employed in this paper is a static, short-run model of the US that divides the economy into 57 producing sectors. The model captures the interaction among producers, nine household income groups, federal and state/local governments, and the rest of the world. Production activities are modeled using nested constant elasticity of substitution (CES) functions that allow for a flexible representation of production activities using inputs of capital, energy, labor, materials, transportation, and other services. The nesting of production inputs is shown in figure 1 of Appendix A. Supply and trade in goods/services are also modeled using CES functions to represent the choice between domestic sales and imports as imperfect substitutes, while the constant elasticity of transformation (CET) function is used to determine the relative allocation of production to domestic and export markets.

Household behavior is modeled using a linear expenditure system (LES) with a sub-nest of CES functions as shown in figure 2 of Appendix A. The CES functions combine purchases of market goods from the 57 production sectors into ten commodities (Food, Housing, Gasoline, Local Transit, Other Transportation, Health, Equipment, Water/Sanitary Services, Electricity, Other Fuels, Other Goods, and Other Services) that are directly consumed by households according to the LES expenditure system. Households are assumed to save a fixed proportion of disposable incomes. Government savings is a residual that adjusts to a fixed real expenditure on goods and services, and external savings adjust to maintain the balance of payments. Government allocates expenditures to individual commodities using fixed expenditure shares. The model also includes equations for transfers among the various institutions (households, government and rest of the world) in the economy. The model is closed with equilibrium conditions for supply and demand of goods and services, as well as between incomes and expenditures. Capital stock is fixed, while returns to capital adjust freely in each economic sector. A Keynesian closure rule, which allows for unemployment under a fixed wage rate, is adopted for the labor market.

Data for the model is derived from the detailed 2006 Social Accounting Matrix (SAM) for the US derived from the Impact Planning and Analysis (IMPLAN) database (MIG, 2008). This is based on the National Income and Product Accounts and an update of the benchmark US Department of Commerce I-O Table 1. Armingon...
elasticiites (elasticity of substitution between domestic and imported goods) are based on previous work and other studies. The elasticiites are between 2-3 for agricultural and manufacturing sectors, and around 1 for most of the other sectors of the economy. Income elasticiites are between 0.1-0.5. Production input substitution elasticiites are from previous work for the top three levels in figure 1 in Appendix A, while those for the lower nests, being unavailable in the literature, are set to values of less than 0.5 but greater than zero. For further details on the model structure see Rose et al. [11].

Incorporating FMD Scenarios in the CGE Model

Based on a general analytical framework for studying the impacts of terrorism attacks developed in previous studies [19,24], we model three types of economic shocks: target-specific direct impacts, impacts of behavioral linkages, and remediation costs. Another major category, loss of life, is excluded as FMD does not affect human health. The economy-wide impacts of an FMD outbreak occur through both ordinary and extended linkages (behavioral and systemic) between sectors of the economy that are directly affected and the rest of the economy. The direct impacts of the FMD on various sectors of the economy are estimated and then converted into final expenditure changes, which are imposed as shocks to the economy in the CGE model according to the following two steps:

1. Identification of and synchronization of the values of parameters/variables of the model that match the identified sources of direct impacts.
2. Simulation of the model with perturbation of the identified variables and/or re-specification of related equations.

Table 1 identifies the key parameters and variables of the model related to an FMD attack. The first column of the table identifies the type of effect, including the initial source of shock to the economy, responses by different actors and remediation efforts, while the second column identifies actions in the economy corresponding to these effects. The third and fourth columns identify parameters of the model that are used to specify the initial effects or through which the effects are transmitted to the rest of the economy in the simulations. The fifth column contains comments on the type of mechanisms governing these effects in the economy. The table shows that the various types of effects can be matched to four types of changes in the economy: constraints on production of livestock; changes in exports of livestock and meat; shifts in consumer preferences for different types of meats and substitutes, as well as for domestic and imported meats; government expenditures on remediation services.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Agent of Change</th>
<th>Computation</th>
<th>Workings</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Initial Shock</td>
<td>Slaughtering of livestock</td>
<td>Constrain livestock gross output</td>
<td>(see Response)</td>
<td>Destruction of output</td>
</tr>
<tr>
<td>2. Response (Ordinary)</td>
<td>Reduction in output of livestock sectors</td>
<td>a) Initial price increase because of constraint on livestock output</td>
<td>Demand for livestock rationed by price</td>
<td>Inherent substitution</td>
</tr>
<tr>
<td></td>
<td>Δ Consumer preferences</td>
<td>b) Increase share of beef substitutes</td>
<td>Substitution increases</td>
<td>Adaptive substitution</td>
</tr>
<tr>
<td></td>
<td>Δ Import demand</td>
<td>c) No additional step</td>
<td>Substitution towards imports</td>
<td>Inherent substitution</td>
</tr>
<tr>
<td></td>
<td>Δ Import preferences</td>
<td>d) Increase share of beef imports</td>
<td>More substitution towards imports</td>
<td>Adaptive substitution</td>
</tr>
<tr>
<td></td>
<td>Δ Export demand</td>
<td>e) No additional step</td>
<td>Foreign demand for livestock rationed by price</td>
<td>Inherent substitution</td>
</tr>
<tr>
<td>3. Response (Fear)</td>
<td>Δ Export demand</td>
<td>a) Constrain livestock &amp; meat export demand</td>
<td>Reduces livestock exports</td>
<td>Behavioral linkage</td>
</tr>
<tr>
<td></td>
<td>Δ Domestic demand</td>
<td>b) Shift demand curve for beef downward</td>
<td>Reduces price</td>
<td>Behavioral linkage</td>
</tr>
<tr>
<td>4. Remediation (deficit finance)</td>
<td>Δ Final demand for remediation</td>
<td>Increase government demand for Vet. &amp; Remediation services</td>
<td>Final demand increase financed by deficit</td>
<td>Policy response</td>
</tr>
<tr>
<td>5. Remediation (government expenditure offset)</td>
<td>Δ Government final demand expenditures</td>
<td>Change government expenditure distribution</td>
<td>Shifts expenditure towards Veterinary &amp; Remediation</td>
<td>Budget/Policy response</td>
</tr>
</tbody>
</table>

Table 1: Parameters and Variables for Simulating a FMD Outbreak in the CGE Model.
Shifts by households from beef to alternatives are implemented by reducing the value of $\lambda$ for beef and increasing that for poultry. Shifts from domestic to imported beef are implemented in a similar way in the corresponding domestic-import substitution functions.

Deficit financed remediation expenditures are implemented by simply increasing real government expenditure on veterinary services without reducing other expenditures. This implies that the extra expenditure reduces government savings. The alternative implementation of remediation expenditures involves an increase in the share of veterinary services in real government expenditures and a proportional reduction of government expenditures on all other goods and services.

Potential FMD Outbreak Scenarios for the United States

Simulations of the economic impacts of an FMD outbreak are based on hypothetical scenarios because the US has not had an outbreak since 1929. In the current study we specify potential FMD outbreak scenarios based on studies that conducted epidemiological model simulations and impact estimates from recent outbreaks in other countries [8,9,12].

Outbreak scenario and operational costs

We simulate the economic impacts of three FMD attack scenarios: base, medium and extreme scenarios. The base scenario is derived from Ekboir JM [9] and its remediation costs are linearly extended to the other two scenarios. Remediation costs include all operating costs required to contain the spread of the disease and to mitigate the impacts of the terrorist event. The target-specific direct impact in this study is the loss of animals.

The base case scenario assumes that a terrorist group deliberately introduces the FMD virus into the South San Joaquin Valley of California. Ekboir JM [9] presented seven epidemiological scenarios and estimates of direct operating costs, each of which uses different parameters. We use his Scenario 1 simulation, which is the worst but most probable outcome. In this simulation, he assumed high dissemination rates, no depopulation of latent infections and that 90 percent of the infected herds are eliminated each week. Ekboir's simulation result reports that all susceptible herds in the South San Joaquin Valley would be infected in four weeks and all herds in the valley would be destroyed by the end of the sixth week after the outbreak. As a result, 808,000 animals including about 570,000 dairy cows are slaughtered.

The remediation costs of a FMD outbreak include cleaning and disinfection (C&D) costs and the costs of quarantine enforcement. We use Ekboir's estimates of these costs after adjusting to 2006 dollars using the GDP deflator. Remediation activities are estimated at about $463 million including $327 million of C&D costs and $136 million for quarantine enforcement. We note that remediation activities would have dual impacts on the economy [24]. On the one hand, the expenditures on remediation activities would have stimulative effects on related industries such as veterinary services and waste management. We model these effects by increasing the final demand for corresponding sectors. On the other hand, remediation activities would draw resources from other economic activities. We model two alternative ways to finance the remediation activities: increased deficit spending and reductions in other Federal government expenditures. In the case of deficit spending, there would be little economic loss in the current fiscal year, although the increased deficit will be a burden to the economy in the long run. If the government reduces other expenditures for the remediation activities, both positive (stimulus) and negative effects would occur in the same year. The net effect will depend on the relative size of multiplier effects between remediation sectors and general government spending.

The value of slaughtered animals is estimated at about $1.3 billion. Although the monetary compensation for these slaughtered animals is clearly an outlay to the Federal government, we do not include this compensation in CGE modeling because it is a transfer payment and not a real resource cost. Rather, we model the slaughtering of animals as a constraint on animal supply from livestock farming to the meat processing industry. We reduce outputs in beef, dairy and other livestock farming sectors by 0.23 percent, 6.27 percent, and 0.02 percent, respectively.

As mentioned above, this base case is drawn from the simulation results of a natural FMD outbreak in which the disease is successfully contained within the quarantined area. In case of agroterrorism, however, a simultaneous attack on multiple targets in different states is more likely, and the impacts would be aggravated. To simulate a simultaneous attack, we model additional medium and large cases involving an 8 percent and 30 percent loss of outputs of livestock farming, respectively. The large case is not improbable given the geographically dispersed locations of each segment of the animal supply chain and hence the movement of animals in US livestock farming. Indeed, an FMD simulation exercise by the North Carolina Department of Agriculture called "Crimson Sky" reports that the disease can reach 35 states within 10 days, and about 40% of cattle livestock would need to be slaughtered if five farms are infected simultaneously [25]. Another study also warns that FMD could affect 30-70% of the US livestock if the government fails to stamp out the disease within a reasonable time frame [5]. For these alternative scenarios, we extend the remediation costs of the base case in proportion to the loss of outputs of all three livestock farming sectors.

Demand changes in red meat markets

In terrorism events, major economic losses may occur through behavioral and systems linkages, and these costs are often larger than direct costs and ordinary multiplier effects [19]. For instance, economic impacts due to reduced airline travel and tourism were estimated to be several times larger than the loss due to business interruption and relocation after the September 11th terrorist attacks on the World Trade Center in 2001 [11]. Similarly in an agroterrorism event like a FMD attack, it is likely that major economic costs would occur from behavioral changes of domestic consumers and the international trade system of livestock and red meats [24].

It is very likely that US consumers would reduce red meat consumption and seek substitute sources of protein, although FMD does not harm human health. During the 2001 FMD outbreak in the UK, US consumers were not able to distinguish FMD from Bovine Spongiform Encephalopathy (BSE), which is also known as mad cow disease and is a serious threat to human health [12]. Terrorism events may also induce excessive risk aversion due to intense emotions and fear [26]. In addition, most of the countries that currently import US livestock and red meat products are expected to impose trade restrictions partly for disease control and partly due to the exercise of trade protectionism.

We model the economic impacts due to reductions in domestic and foreign demands for US livestock and red meat products. Best estimates of these adjustment parameters can be found in historical incidences of the same or similar events (a type of "data transfer"). Since there has been no FMD outbreak in the US since 1929, we studied the demand changes after the 2001 FMD outbreak in the UK and the 2003 BSE case in the US.
In the UK, FMD infection started in February 2001 and was eliminated by the end of September 2001 after slaughtering about 6.6 million animals. Disease-free status was declared almost a year after the initial disease outbreak [8]. In spite of the stunning scenes of massive slaughter aired through TV networks, however, UK consumers were little affected. UK domestic consumption of red meats was higher by 1.3% and 5.2% in 2001 and 2002, respectively, compared to the 1998-2000 average level. It was the export of red meats that suffered a substantial reduction during the FMD outbreak and following years. As shown in Table 2, the export of pig and sheep meats decreased by about 67% in 2001 and by about 45% in 2002, compared to the 1997-1999 average level.

The US also experienced similar changes after a Canada-born dairy cow in the State of Washington was found to be positive for BSE in December 2003. The export of beef fell dramatically, but domestic consumption was little affected (Table 3). The export market impact was particularly large because the major target of US beef exports was the high quality international beef market. For instance, Japan and Korea, which had imported about 56% of US beef exports before the BSE discovery, completely shut down their imports of beef and related products [27].

We use these two historical animal disease outbreaks in constructing scenarios for the reduction in foreign demand for US red meat products. We assume 80% decline as the upper bound and 65% reduction as the lower bound of our estimates. We expect that the impacts of a FMD agroterrorism attack on US livestock would be larger than those of the 2001 UK FMD outbreak considering the strict standards exercised by the major importers of US beef after the 2003 BSE discovery. We also assume 25 percent reduction in the domestic demand for red meats to capture the higher level of consumer fears during a terrorism event. Table 4 summarizes the various simulation scenarios examined in this paper. Cases 1-6 examine the economic effects of the individual major impacts highlighted above, while cases 1a-3a and cases 1b-3b examine the combined effects of these impacts along with remediation expenditures and increased imports. For the latter, we assume that the import share parameters for the meat processing sector increases by the same magnitude as the percent decrease in domestic output of beef cattle farming.

Results of Potential FMD Outbreak Scenario Simulations

Results of the simulation scenarios outlined above are presented in this section. First we discuss the results of individual FMD impact cases presented in Table 5. Tables 6 and 7 present results for the combined impacts, remediation expenses and increased beef import cases.

Economic effects of each major impact of an FMD outbreak

Table 5 shows that the three production loss scenarios, cases 1-3, lead to overall economic output losses of between 0.09 percent and 1.13 percent, and value-added losses of between 0.06 percent and

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</tr>
</thead>
<tbody>
<tr>
<td>Red meat</td>
<td>800.27</td>
<td>296.59</td>
<td>473.52</td>
<td>-62.9%</td>
<td>-40.8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bovine meat</td>
<td>43.06</td>
<td>49.52</td>
<td>60.46</td>
<td>15.0%</td>
<td>40.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pig meat</td>
<td>409.68</td>
<td>135.53</td>
<td>218.57</td>
<td>-66.9%</td>
<td>-46.8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheep and goat meat</td>
<td>347.54</td>
<td>111.94</td>
<td>194.49</td>
<td>-67.9%</td>
<td>-44.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: UN Food and Agriculture Organization Statistical Database (FAOSTAT, 2008).

Table 2: UK Exports of Red Meats, 1997-2002.
overall economic impacts under cases 1a and 2a may be unexpected from comparisons of the individual results for cases 1 and 2 in table 5. However, the results in table 6 illustrates the importance of modeling the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1, being larger than that for case 1, suggest that the combination of export reductions and shifts in consumer demand away from beef consumption are binding constraints. The magnitudes of impacts in case 1a, being larger than that for the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1a, being larger than that for the endogenous interaction within the economy in response to imposed shocks. However, the results in table 6 illustrates the importance of modeling the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1, being larger than that for the endogenous interaction within the economy in response to imposed shocks. However, the results in table 6 illustrates the importance of modeling the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1, being larger than that for the endogenous interaction within the economy in response to imposed shocks. However, the results in table 6 illustrates the importance of modeling the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1, being larger than that for the endogenous interaction within the economy in response to imposed shocks. However, the results in table 6 illustrates the importance of modeling the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1, being larger than that for the endogenous interaction within the economy in response to imposed shocks. However, the results in table 6 illustrates the importance of modeling the endogenous interaction within the economy in response to imposed shocks. The magnitudes of impacts in case 1, being larger than that for the endogenous interaction within the economy in response to imposed shocks.
under case 3a with an output loss of about 2.2 percent. Under case 3a the direct production losses are binding and much of the losses are fully absorbed by the indirectly affected sectors of the economy producing impacts similar to case 3. However, the import compensation in case 3a is also larger, thereby muting some of these impacts. As a result, the net national output reduction under case 3a is 0.92 percent compared with 1.13 percent under case 3.

Table 7 further disaggregates the output effects of the combined cases for the agriculture and food sectors in value terms. It shows that in each of the three cases losses for the agriculture and food sectors bear the effects of the outbreak almost equally. In cases 1a and 2a these are about $10 billion, and about $30 billion under case 3a. As expected, the animal processing and beef cattle farming sectors have the largest output losses. The shifts from beef to poultry and fish by households are reflected in increases in the outputs of the latter two sectors with output increases of $4.2 billion.

Cases 1b-3b examines the effect of increasing export losses from 65 percent in Cases 1a-3a to 80 percent. The latter value is comparable to the decline in US beef exports between 2003 and 2004 due to the BSE incident. The results of these simulations show that the economy-wide losses are very close to those under Cases 1a-3a. This is not unexpected given that total exports amounted to only 6 percent of the beef industry output in 2006 - the base year of our model. We simulated alternatives to Cases 2a/2b and 3a/3b, in which the remediation expenditures are financed by shifting funds from other government purchase of goods and services, rather than by increasing the government deficit. These two alternative cases, not reported here, increase the overall national output losses by 0.05 percentage points and slightly over 1.10 percentage points, respectively. As highlighted earlier, the larger losses seen with the financing of remediation costs through shifts in expenditures is due to reductions in purchases of other goods and services, whereas the burden is transferred to the future under deficit financing. As our model is static in time, it does not capture the future impacts of the deficit shift.

Conclusion

This paper presents the results of simulations to estimate the macroeconomic consequences of a range of agroterrorist attacks scenarios to spread Foot and Mouth Disease (FMD) among the animal population in the US [28]. A computable general equilibrium (CGE) model was employed for the analysis. This approach not only enabled us to estimate the ordinary economic consequences of this disease, but also to factor in the implications of behavioral over-reactions and of resilience. The results indicate that an FMD attack would have significant but not devastating impacts on the US economy. The impacts are not large because of the limited animal population initially affected, the limited spread, the limited percentage of beef that goes to exports, and the substitution of other foods for beef.

Due to the lack of historical experience with FMD attacks, and FMD outbreaks in general, it was necessary to invoke several important assumptions. Although the results are robust to basic conditions, future research would benefit from the validation of estimates of the direct impacts of FMD attack scenarios, disease spread across the country, consumer aversion to beef in the short and long term, international reactions to US beef exports, and remediation costs. For example, although our most extreme scenario is based on simulations of the potential spread of FMD from a few entry points, the response to such an outbreak scenario may not be the same as for the less severe scenarios.
Table 7: Output Effects of the Combined Impacts of an FMD Outbreak on Agriculture and Food Sectors (Billions).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Base</th>
<th>Case 1a</th>
<th>Case 2a</th>
<th>Case 3a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy Cattle Farming</td>
<td>39</td>
<td>-2.4</td>
<td>-3.1</td>
<td>-11.7</td>
</tr>
<tr>
<td>Other Livestock</td>
<td>24</td>
<td>-2.9</td>
<td>-3.9</td>
<td>-7.1</td>
</tr>
<tr>
<td>Poultry &amp; Egg Production</td>
<td>29</td>
<td>2.9</td>
<td>3.9</td>
<td>3.3</td>
</tr>
<tr>
<td>Fishing and Aquaculture</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other Agriculture</td>
<td>192</td>
<td>-1.5</td>
<td>-1.4</td>
<td>-2.9</td>
</tr>
<tr>
<td>Total Agriculture</td>
<td>324</td>
<td>-10.1</td>
<td>-10.7</td>
<td>-29.5</td>
</tr>
<tr>
<td>Fluid Milk</td>
<td>35</td>
<td>-1.5</td>
<td>-1.9</td>
<td>-7.2</td>
</tr>
<tr>
<td>Non-Milk Dairy Product</td>
<td>53</td>
<td>-2.3</td>
<td>-3.0</td>
<td>-12.6</td>
</tr>
<tr>
<td>Animal/Meat Processing</td>
<td>114</td>
<td>-19.3</td>
<td>-19.2</td>
<td>-29.3</td>
</tr>
<tr>
<td>Poultry Processing</td>
<td>55</td>
<td>9.2</td>
<td>9.2</td>
<td>10.0</td>
</tr>
<tr>
<td>Seafood Preparation</td>
<td>12</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other Food Processing</td>
<td>356</td>
<td>0.7</td>
<td>2.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Total Food Manufacturing</td>
<td>624</td>
<td>-13.2</td>
<td>-12.9</td>
<td>-31.3</td>
</tr>
<tr>
<td>Total Agriculture &amp; Food Food</td>
<td>948</td>
<td>-23.3</td>
<td>-23.9</td>
<td>-50.5</td>
</tr>
</tbody>
</table>

Alternative responses to an FMD outbreak, such as vaccination, may be more acceptable than slaughtering more than 30 percent of the livestock population because of the potential logistical difficulties. In addition, the process of recovery in the agricultural and food sectors of the economy and other long-run economic effects of a large outbreak of FMD are beyond the scope of this paper. As such, our results provide insights into the potential range of short- to medium-run economic effects of different scenarios of an FMD outbreak.

References

APPENDIX A: Nesting Structure in the Model

Figures 1 and 2 show the nesting structure for production and consumption in the model respectively. The nesting structures were chosen to enable flexible modeling of production and consumption within the economy, and the groupings of inputs and market goods reflect real world substitution possibilities more closely. The consumer nesting can be seen as a form of multi-level budgeting, but also a special case of household production functions. In addition, by using groups of related inputs and commodities it is easier to isolate and simulate various sources of shocks to the economy.

Figure 1: Nesting Structure of the Production Function in the CGE Model

L = Labor; K = Capital; E = Energy; M = Materials; T = Transport; S = Services; FS = Financial Services; OS = Other Services; CM = Chemicals; OM = Other Materials; TR = Transport; Services (Truck, Rail, Water and Air); OT = Other Transport Services

Figure 2: Nesting Structure for Household Consumption in the CGE Model