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Estimating the State-by-State Economic Impacts of a Foot-and-Mouth Disease Attack

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Abstract

The agricultural sector is highly vulnerable to bioterrorism attacks with the potential for severe economic consequences. This article presents estimates of state-by-state total economic impacts of a hypothetical agroterrorism attack that uses foot-and-mouth disease (FMD) pathogens, which is one of the most contagious animal diseases and can be easily weaponized. The authors estimate the economic impacts across the U.S. states by applying the National Interstate Economic Model (NIEMO), a multiregional input output (MRIO) model. Total economic impacts range from $23 billion to $34 billion. The overwhelming sources of the losses are due to domestic and international demand cuts. The results of this research highlight the point that the economic impacts are nationwide, regardless of the location of the attack because of large-scale export losses.

Keywords

foot-and-mouth disease, agroterrorism, economic impacts, multiregional input output model

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Introduction

Agroterrorism presents an obvious and major terrorist threat to the United States and the world, with the potential for severe economic consequences—including significant human health risks. Cupp, Walker, and Hillison (2004) cite Chalk (2001, 2) to define agroterrorism as "the deliberate introduction of a disease agent, either against livestock or into the food chain, for purposes of undermining stability and/or generating fear." An agroterrorism attack can be implemented at relatively low cost by an attacker. Terrorists can readily contaminate livestock, crops, or any targets in the food supply chain, including farms, processing plants, and distribution systems. Security levels have been significantly heightened for potential urban targets of terrorism and infrastructure since the attacks of September 11, 2001. However, it remains almost impossible to identify and protect all potential targets of agroterrorism.

The agricultural sector is particularly vulnerable because biological attacks on agriculture require relatively little scientific expertise and technology, while a full-scale bioterrorist attack on human populations is more technically challenging (Wheelis, Casagrande, and Madden 2002). Many types of pathogens that can cause crop and animal disease are highly contagious and can be easily weaponized. Pathogens causing listed diseases classified by the Office International des Epizooties (OIE) are the greatest threats because they are highly transmittable and may potentially have serious socioeconomic and/or public health consequences, including international trade losses. The long list includes foot-and-mouth disease (FMD), avian influenza (AI), and exotic Newcastle disease (END).

Agriculture is a relatively vulnerable economic sector that can be easily disrupted by a bioterrorist attack, in part because of vertical integration in production (Cupp, Walker, and Hillison 2004), although the poultry sector is much more integrated than the animal sector.. During the natural outbreak of FMD in the United Kingdom in 2001, about 6.9 million animals had to be slaughtered either for disease control or to mitigate losses to farmers because of an animal movement ban (Thompson et al. 2002). The economic losses to agriculture and the food chain were estimated to be about £3.1 billion, with tourism suffering losses of a similar amount (Thompson et al. 2002). Beyond these economic losses, there was also considerable institutional disruption. National elections had to be postponed and the Ministry of Agriculture, Fisheries and Food was replaced by the Department of the Environment, Food and Rural Affairs after the FMD outbreak (Manning, Baines, and Chadd 2005).

The costs of disruption in agricultural and related sectors are amplified where export markets are large. Non-FMD endemic countries will normally prevent transmission of the virus by not permitting importation of livestock or animal products from countries subject to FMD, vaccinating herds after an outbreak is known to have occurred (strict protocols may govern vaccination practices; see OIE 2006, chap. 2.1.1, Section D), and interrupting transmission by destroying the host (Blackwell 1980). It is likely that foreign importers would totally shutdown the imports of related agricultural products when a highly contagious disease is identified. This is why impacts on export markets are much deeper and prolonged than the impacts on domestic demand. For instance, the discovery of bovine spongiform encephalopathy (BSE, also known as Mad Cow Disease) in a Canadian-born dairy cow in the state of Washington caused major beef importing countries to immediately impose a ban on U.S. beef products, resulting in a 90 percent drop in exports (Park, Park, and Gordon 2006). Restrictions on access to international markets affect agriculture throughout the national economy, beyond the region where the outbreak occurred.

This article presents estimates of state-by-state economic impacts of a hypothetical bioterrorist attack using FMD pathogens. FMD is one of the highest priority animal diseases because it can be easily disseminated and has the potential for catastrophic economic disruption. FMD is a highly contagious viral disease that affects cloven-hoofed animals such as cattle, swine, sheep, goats, and deer. It can be transmitted not only by direct contact but also via air and even inanimate objects such as animal byproducts, water, and straw (Federal Inter-Agency Working Group 2003, 3). Terrorists can easily disseminate the FMD virus by introducing a single piece of contaminated meat or sausage to a farm or feed lot (State of Minnesota 2002).

The economic costs inflicted by intentional dissemination of FMD pathogens could be very high. Ekboir (1999) estimated the cost of an FMD epidemic in California to be $4.5 to $13.5 billion. We estimate the economic impacts across the U.S. states by applying our National Interstate Economic Model (NIEMO), a multiregional input output (MRIO) model. The next section includes a discussion of the analytical framework and NIEMO, followed by the description of a hypothetical FMD attack. Following this, we provide estimates of direct operational costs and predictions of potential demand changes in both domestic and export red meat markets, which we use as input data to estimate total economic impacts via NIEMO. A short conclusion and discussion follows the economic impact estimates.

Analytical Framework for Economic Impact Analysis and NIEMO

We conduct the economic impact analysis of a hypothetical FMD attack in four steps. First, we adopt a plausible scenario for a hypothetical FMD outbreak. This scenario includes the location of the attack, simulation of the epidemic, and the emergency response. These determine the magnitude of direct damages.

Second, based on this scenario, direct operational costs are estimated. These include:

- the costs of killing and disposing of animals,
- compensation payments to owners of slaughtered animals,
- cleaning and disinfection costs, and
- the costs of quarantine enforcement.

While most previous studies stop at estimating these operational costs, we attempt to estimate the possible dual impacts of the resources directed to these hazard mitigation activities. On one hand, these operational costs draw resources away from the U.S. economy that could have been placed in other productive uses. Assuming that most of expenditures on hazard mitigation services come from the Federal government, we model the associated negative impact as reduced purchasing power by households (taxpayers). The resources employed in the hazard mitigation activities might have a stimulus effect on the corresponding economic sectors. Consequently, we estimate the net effects throughout the economy within the MRIO framework.

The third step inquires into the disruptions of domestic and export demands of U.S. red meat-related products. Because there have been no domestic FMD incidents since 1929, we draw on other historical outbreaks of animal diseases to suggest plausible consumer behavior responses. We considered the aftermaths of the 2001 FMD outbreak in the United Kingdom and the 2003 BSE case in the United States.

Finally, we use NIEMO to estimate total economic impacts including indirect impacts. We have recently developed and applied NIEMO to estimate the impacts of various natural and man-made disasters. While many types of economic approaches, including benefit-cost analysis, single-region I–O modeling, social accounting models, partial equilibrium models, and computable general equilibrium (CGE) models, are available for estimating economic impacts of animal diseases (Rich, Miller, and Winter-Nelson 2005; Rich, Winter-Nelson, and Miller 2005), none of these tools provides the national economic impacts at the level of individual states. We have chosen to use an MRIO model to highlight the fact that an FMD outbreak confined to a single state would have nationwide economic impacts, differentially distributed across state borders.

We briefly introduce our model NIEMO because the details of the model are explained elsewhere (Park et al. 2007). NIEMO is currently the only operational MRIO model of the United States. The main building blocks were the Minnesota IMPLAN Group's 509-sector input–output models for each of the fifty states (and the District of Columbia) and the 1997 and 2002 U.S. Commodity Flow Surveys. A large part of the work involved defining a set of industrial sectors that could reconcile these and other data sources. We designate the resulting 47-sector system "the USC Sectors." NIEMO has been applied in a variety of economic impact studies (Richardson et al. 2007; Park et al. 2007).

The following paragraphs and equations summarize the model. The traditional Leontief demand-side model is expressed as,

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1} \bullet \mathbf{Y}. \tag{1}$$

Where $\mathbf{X}$ is the $m \times 1$ total output vector for m sectors, $\mathbf{Y}$ is the $m \times 1$ vector of final demands from private consumers, governments, investments, and net exports of outputs from m sectors, and $\mathbf{A}$ is the $m \times m$ matrix of technical coefficients, which captures interindustry relationships in terms of backwards linkages between m sectors.

The inverse matrix in equation (1) is referred to as the demand-driven IO model. The demand driven version of NIEMO can be expressed similarly as,

$$\mathbf{X}_{\text{NIEMO}} = (\mathbf{I} - \mathbf{W})^{-1} \bullet \mathbf{Y}_{\text{NIEMO}}. \tag{2}$$

Where $\mathbf{X}_{\text{NIEMO}}$ is the $nm \times 1$ total output vector for USC sectors $m(= 1, ..., 47)$ in each region $n(= 1, ..., 52)$, $\mathbf{Y}_{\text{NIEMO}}$ is the $nm \times 1$ vector of region-specific final demands and foreign exports, and $\mathbf{W}$ is an $nm \times nm$ matrix that combines technical coefficients with coefficients describing interregional trade flows.

The matrix $\mathbf{W}$ is defined as,

$$\mathbf{W} = \mathbf{C}_{\text{NIEMO}} \bullet \mathbf{A}_{\text{NIEMO}}. \tag{3}$$

Where $\mathbf{A}_{\text{NIEMO}}$ is block diagonal matrix of technical coefficients linking input commodities to output industries within each region $n(= 1, ..., 52)$, and $\mathbf{C}_{\text{NIEMO}}$ is an $nm \times nm$ collection of diagonal matrices describing interregional trade flows. The matrix $\mathbf{C}_{\text{NIEMO}}$ is defined as,

$$\mathbf{C}_{\text{NIEMO}} = \mathbf{C} \bullet (\hat{\mathbf{C}}_{\mathbf{R}})^{-1}, \tag{4}$$

Where $\mathbf{C}$ is an $nm \times nm$ matrix of trade flows, and $\hat{\mathbf{C}}_{\mathbf{R}}$ is an $nm \times nm$ matrix formed by diagonalizing the $1 \times nm$ row vector $\mathbf{C}_{\mathbf{R}}$, consisting of the column sums of $\mathbf{C}$.

Note that we identify losses of foreign exports and final demands losses or gains as different types of direct impacts and that these vary across scenarios. Foreign exports losses and government expenditures define a region-specific vector of direct impacts. Final demand losses or gains define vectors of regionally distributed direct impacts. Our scenarios involve two mechanisms for distributing impacts across regions. First, we use the standard MRIO procedure to distribute calculated, region-specific final demand impacts across states,

$$\mathbf{Y}'_{\text{NIEMO}} = \mathbf{C}_{\text{NIEMO}} \bullet \mathbf{Y}_{\text{NIEMO}}, \tag{5}$$

Distributing final demand losses resulting from the complete elimination of activity in a given sector is more complicated. This requires modifying the commodity trade coefficients matrix $\mathbf{C}_{\text{NIEMO}}$ to delete domestic exports from the quarantine area, in this case California. We set the entries for the California row vector describing USC Sector 1 *Live animals and fish, meat, seafood* in the matrix $\mathbf{C}_{\text{NIEMO}}$ to zero. In addition, outbound California flows from this sector are redistributed to origins in other states based on existing flow proportions. This defines a modified matrix $\mathbf{C}_{\text{MOD.NIEMO}}$ that is used to allocate final demand losses.

$$\mathbf{Y}'_{\text{MOD.NIEMO}} = \mathbf{C}_{\text{MOD.NIEMO}} \bullet \mathbf{Y}_{\text{NIEMO}}. \tag{6}$$

This provides three types of direct impacts: region-specific direct impacts $\Delta\mathbf{Y}_{\text{NIEMO}}$ and, via equations (5) and (6), regionally distributed impacts $\Delta\mathbf{Y}'_{\text{NIEMO}}$ and $\Delta\mathbf{Y}'_{\text{MOD.NIEMO}}$. Total economic impacts are obtained as

$$\Delta \mathbf{X}_{\text{NIEMO}} = (\mathbf{I} - \mathbf{W})^{-1}\Delta \mathbf{Y}_{\text{NIEMO}} + (\mathbf{I} - \mathbf{W})^{-1}\Delta \mathbf{Y}'_{\text{NIEMO}} + (\mathbf{I} - \mathbf{W})^{-1}\Delta \mathbf{Y}'_{\text{MOD.NIEMO}}$$
$$= (\mathbf{I} - \mathbf{W})^{-1}[\Delta \mathbf{Y}_{\text{NIEMO}} + \Delta \mathbf{Y}'_{\text{NIEMO}} + \Delta \mathbf{Y}'_{\text{MOD.NIEMO}}]. \quad (7)$$

FMD Outbreak Scenario and Operating Costs

Our economic impact study is based on a hypothetical FMD outbreak scenario in which a terrorist group spreads the FMD virus into California's South San Joaquin Valley, which consists of key agricultural counties of Fresno, Kings, Tulare, and Kern. Rather than conducting our own epidemic simulations, we have chosen to depend on the results of the FMD study by Ekboir (1999). We use his epidemiological scenario and estimates of direct operating costs, but we focus on estimating total economic impacts by state. We should point out that a simultaneous attack on several states is both feasible and likely, so that the impacts that we measure here could easily be magnified.

We use the results of Ekboir's scenario 1 simulation in which he assumed

- high dissemination rates,
- no depopulation of latent infections, and
- 90 percent of infectious herds eliminated each week.

In this scenario, all herds in the South Valley are infected in four weeks and are destroyed by the end of sixth week, although the FMD disease is successfully contained within the quarantined area. This scenario presents the most serious but probable outcome among his seven suggested simulations.

Even in the event that some proportions of the animals in the region are not infected, the animals could be slaughtered as a precaution in exchange for government compensation. Vaccination is normally only undertaken as a prophylactic step in countries where an outbreak has yet to occur (Bates, Thurmond, and Carpenter 2003); and sometimes as part of a coordinated, long-term eradication strategy (Leforban 1999). In the aftermath of the 2001 FMD outbreak in the United Kingdom, about 2.6 million animals were slaughtered to minimize economic losses of farmers because of movement restrictions on their livestock, while about 4 millions were killed for so-called humane slaughter, a euphemism (Thompson et al. 2002). However, in our analysis the number of slaughtered animals is not the most critical factor in economic loss estimations because the major costs of an FMD outbreak are from reduced domestic and international demands for U.S. meat products. These reductions are almost independent of the number of slaughtered animals.

Ekboir (1999) also provides an estimate of direct operating costs across three categories:

- compensation payments to producers for slaughtered animals,

Table 1. Compensation Payments for Slaughtered Animals

	Number of Herds Destroyed	Animals Per Herd	Number of Animals Killed	Compensation per Herd ($1,000)		Compensation Costs ($1,000)
				Destroyed Feed	Destroyed Animals	
Large dairies	175	2,000	350,000	619.6	2,648.2	571,872
Small dairies	441	500	220,500	151.1	662.1	358,618
Feedlots	15	15,000	225,000	1,002.7	14,896.3	238,484
Large pig operations	23	500	11,500	27.6	60.7	2,030
Backyard operations	1,001	1	1,001	–	0.1	121
Total			808,001			1,171,126

Source: Ekboir (1999).
Note: 1. All dollar values are adjusted to 2001 dollars using the Consumer Price Index for all urban consumers (CPI-U).
2. There are no significant cow-and-calf operations in California.
3. Our research results include the costs of killing and disposing of animals. Ekboir does not estimate these costs.

- cleaning and disinfection costs, and
- the costs of quarantine enforcement.

We use his estimates as direct impacts after adjusting to 2001 dollars (2001 was chosen because this is the year of our input–output (IO) data using the Consumer Price Index for all urban consumers (CPI-U). We use the urban consumer price index rather than a farm costs index because many of the indirect and induced impacts are related to urban consumption spending In the current U.S. FMD emergency response plan, farmers expect to be paid a fair market value for all slaughtered animals (Mathews and Janet 2003). Table 1 shows compensation cost estimates by farm types. Table 2 contains cleaning and disinfection costs, including the costs of disinfectants and pesticides, and wages for the cleaning and disinfection crews. In addition, the cost of quarantine enforcement to maintain 300 checkpoints through 120 quarantine days after slaughtering the last exposed animal was estimated to be $286.9 millions.

Final Demand Changes in the Market for Red Meat

We expect that major economic losses from agroterrorism events would occur from consumers' responses in produce markets, especially from abroad. Domestic demand for red meats will probably be affected first, though some proportion of the reduced domestic demand for red meats could be substituted by increasing consumption of poultry. Although FMD is known to not be harmful to human health, it is

Table 2. Costs of Cleaning and Disinfection

	Number of Herds	Cost per Herd ($1,000)	Cleaning and Disinfection Costs ($1,000)
Large dairies	175	150.9	26,405
Small dairies	441	90.8	40,022
Feedlots	15	148.7	2,231
Large pig operations	23	102.5	2,358
Backyard operations	1,001	35.6	35,676
Processing plants	27	449.5	12,138
Total			118,829

Source: Ekboir (1999).
Note: All dollar values are adjusted to 2001 dollars using the Consumer Price Index for all urban consumers (CPI-U).

quite possible that people would choose to avoid or reduce red meat consumption. People tend to neglect the odds and are likely to show excessive risk aversion in cases of terrorism when intense emotions are involved (Sunstein 2003). Further, U.S. consumers were not able to distinguish FMD from BSE during the 2001 FMD outbreak in the United Kingdom (Paarlberg, Lee, and Seitzinger 2002).

Second and more importantly, many countries importing U.S. livestock and red meat products are likely to impose trade restrictions. While the impacts on domestic demand can perhaps be mitigated by government efforts, the demand shocks on exports are totally exogenous. The U.S. red meat industries are likely to suffer an extended ban on foreign exports, regardless of the size of the FMD outbreak.

While the direction of changes in consumer behavior and demands can easily be predicted, it is less simple to quantify the magnitudes of these changes. Given that there has been no historic FMD outbreak in the United States since 1929, the 2001 FMD outbreak in the United Kingdom and the 2003 BSE case in the United States provide the best set of comparisons.

U.K. FMD Outbreak in 2001

In the United Kingdom, FMD cases continued from February 2001 to the end of September 2001. Disease-free status was declared on January 2002 (Thompson et al. 2002). The FMD outbreak resulted in killing about 6.6 million animals, but only modestly affected domestic consumption of red meats in 2001 or in the following years (see Figure 1). Compared to the 1998–2000 average, total domestic consumption of red meats increased by 1.3 and 5.2 percent in 2001 and 2002, respectively. Public response to an intentional agroterrorist attack would like be much more intense than the reaction to this natural event. Further, a significant drop in beef consumption and increased consumption of poultry, a substitution effect, can be identified during the period after the BSE outbreak in 1992.

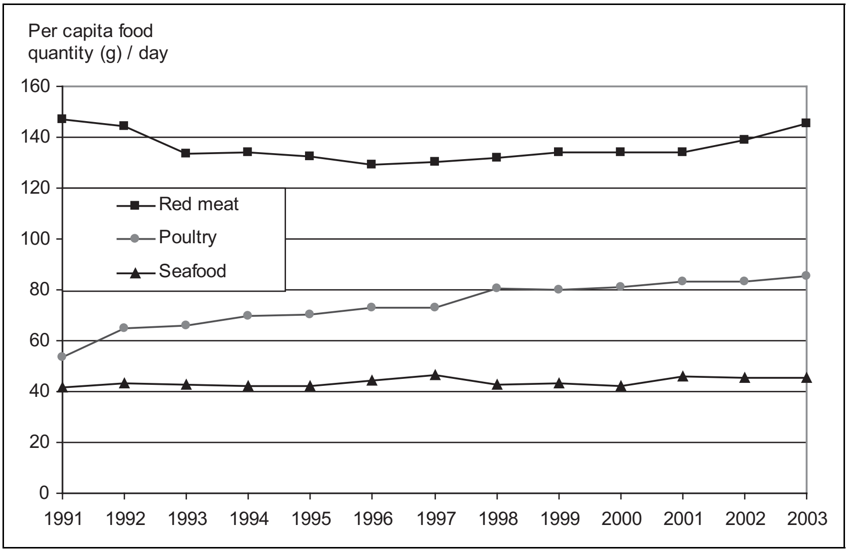

Figure 1. Per capita daily food consumptions in the United Kingdom, 1991–2003
Source: UN FAOSTAT. Statistical database by the Food and Agriculture Organization of the United Nations.

The exports of pig meats and sheep and goat meats sharply declined in 2001 and did not recover to the previous levels until 2002 (see Figure 2 and Table 3). Beef data are not relevant in this case because the export of bovine meat (beef) had dramatically declined since 1996, when the Spongiform Encephalopathy Advisory Committee (SEAC) announced a possible link between a new variant of Creutzfeldt-Jakob Disease (nvCJD) and BSE-infected beef (Caskie, Davis, and Moss 1999). Despite the partial reduction of the export ban later, U.K. beef exports remained at levels between 4 and 11 percent of their 1995 peak ($863 millions) until 2004.

U.S. BSE Outbreak in 2003

On December 23, 2003, it was made public that a Canada-born dairy cow in the state of Washington had tested positive for BSE. As in the U.K. FMD outbreak, beef exports collapsed while domestic consumption was barely affected. The FAOSTAT (Food and Agriculture Organization Statistical Database) of the United Nations indicated that beef exports declined by 81 and 71 percent in 2004 and 2005, respectively, compared to the level of the early 2000s (Table 4). The BSE impact on beef exports was particularly large because high-quality international beef markets account for the largest shares of U.S. beef exports. Japan and Korea, which had imported 56 percent of U.S. beef exports in 2003 completely ceased any imports of beef and related products immediately after the BSE discovery (Coffey et al. 2005).

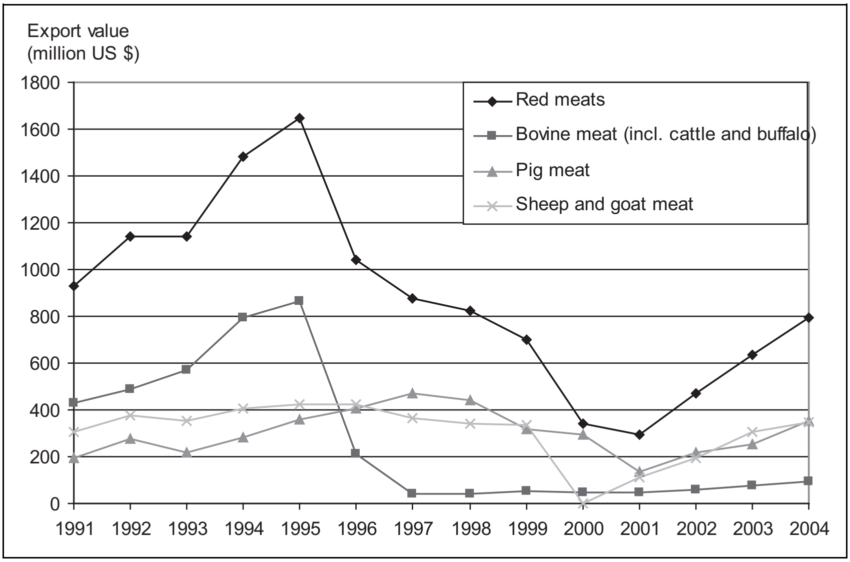

Figure 2. Trends in U.K. export of red meats, 1991–2004. Source: UN FAOSTAT.

Table 3. U.K. Export of Red Meats, 1997–2002

Export (Million U.S. $)	1997–1999 Average	2001	2002	Change 2001	Change 2002
Red meat	800.27	296.59	473.52	−62.9%	−40.8%
Bovine meat (including cattle and buffalo)	43.06	49.52	60.46	15.0%	40.4%
Pig meat	409.68	135.53	218.57	−66.9%	−46.6%
Sheep and goat meat	347.54	111.54	194.49	−67.9%	−44.0%

Source: UN FAOSTAT.

Table 4. Domestic Consumption and Export of Red Meats in the United States, 2001–2005

Meat, Beef, and Veal (1,000 MT CWE)	2001–2003	2004	2005	Change 2004	Change 2005
Domestic consumption	12,476	12,667	12,666	1.5%	1.5%
Exports	1,094	209	313	−80.9%	−71.4%

Note. MT = Metric ton; CWE = Carcass Weight Equivalent.
Source: UN FAOSTAT.

Assumptions for Domestic and Foreign Demands for U.S. Red Meats

Given the difficulty of accurately predicting changes in domestic consumer behavior, we decided to adopt a range of estimates. We tested four scenarios combining assumptions about changes in foreign export and domestic demand for U.S. red meats.

Scenario 2 is our base scenario, in which we assume an 80 percent reduction in foreign export demand but no change in domestic demand. We have treated the 81 percent decline in beef exports in the 2003 U.S. BSE case as our upper bound of foreign demand loss. This reflects our conservatism; a referee suggested that a 100 percent loss is more likely. It should be pointed out that although FMD, unlike BSE, is not a direct threat to human health, it is a far more contagious disease. Scenario 1 represents a lower bound of foreign export demand loss, 65 percent. In 2001 in the United Kingdom, FMD impacts on pig, sheep, and goat meat were about 67 percent. We expect that FMD impact in the United States would be larger because of the strict standards previously demonstrated by the major importers of U.S. beef.

In Scenarios 3 and 4, we adopt the same assumptions as previous studies and assume a 10 percent reduction in domestic demand for red meats and a 10 percent increase of poultry demand as a substitute (Paarlberg, Lee, and Seitzinger 2002; Devadoss et al. 2006) in addition to the export demand losses associated with Scenarios 1 and 2. Results from a CGE study of the 2003 BSE case (Devadoss et al. 2006) showed that a 10 percent reduction in beef consumption induced households to substitute consumption of 7.1 percent more pork and 5.5 percent poultry, respectively. Paarlberg, Lee, and Seitzinger (2002) is also an FMD study, while the Devadoss et al. (2006) study focuses on BSE, which affects only beef. In the case of FMD, the substitute effect toward poultry is higher because of reductions in demand for both beef and pork.

Estimates of Total Economic Impacts

We estimated state-by-state economic impacts including indirect effects via a MRIO framework, implementing NIEMO. All the direct impacts that drive the model are summarized in Table 5. While we have four different scenarios for red meat demand changes, we treat operating costs in the same way for all four scenarios.

We attempt to capture both the positive and the negative economic impacts of operating costs. First, California's expenditures on decontamination and quarantine activities enter the model as increased final demands for corresponding industrial sectors such as veterinary services (IMPLAN sector 449) and environment and other technological consulting services (IMPLAN sector 445). However, compensation costs for indemnity reflect a wealth loss to the economy. Second, Federal spending on these activities and indemnity compensation will be paid for by taxpayers nationwide and will ultimately reduce household consumption. Thus, we model all operating

Table 5. Summary of Direct Impacts

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Meat Demand Changes				
Foreign exports of red meats	−65%	−80%	−65%	−80%
Domestic demand for red meats			−10%	−10%
Domestic demand for poultry			+10%	+10%
Operational costs				
Compensation costs	−$ 1,171.126 millions × 1.05 reduction in overall household expenditures			
Cleaning and decontamination	−$ 118.829 millions × 1.05 reduction in overall household expenditures +$ 118.829 millions in environment consulting and in waste and disposal services in California			
Quarantine costs	−$ 286.9 millions × 1.05 reduction in overall household expenditures +$ 286.9 millions in veterinary services in California			

Note: a. The lower bound for the decrease in foreign exports (65%) is drawn from the 2001 FMD case in the United Kingdom.
b. The upper bound for the decrease in foreign exports decrease (80%) is based on the 2003 BSE case in the United States.
c. Compensation payments are paid to farmers as are most of the quarantine cost reimbursements. Cleaning and decontamination costs are also shared but primarily borne by the public sector.
d. The decrease in domestic demand for red meats and the increase in poultry demand are based upon the results of a CGE study by Devadoss et al. (2006).

costs as reduced household spending. We used the expenditure pattern of households in the $35,000–$50,000 income bracket to which median household income belongs.

In modeling operating costs, it is important to consider the social costs of taxation that incur when transferring purchasing power from taxpayers to governments (Slemrod and Yitzhaki 1996). In broad terms, the costs broadly consist of administrative, compliance, and deadweight losses (Tran-Nam et al. 2000). In the interests of conservatism, we consider only the operating costs of taxation, including the administrative costs of collecting taxes and compliance costs incident to taxpayers. The magnitude of these costs is less controversial than the deadweight losses resulting from additional taxation.

A survey of empirical estimates (Evans 2003) shows that compliance costs are typically a multiple of administration costs. The compliance costs of the U.S. income tax in 1982 were estimated to range from 5 to 7 percent of the revenue (Slemrod and Sorum 1984). The administrative and compliance costs of the U.K. income tax were estimated to be 2.3 and 3.6 percent, respectively (Sandford et al. 1989). The operating costs associated with the Canadian income tax amounted to about 7 percent of revenue in 1986 (Vaillancourt 1989). We use an intermediate value of 5 percent to account for the operating costs of taxation. Thus, we reduce household

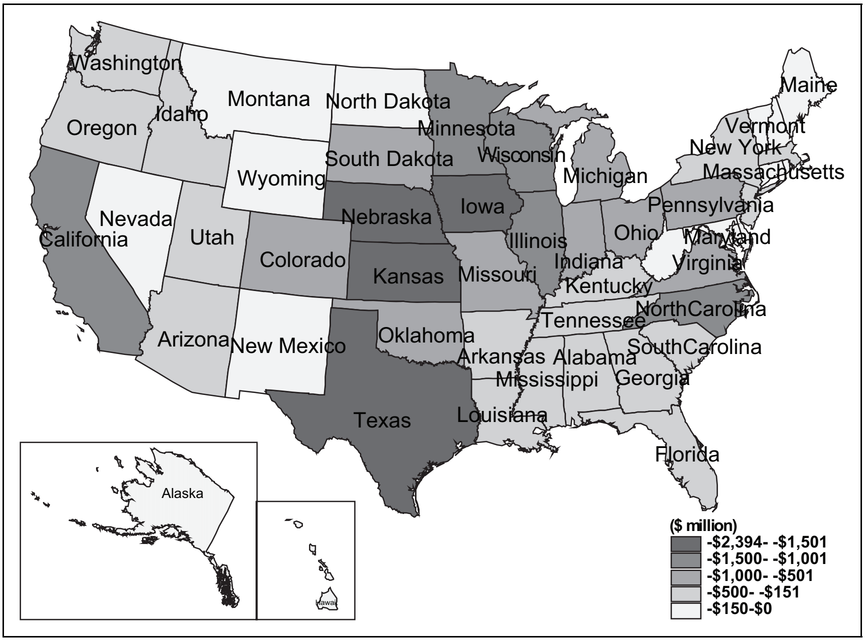

Figure 3. Total economic impacts by state (scenario 2).

consumption (final demand) by $1.05 for each dollar the government expends on FMD hazard mitigation activities.

The direct losses in the final demand for red meat and the associated substitution effects in each of the four scenarios are estimated using 2001 IMPLAN data. The affected IMPLAN sectors are sectors 11, 13, 67, 68, and 69 in the case of red meat and sectors 12 and 70 in the case of poultry (that benefits from reduced red meat consumption). These industries are represented in NIEMO by two of the 47 USC, Sector 1 *Live animals and fish, meat, seafood*, and their preparation, and Sector 5 *Other prepared foodstuffs and fats and oils*. Note that we attempt to eliminate any residual impacts of the 2003 BSE effects using 2001 data.

All these direct impacts are distributed by state as explained in Figure 3 and in Appendix A1 and applied as inputs to the demand-side version of NIEMO to estimate indirect impacts resulting from backward economic linkages. We believe that demand-side impacts would dominate supply-side impacts that might originate from any shortage of livestock due to animal slaughter.

We also assume that there is little demand-side impact in dairy markets. However, our estimation of total economic impacts may omit important supply-side impacts incident to dairy industries. As of 2002, California and the four-county South San Joaquin Valley area accounted for about 21 and 9 percent of total U.S. milk production, respectively. Thus, the FMD outbreak in our scenario would disrupt about 10 percent of total U.S. milk production for about one year. The loss in milk production would lead to supply constraints if other regions cannot increase milk production capacity quickly and hence reduced production of other dairy products such as cheese and butter. These economic impacts resulting from forward economic linkages associated with milk production could be estimated using a supply-side IO model.

Our results for Scenario 2 are summarized in Figure 3 and in Tables A2 and A3. Total economic impacts range from just under $23 billion to just over $34 billion. The overwhelming sources of the losses are due to domestic and international demand cuts. Although the scenario outbreak occurs in California, all of the major farm states are hit hard.

Discussion and Conclusions

Our results describe at the state level the nationwide costs of an agroterrorism event in California. These results suggest that the economic impacts of a hypothetical agroterrorism event using FMD pathogens could be large and nationwide. This implies the importance of cooperation between federal and state governments and among state governments to limit the possibility of an attack or at least its effects. Our results benchmark what various states should be willing to pay to avoid a successful attack in California.

What might be done by the federal government? Agroterrorism is not classified as one of the weapons of mass destruction (WMD) under current federal law (Cupp, Walker, and Hillison 2004), but the results of this economic impact study illustrate and elaborate the point that the losses from such an attack could be widespread and substantial. Recent federal legislation introduced by U.S. Senators Burr (R-North Carolina) and Collins (R-Maine, 2007) focuses on reinforcing the existing U.S. Department of Agriculture Regional Emergency Animal Disease Eradication Organization (READEO) approach (Bowman and Arnoldi 1999) by clarifying lines of authority and improving coordination in the event of an agroterrorism attack but falls short of Cupp et al.'s recommendation to classify weaponized pathogens as WMD. However, as in much of the research on the economic impacts of disasters, the results and their policy implications vary little, regardless of whether the disaster is natural or man-made. We applied the terrorist example because of our association with counterterrorism research, although we have also applied this and related models to Hurricane Katrina and earthquakes.

Primarily because of the impact of a sizeable FMD attack/epidemic on U.S. meat export revenues, the economic costs would be substantial. Other studies of terrorist attacks (e.g., a radiological device planted at the Los Angeles-Long Beach seaports, a conventional bomb attack at a theme park or in a major Downtown, the shooting down of an airplane with a rocket-propelled grenade, or the effects of 9/11) have also indicated very high costs. One argument is that the public and private costs of preventing the full range of potential terrorist attacks would be impossible to cover.

Preventive measures to avoid a man-made FMD attack would be especially difficult because of the large number of target locations so a plausible strategy might be to focus more on mitigation and recovery.

Our approach provides an initial means of measuring the nationwide costs of state-specific attacks. However, state-level impacts are likely to be similar for any event that leads to a substantial loss of overall export demand for U.S. red meat. An attack in Texas would produce a pattern of state-level impacts that is somewhat different from the pattern associated with the California scenario because trade flows between Texas and the rest of the United States are different from the trade flows between California and the rest of the United States, and NIEMO accounts for this. However, both scenarios would be similar in terms of state-level impacts because of large-scale export losses. Figure 3 shows that the main losses are in Texas, Kansas, Iowa, and Nebraska even in the event of a distant attack (or epidemic) in California. The explanation, of course, is export losses not direct epidemic costs. If there is a federal strategy that can reduce the likelihood of export losses, the benefits could be substantial. Transparent inspection and processing procedures might also limit the extent of any foreign boycott of U.S. beef exports.

Linear models such as NIEMO do not capture many realistic market adjustments and can overstate impacts. Prices are not present in these models, and the adjustments induced by equilibration of prices are unaccounted for. However, in an attempt to deal with price-substitution effects, there is a model currently under development, we call it FlexNIEMO, which could address this issue. On the other hand, we have not attempted to model possible behavioral changes associated with the psychological impacts on the general population. This is outside our field of expertise. But these changes would certainly amplify the costs. We have also been conservative in other respects. For example, we ignore the impacts of supply-side constraints and the deadweight losses of additional taxation to fund government responses. These would also increase the cost estimates. The hope is that possible overestimates and underestimates associated with our approach roughly balance and that the results provide a reasonable benchmark for total costs and their incidence with respect to geography and economic sectors.

Appendix

Table A1. Direct Impacts by Scenario and State ($Millions)

	Changes in Demands for Meats by Scenario				Operational Costs[a]	
State	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Reduced Household Consumption	Federal Expenditures
Alabama	−37.982	−46.747	−111.620	−120.385	−22.417	0
Alaska	−0.801	−0.986	−22.318	−22.503	−4.243	0
Arizona	−55.067	−67.775	−69.671	−82.379	−26.085	0
Arkansas	−58.372	−71.842	−133.829	−147.300	−12.680	0
California	−244.309	−300.687	−325.827	−382.206	−207.367	405.729
Colorado	−217.135	−267.243	−254.745	−304.853	−28.957	0
Connecticut	−8.299	−10.214	−18.004	−19.919	−23.438	0
Delaware	−1.280	−1.575	−20.443	−20.738	−4.541	0
District of Columbia	−0.079	−0.097	−0.877	−0.896	−11.200	0
Florida	−68.154	−83.882	−122.850	−138.578	−86.338	0
Georgia	−105.416	−129.743	−208.500	−232.827	−47.405	0
Hawaii	−7.189	−8.848	−10.164	−11.823	−6.505	0
Idaho	−67.490	−83.064	−81.247	−96.821	−6.574	0
Illinois	−450.576	−554.555	−537.471	−641.450	−73.210	0
Indiana	−121.322	−149.320	−173.656	−201.653	−32.766	0
Iowa	−796.413	−980.200	−890.423	−1074.210	−16.146	0
Kansas	−561.595	−691.194	−618.586	−748.185	−16.122	0
Kentucky	−116.134	−142.934	−162.525	−189.325	−23.246	0
Louisiana	−39.762	−48.938	−69.827	−79.002	−22.034	0
Maine	−7.367	−9.067	−17.800	−19.500	−6.282	0
Maryland	−12.601	−15.509	−44.048	−46.956	−36.887	0
Massachusetts	−23.578	−29.019	−50.530	−55.971	−43.048	0
Michigan	−122.327	−150.556	−164.006	−192.235	−60.284	0
Minnesota	−233.695	−287.624	−301.507	−355.437	−30.726	0
Mississippi	−100.202	−123.325	−154.546	−177.670	−13.324	0
Missouri	−126.949	−156.245	−191.867	−221.163	−32.505	0
Montana	−14.357	−17.670	−19.928	−23.241	−4.530	0
Nebraska	−727.223	−895.044	−811.812	−979.633	−9.706	0
Nevada	−3.713	−4.570	−7.655	−8.512	−11.441	0
New Hampshire	−5.659	−6.965	−11.606	−12.912	−7.216	0
New Jersey	−45.959	−56.565	−76.504	−87.110	−51.309	0
New Mexico	−12.749	−15.692	−21.979	−24.921	−9.858	0
New York	−53.054	−65.298	−108.169	−120.412	−114.853	0
North Carolina	−356.602	−438.895	−482.628	−564.921	−45.490	0
North Dakota	−14.110	−17.366	−20.096	−23.353	−3.582	0
Ohio	−122.482	−150.747	−180.974	−209.239	−64.024	0
Oklahoma	−183.996	−226.457	−224.704	−267.164	−17.876	0
Oregon	−28.801	−35.448	−46.062	−52.708	−18.157	0
Pennsylvania	−233.088	−286.878	−309.539	−363.329	−68.795	0

(continued)

Table A1 (continued)

State	Changes in Demands for Meats by Scenario				Operational Costs[a]	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Reduced Household Consumption	Federal Expenditures
Rhode Island	−1.518	−1.869	−5.098	−5.449	−5.340	0
South Carolina	−43.155	−53.113	−75.275	−85.234	−20.696	0
South Dakota	−148.458	−182.718	−169.116	−203.376	−4.157	0
Tennessee	−95.428	−117.450	−138.513	−160.535	−30.481	0
Texas	−616.751	−759.078	−786.729	−929.056	−124.702	0
Utah	−54.840	−67.496	−66.401	−79.056	−10.832	0
Vermont	−3.879	−4.775	−6.614	−7.510	−3.234	0
Virginia	−167.316	−205.928	−233.365	−271.976	−54.475	0
Washington	−119.733	−147.364	−169.644	−197.275	−38.363	0
West Virginia	−7.584	−9.334	−19.245	−20.995	−8.553	0
Wisconsin	−240.128	−295.542	−304.882	−360.296	−30.467	0
Wyoming	0.000	−14.062	−5.015	−19.077	−3.233	0
Foreign	0.000	0.000	−201.474	−201.474	0	0
Total	−6,884.7	−8,487.5	−9,259.9	−10,862.7	−1,655.7	405.7

Note: a. While our four scenarios include different assumptions about changes in the demand for meats, the same set of operating costs are applied to all scenarios.

Table A2. Total Economic Impacts by Scenario and State ($Millions)

State	Impacts from Changes in Demands for Meats				Impacts from Operational Costs	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Reduced HHs Consumption	Federal Expenditures
Alabama	−208.600	−256.738	−393.048	−441.186	−40.954	0.261
Alaska	−25.435	−31.305	−73.782	−79.652	−7.462	0.024
Arizona	−128.712	−158.414	−163.437	−193.140	−41.341	0.577
Arkansas	−306.765	−377.557	−522.013	−592.805	−24.680	0.238
California	−1032.497	−1270.765	−1343.324	−1581.593	−339.992	523.638
Colorado	−536.071	−659.780	−638.039	−761.748	−47.871	0.513
Connecticut	−30.442	−37.466	−51.614	−58.639	−37.616	0.163
Delaware	−16.413	−20.200	−59.522	−63.309	−8.063	0.054
District of Columbia	−2.554	−3.143	−4.515	−5.104	−16.410	0.027
Florida	−204.187	−251.307	−329.185	−376.305	−135.684	0.396
Georgia	−316.855	−389.975	−553.714	−626.834	−80.636	0.280
Hawaii	−23.752	−29.234	−32.310	−37.791	−10.446	0.049
Idaho	−194.922	−239.904	−240.659	−285.641	−11.720	0.102

(continued)

Table A2 (continued)

State	Impacts from Changes in Demands for Meats				Impacts from Operational Costs	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Reduced HHs Consumption	Federal Expenditures
Illinois	−1113.645	−1370.640	−1358.652	−1615.647	−127.779	0.828
Indiana	−366.965	−451.649	−508.690	−593.374	−61.618	0.499
Iowa	−1919.543	−2362.515	−2197.879	−2640.851	−31.220	0.361
Kansas	−1443.522	−1776.643	−1637.551	−1970.672	−30.538	0.298
Kentucky	−307.112	−377.984	−423.962	−494.835	−42.464	0.282
Louisiana	−164.156	−202.039	−252.925	−290.807	−43.289	0.628
Maine	−27.710	−34.105	−51.043	−57.438	−11.157	0.072
Maryland	−60.463	−74.415	−128.351	−142.304	−58.239	0.153
Massachusetts	−73.740	−90.757	−130.167	−147.184	−68.790	0.307
Michigan	−355.512	−437.553	−472.376	−554.418	−106.037	0.607
Minnesota	−776.765	−956.018	−984.720	−1163.974	−54.516	0.503
Mississippi	−341.675	−420.523	−503.681	−582.529	−24.582	0.133
Missouri	−482.248	−593.536	−674.043	−785.332	−56.752	0.440
Montana	−77.281	−95.115	−100.380	−118.213	−8.455	0.152
Nebraska	−1817.752	−2237.234	−2066.727	−2486.208	−19.034	0.173
Nevada	−17.447	−21.473	−27.325	−31.351	−17.875	0.121
New Hampshire	−17.514	−21.555	−30.547	−34.589	−12.137	0.088
New Jersey	−154.742	−190.451	−230.003	−265.713	−84.624	0.722
New Mexico	−64.789	−79.740	−94.038	−108.990	−16.870	0.060
New York	−216.540	−266.511	−348.042	−398.013	−179.266	1.046
North Carolina	−817.019	−1005.561	−1111.042	−1299.585	−79.187	0.416
North Dakota	−108.950	−134.092	−140.231	−165.373	−6.836	0.045
Ohio	−456.016	−561.250	−633.686	−738.920	−116.001	0.790
Oklahoma	−545.669	−671.593	−674.841	−800.764	−34.633	0.298
Oregon	−104.255	−128.314	−151.587	−175.646	−31.401	0.521
Pennsylvania	−585.944	−721.161	−787.791	−923.009	−120.564	0.719
Rhode Island	−10.253	−12.619	−18.885	−21.251	−8.874	0.045
South Carolina	−133.169	−163.900	−211.460	−242.191	−36.693	0.174
South Dakota	−407.753	−501.850	−474.621	−568.718	−7.758	0.048
Tennessee	−284.531	−350.192	−402.137	−467.798	−53.805	0.323
Texas	−1707.053	−2100.988	−2182.065	−2576.000	−227.345	2.895
Utah	−141.137	−173.706	−173.186	−205.756	−19.063	0.321
Vermont	−15.198	−18.705	−23.450	−26.957	−5.641	0.032
Virginia	−385.859	−474.904	−538.542	−627.586	−88.173	0.195
Washington	−316.742	−389.836	−435.888	−508.982	−64.300	1.013
West Virginia	−35.572	−43.781	−64.216	−72.424	−16.432	0.081
Wisconsin	−787.797	−969.596	−1001.170	−1182.969	−58.774	0.599
Wyoming	−57.488	−70.755	−75.255	−88.522	−6.278	0.047
U.S. subtotal	−19,726.7	−24,279.0	−25,726.3	−30,278.6	−2,839.9	542.4
Foreign	−795.8	−979.4	−1,246.7	−1,430.4	−76.7	5.2
Total	−20,522.5	−25,258.5	−26,973.0	−31,709.0	−2,916.6	547.6

Table A3. Direct and Total Economic Impacts by Scenario and State ($Millions)

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
State	Direct	Total	Direct	Total	Direct	Total	Direct	Total
Alabama	−60.40	−249.29	−69.16	−297.43	−134.04	−433.74	−142.80	−481.88
Alaska	−5.04	−32.87	−5.23	−38.74	−26.56	−81.22	−26.75	−87.09
Arizona	−81.15	−169.48	−93.86	−199.18	−95.76	−204.20	−108.46	−233.90
Arkansas	−71.05	−331.21	−84.52	−402.00	−146.51	−546.46	−159.98	−617.25
California	−45.95	−848.85	−102.33	−1087.12	−127.47	−1159.68	−183.84	−1397.95
Colorado	−246.09	−583.43	−296.20	−707.14	−283.70	−685.40	−333.81	−809.11
Connecticut	−31.74	−67.89	−33.65	−74.92	−41.44	−89.07	−43.36	−96.09
Delaware	−5.82	−24.42	−6.12	−28.21	−24.98	−67.53	−25.28	−71.32
District of Columbia	−11.28	−18.94	−11.30	−19.53	−12.08	−20.90	−12.10	−21.49
Florida	−154.49	−339.48	−170.22	−386.60	−209.19	−464.47	−224.92	−511.59
Georgia	−152.82	−397.21	−177.15	−470.33	−255.90	−634.07	−280.23	−707.19
Hawaii	−13.69	−34.15	−15.35	−39.63	−16.67	−42.71	−18.33	−48.19
Idaho	−74.06	−206.54	−89.64	−251.52	−87.82	−252.28	−103.40	−297.26
Illinois	−523.79	−1240.60	−627.76	−1497.59	−610.68	−1485.60	−714.66	−1742.60
Indiana	−154.09	−428.08	−182.09	−512.77	−206.42	−569.81	−234.42	−654.49
Iowa	−812.56	−1950.40	−996.35	−2393.37	−906.57	−2228.74	−1090.36	−2671.71
Kansas	−577.72	−1473.76	−707.32	−1806.88	−634.71	−1667.79	−764.31	−2000.91
Kentucky	−139.38	−349.29	−166.18	−420.17	−185.77	−466.14	−212.57	−537.02
Louisiana	−61.80	−206.82	−70.97	−244.70	−91.86	−295.59	−101.04	−333.47
Maine	−13.65	−38.80	−15.35	−45.19	−24.08	−62.13	−25.78	−68.52
Maryland	−49.49	−118.55	−52.40	−132.50	−80.93	−186.44	−83.84	−200.39
Massachusetts	−66.63	−142.22	−72.07	−159.24	−93.58	−198.65	−99.02	−215.67
Michigan	−182.61	−460.94	−210.84	−542.98	−224.29	−577.81	−252.52	−659.85
Minnesota	−264.42	−830.78	−318.35	−1010.03	−332.23	−1038.73	−386.16	−1217.99
Mississippi	−113.53	−366.12	−136.65	−444.97	−167.87	−528.13	−190.99	−606.98
Missouri	−159.45	−538.56	−188.75	−649.85	−224.37	−730.36	−253.67	−841.64
Montana	−18.89	−85.58	−22.20	−103.42	−24.46	−108.68	−27.77	−126.52
Nebraska	−736.93	−1836.61	−904.75	−2256.10	−821.52	−2085.59	−989.34	−2505.07
Nevada	−15.15	−35.20	−16.01	−39.23	−19.10	−45.08	−19.95	−49.11
New Hampshire	−12.87	−29.56	−14.18	−33.61	−18.82	−42.60	−20.13	−46.64
New Jersey	−97.27	−238.64	−107.87	−274.35	−127.81	−313.91	−138.42	−349.62
New Mexico	−22.61	−81.60	−25.55	−96.55	−31.84	−110.85	−34.78	−125.80
New York	−167.91	−394.76	−180.15	−444.73	−223.02	−526.26	−235.27	−576.23
North Carolina	−402.09	−895.79	−484.39	−1084.33	−528.12	−1189.81	−610.41	−1378.36
North Dakota	−17.69	−115.74	−20.95	−140.88	−23.68	−147.02	−26.93	−172.16
Ohio	−186.51	−571.23	−214.77	−676.46	−245.00	−748.90	−273.26	−854.13
Oklahoma	−201.87	−580.00	−244.33	−705.93	−242.58	−709.18	−285.04	−835.10
Oregon	−46.96	−135.14	−53.61	−159.19	−64.22	−182.47	−70.87	−206.53
Pennsylvania	−301.88	−705.79	−355.67	−841.01	−378.33	−907.64	−432.12	−1042.85
Rhode Island	−6.86	−19.08	−7.21	−21.45	−10.44	−27.71	−10.79	−30.08
South Carolina	−63.85	−169.69	−73.81	−200.42	−95.97	−247.98	−105.93	−278.71
South Dakota	−152.61	−415.46	−186.87	−509.56	−173.27	−482.33	−207.53	−576.43
Tennessee	−125.91	−338.01	−147.93	−403.67	−168.99	−455.62	−191.02	−521.28
Texas	−741.45	−1931.50	−883.78	−2325.44	−911.43	−2406.52	−1053.76	−2800.45
Utah	−65.67	−159.88	−78.33	−192.45	−77.23	−191.93	−89.89	−224.50
Vermont	−7.11	−20.81	−8.01	−24.31	−9.85	−29.06	−10.74	−32.57
Virginia	−221.79	−473.84	−260.40	−562.88	−287.84	−626.52	−326.45	−715.56
Washington	−158.10	−380.03	−185.73	−453.12	−208.01	−499.18	−235.64	−572.27
West Virginia	−16.14	−51.92	−17.89	−60.13	−27.80	−80.57	−29.55	−88.78
Wisconsin	−270.60	−845.97	−326.01	−1027.77	−335.35	−1059.34	−390.76	−1241.14
Wyoming	−14.66	−63.72	−17.30	−76.99	−19.67	−81.49	−22.31	−94.75
U. S. subtotal	−8,146.1	−22,024.2	−9,737.5	−26,576.6	−10,319.8	−28,023.8	−11,911.2	−32,576.2
Foreign	0.0	−867.2	0.0	−1,050.9	−201.5	−1,318.2	−201.5	−1,501.8
Total	−8,146.1	−22,891.5	−9,737.5	−27,627.4	−10,521.3	−29,342.0	−12,112.7	−34,078.0
Total multipliers		2.810		2.837		2.789		2.813

Authors' Note

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