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Measuring Welfare Effects of an FMD Outbreak in the United States

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Questions have been raised regarding the economic costs of a foot-and-mouth disease (FMD) outbreak in the United States. This analysis examines how welfare changes are measured and argues that they must be decomposed by groups. Producers with animals quarantined and slaughtered because of FMD measure their welfare change using lost sales. Producers not quarantined measure their welfare change using producer surplus. The change in national sales revenue is accurate when the supply elasticity is low. Welfare changes for consumers also must be decomposed because the change in aggregate consumer surplus hides important shifts in welfare among groups of consumers.

Key Words: economic effects, foot-and-mouth disease, livestock, meat

JEL Classifications: D60, Q13, Q17, Q18

The United States has been free of foot-and-mouth disease (FMD) since 1929, but the recent outbreaks in several nations prompted concern about the possible economic effects of a U.S. outbreak. Research estimating the effects of a U.S. FMD outbreak is limited. McCauley et al. performed a comprehensive study using the 1966–1967 U.K. outbreak as a guide. Ekboir examined the potential effects of an FMD outbreak in California and calculated a range of losses of \$8.5–\$13.5 billion. A substantial share of those estimated effects, \$6 billion, resulted from the assumption that U.S. meat exports would cease. Paarlberg, Lee, and Seitzinger determine the effects of an FMD outbreak in the United States similar to the 2001 outbreak in the United Kingdom. They estimate a U.S. farm income loss of \$14.0 billion and a reduction in national consumer expenditure of 7%.

One problem with the above estimates is that they are not measures of changes in economic well-being by agents from an FMD outbreak. For example, the reduction in consumer expenditure calculated by Paarlberg, Lee, and Seitzinger cannot be interpreted as a welfare gain for consumers because a substantial share of that reduction is a result of some consumers dropping red meat from their consumption bundle. Similarly, the loss in production value could misrepresent the change in economic well-being because some livestock growers have animals destroyed, whereas others do not.

This article investigates how decomposition of welfare changes for agents leads to more accurate measures of changes in national economic welfare for a livestock disease outbreak. It argues that there are substantial differences in welfare changes within groups usually treated as homogeneous for welfare analysis. Correct estimates of the economic effects of an animal disease outbreak and any

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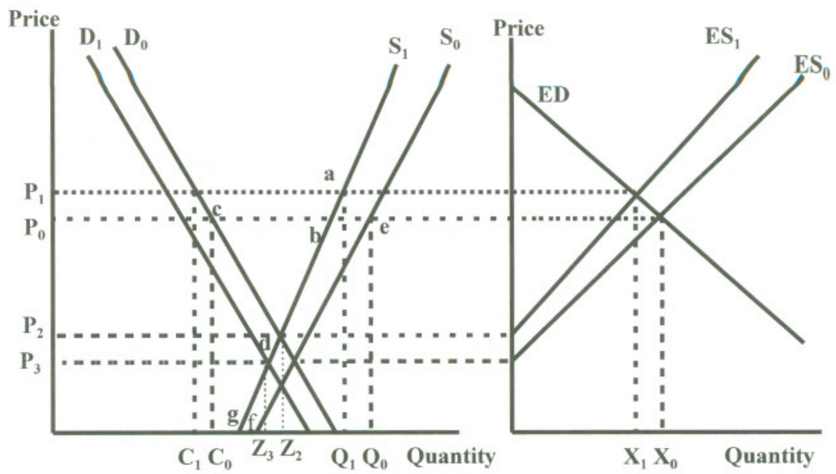

Figure 1. Economic Effects of an FMD Outbreak, Single Commodity

resulting compensation schemes must recognize such differences.

The article is divided into five sections. It begins with a simple conceptual model for a single commodity to demonstrate the effects of a livestock disease outbreak, then the effect on livestock producers is analyzed in detail, and measures of welfare changes for livestock growers are proposed. The third section focuses on consumer welfare changes. The fourth section presents a numerical model for beef used in the fifth section to illustrate the differences with conventional welfare analysis.

Conceptual Effects of an FMD Outbreak

Interpreting the numerical estimates presented later requires an understanding of what effects a simple economic model predicts because of an FMD outbreak. Figure 1 shows the United States as an exporter of a single good—beef.[1] Initial domestic U.S. demand and supply before the FMD outbreak are identified by the lines labeled D_0 and S_0, respectively. The difference between supply and demand gives the quantities available for export (excess supply), denoted as ES_0. The excess demand for U.S. beef is indicated by *ED*. Although the United States does impose tariff-rate quotas on beef imports, for clarity it is assumed in Figure 1 that the United States has no domestic or trade policy interventions.

Before the FMD outbreak, the equilibrium price, P_0, is determined where U.S. excess supply equals excess demand from the rest of the world (ROW). The initial quantity of beef consumed in the United States is C_0, and the quantity of meat supplied is Q_0. The quantity of beef exports, X_0, is the difference $X_0 = Q_0 - C_0$. Consumer surplus measures the difference between what consumers are willing to pay for each unit consumed and what they must pay and is the area of the triangle above the price and to the left of the demand. Producer surplus is a measure of rents to fixed inputs plus profits—the area below the price and to the left of the supply line.

Assume there is an FMD outbreak in the United States. This outbreak is decomposed into three separate potential effects. The first effect is the lost beef output from a control strategy of quarantine and slaughter, called stamping-out. Effect two is a total loss of beef exports from the assumption that the United States either embargoes beef exports or foreign buyers refuse to import beef from the United States. The third effect is a potential adverse consumer reaction to beef consump-

[1] The United States is an importer of some types of beef and an exporter of other types. Because one of the critical effects is the loss of export sales the graphical model focuses on exports only. Imports are ignored in Figure 1, but are considered in the numerical model.

tion. Although FMD is rarely transmissible to humans, consumers have reacted negatively to FMD outbreaks in other nations like Taiwan (Greene and Southard). Consumers in the United States have reacted negatively to other food issues like bovine somatotropin (BST) and genetically modified foods even when health risks are minimal or negligible (Bromley). There are livestock diseases like bovine spongiform encephalopathy (BSE) that have been linked to human diseases, and some consumers do not understand the difference between the human health risks posed by FMD and BSE.

Under stamping-out, the U.S. supply of beef is reduced—the U.S. supply shifts to the left to S_1. This reduces the U.S. excess supply, which shifts to ES_1. If this is the only effect, the price rises to P_1 and exports decline to X_1 with U.S. consumption and output falling to C_1 and Q_1. Consumers in the United States suffer a welfare loss because the higher price reduces consumer surplus. The change in welfare for producers in aggregate is complex (see Orden and Romano). There is a loss as the supply shifts—the area between S_0 and S_1 below P_0; yet, the price of beef is higher, so there is also a gain, shown as area P_0P_1ab. Normally these areas are measured and the change in total producer surplus indicates the change in producer welfare for the sector. Below, we argue that, for a livestock disease outbreak, the change in producer surplus from the aggregate U.S. supply relations does not accurately measure the effect on national producer welfare.

If the United States cannot export beef because of an FMD outbreak, U.S. price is determined where domestic demand equals domestic supply, falling to $P_2 < P_0$. The quantities produced and consumed match—point Z_2. Compared to the initial equilibrium, consumers benefit from the lower U.S. price, area P_0P_2cd. Producers lose welfare as both the price and quantity produced are lower, but the economic loss for beef producers still cannot be measured using producer surplus calculated from the national supply relationships S_0 and S_1.

If some consumers become fearful of eating beef because of the outbreak, the demand for beef shifts to the left to D_1 and the price falls further to P_3. The quantities consumed and produced are also lower—point Z_3. The producer welfare loss is magnified, whereas the change in consumer welfare is ambiguous. The price decline is a benefit, but the shift in demand causes the quantity consumed to be lower.

Change in Producer Welfare

Understanding why the national supply relation should not be used to measure the change in economic well-being of livestock growers during a disease outbreak requires an examination of producer surplus and recognizing that growers can no longer be treated as homogeneous. Producer surplus for an individual livestock grower is total revenue less payments to variable factors of production, with producer surplus for the sector the sum across producers. For a supply shift from S_0 to S_1, like that shown in Figure 1, the change in sector producer surplus is measured as $P_0P_1ab - befg$. That measure assumes that Q_1 is the output of the sector. However, the actual livestock output exceeds that level with total sales being Q_1. Nor does the difference $Q_0 - Q_1$ indicate the animals (meat) quarantined and slaughtered under the FMD control program because of the price response by producers with animals not quarantined and destroyed. The meat lost through quarantine and slaughter is shown as distance $b - e$ in Figure 1, which exceeds distance $Q_0 - Q_1$. Only when supply is perfectly inelastic will the output change match the removal of animals (meat).

Measuring the welfare change for producers requires dividing them into groups with separate supply relations. In Figure 2a, producers with animals that are not quarantined and slaughtered under the stamping-out policy are U-producers, with a supply denoted S_U. Panel 2b represents producers with animals that are quarantined and slaughtered because the animals either are infected with FMD or are in a control zone surrounding infected pre-

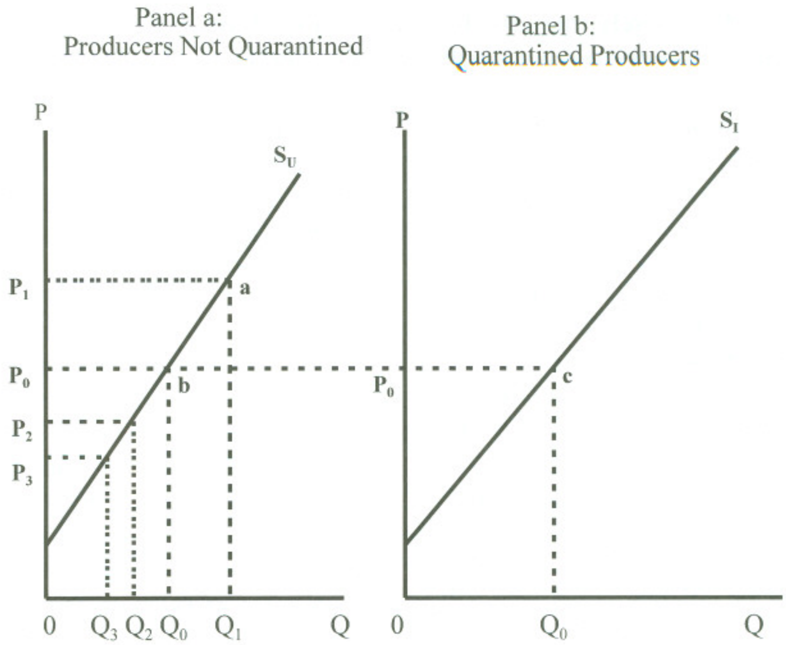

Figure 2. Producer Surplus Changes for (a) Not quarantined and (b) Quarantined Producers

mises, or *I*-producers.[2] *I*-producers have a supply shown as S_I. The market effects are described in Figure 1. The change in welfare for *U*-producers in Figure 2a is measured by the price change along their supply relation—producer surplus. When only the supply shock is considered, the price rises from P_0 to P_1, and the producer surplus for *U*-producers increases by P_0P_1ab. If the price falls, which happens when the other shocks are considered, *U*-producers incur producer surplus losses also measured along S_U. *I*-producers in Figure 2b produce Q_0 animals (meat), as indicated by S_I, but receive no sales revenue because their animals are quarantined and slaughtered. In the absence of government compensation, their loss consists of the variable costs incurred to produce at Q_0 plus the fixed costs and profits or their gross revenue, rectangle $0P_0cQ_0$. The welfare change for livestock producers in total is the sum of the separate changes for each group and does not correspond to producer surplus as measured in Figure 1. When *U*-producers can respond to price, the change in aggregate producer welfare differs from both the change in sector producer surplus and sector gross revenue. As supply approaches being perfectly inelastic, the loss in sector welfare approaches the change in gross revenue.

Change in Consumer Welfare

Measuring the change in consumer welfare is complicated by an asymmetry in possible consumer responses to an FMD outbreak. One group, aware that FMD is rarely transmissible to humans, consumes beef just as before the FMD outbreak. Another group, fearing imagined health effects, is hypersensitive and no longer consumes beef, which drops out of their consumption bundle.[3] Measuring the

[2] In the recent outbreak in Britain, animals on farms neighboring farms with infected animals were also destroyed as part of the stamping-out policy. These animals need to be included in the supply removed from the market.

[3] Part of the European response to restore consumer confidence in the beef supply following the BSE outbreak is to establish a traceability system. Such a system for FMD might mitigate adverse consumer reaction. However, previous experience with hypersensitive consumers in the cases of Chilean grapes and Alar suggests some consumers would curtail beef consumption even with traceability since the consumer cannot be sure of product quality *ex ante*.

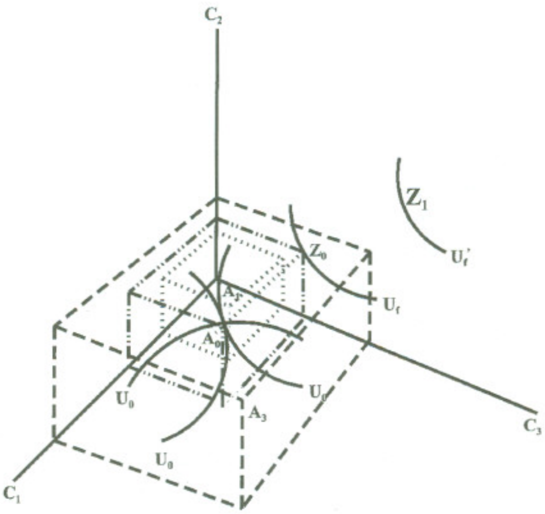

Figure 3. Consumer Welfare Changes with an FMD Outbreak

changes in welfare for the first type of consumers is straightforward, whereas determining the welfare change for the second group is more complicated.

The issue with measuring the changes in consumer welfare can be illustrated using Figure 3. To simplify the presentation, assume there are only three goods available to the consumer, denoted goods 1, 2, and 3. Prior to the FMD outbreak, there is one representative consumer who consumes positive quantities of each good shown by the interior point A_0 with utility U_0.

If a quarantine and slaughter control program is the only shock of an FMD outbreak, Figure 1 shows a higher market price. Assuming good 1 is beef, the consumption bundle moves to the interior point A_1. Point A_1 is on a lower level of utility than point A_0, and there is a welfare loss to consumers. Visually, this is seen in Figure 3 by observing that the box with A_1 on its corner lies wholly within the box with A_0 on its corner. This confirms the observation made earlier with Figure 1. If the only effect of the FMD outbreak is to reduce beef supply, consumers suffer a welfare loss. That loss can be measured using standard metrics of compensating variation, equivalent variation, or consumer surplus using national demand functions.

If the output losses from quarantine and slaughter are accompanied by a loss of exports, Figure 1 shows the U.S. price of meat falling to P_2. In this case, the consumption bundle would move from A_0 to a point A_2 on a larger box (not shown). There would be a clear welfare gain for consumers.

The situation becomes more difficult when some consumers react adversely to the FMD outbreak. Assume that Figure 3 now applies to two different, individual consumers. Prior to an FMD outbreak, both consumers are identical and consume bundle A_0.

Consumer 1 knows that FMD is rarely transmissible to humans, so the news that there is an FMD outbreak does not affect behavior. This consumer moves from bundle A_0 to bundle A_3 and experiences a welfare gain as the price of good 1 (beef) falls.

Consumer 2 fears that FMD is transmissible to humans so beef, good 1, is voluntarily not consumed and the three-good consumption bundle collapses to two goods. If the consumption levels of goods 2 and 3 are held constant, consumption moves to point Z_0 in Figure 3, with utility denoted U_f. With income and the prices of goods 2 and 3 constant, the assumption of nonsatiation in consumer theory means expenditure not allocated to good 1 would be shifted to goods 2 and 3. The consumption bundle would be above point Z_0 at a point like Z_1 with utility U_f'.

The issue is whether consumer 2 experiences a welfare loss or gain from the FMD outbreak. An assumption of consumer theory is that consumers prefer more of a good to less, $\partial U/\partial C_i > 0$. Thus, $U_f < U_0$ because less of good 1 is consumed given the same quantities of goods 2 and 3 consumed. Utility U_f' is also less than utility U_0 because the prices of goods 2 and 3 are unchanged. The loss in utility could be measured in terms of additional amounts of goods 2 and 3 or income required to return consumer 2 back to the original utility level, U_0. Under a compensation scheme, the implication is that consumer 2 should be compensated for the welfare loss from a misunderstanding of the human health risks of FMD.

However, given the news of an FMD outbreak, consumer 2 voluntarily selects consumption bundle Z_1 over A_0, which is still a feasible bundle. Furthermore, the consumer selects bundle Z_1 over bundle A_3, which is potentially available, given the consumer's expenditure, and represents a utility gain over the preoutbreak utility. Thus, utility level U_f' could be argued to exceed utility U_0. The implication of this argument is that the FMD outbreak generates a utility gain for consumer 2 as the consumer reduces use of a good that is now perceived to have a health risk. From this consumer's perspective, beef before the FMD outbreak and beef after the FMD outbreak are different goods.

The idea that new information changes preferences and appears to lower utility in a static model has been noted and argued to be invalid (Smallwood and Blaylock). Ippolito provides a framework where the timeliness of information matters. Ignorance about product safety boosts current utility at the expense of long-run utility. New information lowers current utility, but extends the lifetime over which utility is earned, so it raises the long-run utility.

The argument here is different. When there is no FMD outbreak, a consumer's FMD concern is not a factor in the consumption decision. Once there is an FMD outbreak, a consumer can be either misinformed (which happens for consumer 2) or informed (consumer 1) of the risks. Information that allows the consumer to move from misinformed to informed is welfare improving. This is the situation analyzed by Smallwood and Blaylock and by Ippolito, where the product has a risk attribute, and the new information allows the consumer a more informed choice. The situation for an FMD outbreak is that consumer 2 would like to eat beef, but given the outbreak voluntarily reduces the choice set. There is a welfare cost associated with the reduced choice of goods to consume, even though consumer 2 is misinformed about the health risk.

Numerical Model

Because of the ambiguity in the welfare effects arising from an FMD outbreak, a numerical model, from an average of annual data from 2000 and 2001, is constructed to compare welfare estimates calculated with aggregate demand and supply relations to welfare measures when producers and consumers are disaggregated. The intention is to examine the potential bias in measuring the welfare of an FMD outbreak using conventional metrics. To keep the illustration simple, only a composite of beef and veal is analyzed.[4]

Supply

National supply is decomposed into separate supply relations for producers with animals quarantined and slaughtered and those with animals that are not quarantined, as shown in Figure 2. When the FMD outbreak occurs, the stamping-out policy removes the market supply of quarantined animals. The supply functions are assumed to be linear to simplify the model.

Calibration of the supply functions requires the quantities of animals (meat) quarantined and those not quarantined. Thus, the magnitude of the FMD outbreak must be specified a priori. For this example, 1 million animals are assumed quarantined and slaughtered, which represents 725.7948 million pounds of beef and veal (2.7%) using commercial slaughter and production data (USDA/ERS).[5] Subtraction of the beef and veal from quarantined animals from total production gives the beef and veal produced from animals not quarantined, as well as animal numbers. The elasticity of

[4] A complete analysis would require including vertical and horizontal linkages to other meats, animals, and feeds. That type of model can be found in Paarlberg, Lee, and Seitzinger. The simple single-commodity model used in this analysis illustrates the argument without the additional complexity of linkages to other commodities.

[5] In the 2001 British outbreak, by January 14, 2002, 594,000 cattle had been slaughtered, or roughly 5.5% of beginning inventory (UK/DEFRA). Those figures do not appear to include slaughter of animals that could not be moved because of movement controls. Our example is purely illustrative. We chose a smaller shock of 1 million animals or 2.7% of total kill because cattle herds in the United States are more geographically dispersed in the western United States and the humidity in that region is lower than in Britain.

supply for beef used is 0.61, which represents a medium-run (18-month) supply response (Marsh). Sensitivity analysis, with an elasticity more appropriate to a short-run (2-month) supply response (0.17), is also performed (Marsh). This information allows calibration of beef supply relations for producers with animals quarantined and slaughtered, as well as for those with animals not removed from the market. These are converted to animal units assuming a fixed output of meat per animal.

The base solution uses data with no outbreak, so the two supply functions are summed to give an aggregate supply function like S_0 in Figure 1. When the FMD outbreak occurs, only the beef supply function from animals not quarantined is allowed. This corresponds to the supply function S_1 represented in Figure 1.

Demand

The demand side of the numerical model must be constructed to allow for potential adverse consumer reaction. Thus, national demand must be separated a priori into consumers who continue to eat beef and veal once an FMD outbreak occurs and those who no longer consume beef and veal. The process used is to construct per capita beef and veal demand equations and then, using an assumed division of the population into two types of consumers, calibrate demand equations for each group. When the hypersensitive consumers react adversely to the FMD outbreak, that demand disappears from the model.

Per capita demand equations are linear and identical for the two types of consumers and are calibrated to U.S. data when no outbreak has occurred.[6] The elasticity used for U.S. beef and veal demand of −0.6212 comes from Huang. The retail beef and veal price used, \$2.322523 per pound, is calculated from total U.S. per capita expenditure (USDA/ERS) multiplied by the after-tax household income budget share of beef and veal of 0.5958% (Blisard) divided by per capita beef and veal consumption (USDA/ERS). This equation is calibrated to per capita beef and veal consumption adjusted to carcass weight to match national supply use data.

The next task is to divide the U.S. population into consumers whose consumption is not affected by the FMD outbreak and those who are hypersensitive. This division is unknown and should be the focus of a future research effort. For this illustration, two situations are considered. In one situation, 5% of consumers are treated as hypersensitive. The second situation considers the implications of 10% of consumers being hypersensitive.

The final task is to select a metric to measure consumer welfare. Conventional metrics are compensating variation, equivalent variation, and consumer surplus. With the beef and veal budget share being 0.5958%, income effects arising from the beef price change can be ignored and consumer surplus is used in this model.

Model Closure

Trade and trade policy give closure but are difficult to model in this example. One reason is that the United States both imports and exports beef. When beef supply is assumed to be homogeneous, as in this model, net trade is usually modeled and the United States would be a net importer of beef. Because one critical effect of an FMD outbreak is the interruption in U.S. beef exports, using net imports is unsatisfactory. Exports are treated as exogenous for calibration of the base model since a ban on exports is imposed in two of the three FMD scenarios.

Modeling imports is complicated by the import policy regime. Prior to the Uruguay Round, the United States operated under the Meat Import Law of 1964, which set supplier-specific quotas. Nations exporting to the United States voluntarily restricted sales to avoid triggering the quotas allowing potential cap-

[6] Nonlinear demand functions can also be used in the model. Model solutions using a nonlinear demand system show that the estimated welfare losses of hypersensitive consumers are very sensitive to the level of the choke price used to calculate consumer surplus. A linear demand using base period data determines a choke price of \$6.06 per pound. The reported welfare losses are sensitive to this value.

ture of rents (Allen, Dodge, and Schmitz). Under these types of policy regimes, the linkage between U.S. and world prices is severed. With the Uruguay Round Agreement on Agriculture (URAA), a supplier-specific tariff-rate quota (TRQ) regime was implemented, with Canada and Mexico exempted under the North American Free Trade Agreement (NAFTA). The URAA also set special 20,000-ton access for fresh beef from Argentina (U.S. Department of the Treasury, Customs Service). The Normal Trade Relations (NTR)-specific tariff of $0.044 per kilogram applies to below-quota imports (USITC). Non-NAFTA imports in excess of the quotas face a 26.4% tariff (Leuck).

Capturing this import policy regime requires excess supply schedules for each supplier that reflect the unique quota faced. Construction of the excess supply elasticities uses standard trade elasticity formulas as found in Bredahl, Meyers, and Collins, plus beef trade flow and country supply–use data (USDA/FAS). The formulas use national demand and supply elasticities. The most comprehensive set of such values appears in Sullivan, Wainio, and Roningen. Those values were complied by country specialists in the Economic Research Service, U.S. Department of Agriculture, for analysis of trade liberalization during the Uruguay Round negotiations. In some cases, more recent estimates are available and are used instead. Demand elasticity estimates for the major Pacific Rim markets of Japan, Korea, and Taiwan from Capps et al. are used. The demand elasticity used for beef in Canada is that reported by Eales. Comparison of these recent estimates with those from Sullivan, Wainio, and Roningen show a high correspondence, so the values from Sullivan, Wainio, and Roningen are used for the other nations. As expected, using the trade elasticity formulas yields elastic excess supply schedules, which serves to dampen U.S. beef price movements since the volume of imports adjusts sharply to changes in the U.S. beef price.

Because NAFTA countries do not face tariff-rate quotas, a single excess supply equation is specified. The presence of tariff-rate quotas for Australia, New Zealand, Argentina, and other nations means each supplier's behavior is described by three equations. One excess supply equation is used when imports from that supplier are below the quota and face a $0.044 per kilogram specific tariff. When imports from a supplier exceed that supplier's quota, an alternative excess supply is used that incorporates the 26.4% *ad valorem* tariff. When imports are at the quota, the tariff-rate quota acts like a pure quota with imports modeled as a constant. Consequently, each scenario must be solved repeatedly to give a solution consistent with the tariff-rate quota faced by each supplying nation.

Results

Several studies use the change in value of livestock sales as a measure of the economic effect of FMD on producers (Ekboir; Paarlberg, Lee, and Seitzinger). As in any policy analysis, the change in sales revenue might not be an accurate measure of the change in producer welfare. Furthermore, the argument made using Figure 2 is that welfare analysis for producers in the event of an FMD outbreak must distinguish between producers with and without quarantined animals.

Table 1 shows changes in beef producer welfare using sales revenue and producer surplus under three outbreak scenarios, with three different supply elasticities. Scenario 1 assumes the only effect is quarantine and slaughter of 1 million head of cattle. Scenario 2 adds a ban on U.S. beef exports to the cattle cull. Scenario 3 includes an adverse consumer reaction, where 5% of consumers no longer eat beef and veal. Multiple metrics for welfare changes are reported. Producer surplus for the sector is calculated by integrating under the total sector supply equation, whereas producer surplus for producers of animals not quarantined comes from the supply equation for only those producers. Total sales revenue is the marketings multiplied by price received. As argued in Figure 2, the welfare change for producers with quarantined animals is their sales revenue. The change in sector welfare consists of the change in producer surplus for non-

Table 1. Estimated Beef Producer Welfare Effects from an FMD Outbreak

	Welfare Effects ($ Million)		
	Scenario 1[a]	Scenario 2[b]	Scenario 3[c]
Supply elasticity = 0.61 change in			
Sector producer surplus[d]	−94.7	−851.1	−1,286.1
Sector sales revenue	−90.5	−1,307.2	−2,003.5
Producer surplus cattle not quarantined	264.4	−492.0	−927.0
Welfare producers with quarantined cattle[e]	−516.6	−516.6	−516.6
Sector welfare[f]	−252.2	−1,008.6	−1,443.6
Supply elasticity = 0.17 change in			
Sector producer surplus[d]	−126.6	−1,087.2	−1,640.2
Sector sales revenue	−111.2	−1,234.1	−1,877.3
Producer surplus cattle not quarantined	346.1	−614.1	−1,167.5
Welfare producers with quarantined cattle[e]	−516.6	−516.6	−516.6
Sector welfare[f]	−170.5	−1,130.7	−1,684.1
Supply elasticity = 0.05 change in			
Sector producer surplus[d]	−125.1	−1,162.9	−1,760.0
Sector sales revenue	−118.9	−1,208.2	−1,833.6
Producer surplus cattle not quarantined	378.6	−659.2	−1,256.3
Welfare producers with quarantined cattle[e]	−516.6	−516.6	−516.6
Sector welfare[f]	−138.0	−1,175.8	−1,772.9

[a] Quarantine and slaughter only.
[b] Quarantine and slaughter plus export ban.
[c] Quarantine and slaughter, export ban, plus adverse consumer reaction.
[d] Producer surplus calculated from aggregate sector supply functions as in Figure 1.
[e] Welfare measured as sales revenue lost.
[f] Change in producer surplus for producers not quarantined, plus lost gross revenue for producers quarantined.

quarantined cattle, plus the loss in sales revenue for animals quarantined and slaughtered.

In scenario 1, when the only effect is animal removal, the price of cattle rises. When the supply elasticity is 0.61, the cattle price rises from $71.18 per cwt to $72.19 per cwt. When the supply elasticity is lowered to 0.17, the price rise is larger, from $71.18 per cwt to $72.51 per cwt. The divergence in welfare effects for producers with cattle not quarantined from those with quarantined cattle, discussed in Figure 2, is shown in Table 1. With the supply elasticity of 0.61, producers with quarantined animals experience a loss of $516.6 million, which is the lost sales revenue in all scenarios. Producers who avoid the FMD infection and can sell cattle receive a higher price and can increase output, so they experience a producer surplus gain of $264.4 million. In scenarios 2 and 3, the cattle price falls so nonquarantined producers experience declines in producer surplus of $492.0 million and $927.0 million. Table 1 also shows the difference between using the change in sector sales revenue as a welfare measure and a metric constructed from the changes for quarantined and nonquarantined producers. When only cattle removal is considered, sector sales revenue is $90.5 million less because of increased price and expanded output by producers with cattle not quarantined. Combining the separate welfare changes for producers with quarantined cattle and those with cattle not quarantined indicates a larger loss of $252.2 million. When the loss in exports and the adverse consumer reaction are included, the relationship between the change in sales revenue and sector welfare reverses because, in those scenarios, prices are falling and producers with cattle not quarantined react to the price decrease by further reducing output. In these scenarios, the fall in sales revenue overstates the welfare loss. In scenario 3, the sales revenue loss is $2,003.5 million, but the loss in producer welfare for the sector is only $1,443.6 million.

Table 1 also reports the change in producer surplus as usually calculated according to Figure 1. For scenario 1, the conventional change in producer surplus is a loss of $94.7 million, while the decomposed measure shows a larger loss of $252.2 million. That pattern remains as the sector producer surplus understates the welfare loss.

The beef supply elasticity used for the model results of 0.61 indicates a medium-run elasticity (Marsh). Consequently, the analysis is repeated with a lower beef supply elasticity of 0.17 to reflect a shorter time period and an elasticity of 0.05 that allows almost no supply response to a beef price change. As expected, less supply adjustment magnifies the price changes. In scenario 1, the price of cattle rises more, whereas scenarios 2 and 3 experience larger price declines. The total welfare changes more closely correspond to the changes in sector gross revenue with the lowest supply elasticity. For example, in scenario 3, the revenue decline for the sector under the lowest elasticity case is $1,833.6 million and the welfare decline calculated from the decomposed measures is $1,772.9 million. The closer correspondence in the values is a result of the change in producer surplus for growers with animals not quarantined under the low-supply elasticity solutions being similar to the loss in sales revenue for those producers.

Table 2 shows changes in consumer surplus as measures of the welfare changes for consumers when 5 and 10% of the population is classified as hypersensitive consumers who do not consume beef following an FMD outbreak. Only the results for scenario 3, which includes the adverse consumer reaction, are shown because the demands are stationary in the first two scenarios and the change in consumer welfare is unambiguous. Because beef and veal only account for 0.5958% of consumer expenditure, the change in consumer surplus is an adequate measure of the welfare change. In both situations the national welfare changes are small, but the changes differ in sign.

Table 2. Change in Consumer Surplus and Expenditure Because of an FMD Outbreak, Scenario 3, by Share of Hypersensitive Consumers (5% and 10%)

	Consumer Surplus/ Expenditure Change ($ Million)	
Consumer Type	5%	10%
Surplus		
No concern	+3,119	+4,428
Hypersensitive	−2,560	−5,121
Total	+559	−693
Expenditure		
No concern	−1,260	−1,842
Hypersensitive	−3,181	−6,362
Total	−4,441	−8,204

When 5% of consumers are hypersensitive, the net consumer welfare change in this model is a gain of $559 million. Hidden within the total change in national consumer surplus are large differences among groups of consumers. Consumers who understand the lack of human health risk from FMD benefit from the price decline with a consumer surplus increase of $3,119 million. Consumers who stop eating beef and veal show a consumer surplus loss of $2,560 million, which is their entire consumer surplus for beef and veal prior to the FMD outbreak.

As the share of hypersensitive consumers increases, the aggregate national gain becomes smaller and eventually turns into a loss. This occurs because, as the share of hypersensitive consumers increases, the consumer surplus lost as demand shifts inward rises faster than the consumer surplus gain from the lower beef price. When 10% of consumers are hypersensitive, total national consumer welfare falls $693 million. Consumers who do not fear eating beef obtain a gain of $4,428 million while the loss to hypersensitive consumers is $5,121 million.

These results indicate that the welfare gains for consumers unconcerned about eating beef following an FMD outbreak balance the welfare loss of hypersensitive consumers when the share of hypersensitive consumers is roughly 7% of the population. When the share of hypersensitive consumers is less than 7%, total U.S. consumer welfare is higher with an FMD outbreak because the gain from the lower beef price dominates the demand shift. As the share of hypersensitive consumers rises beyond 7% in this model, an aggregate consumer welfare loss occurs. This inflection between national gains and losses suggests that improved knowledge of consumer response to an FMD outbreak is critical to determining the welfare effects.

Another critical influence on the results reported in Table 2 is the choke price used in the model. The estimate of the welfare change for the consumer unconcerned about FMD is not sensitive to the value of the choke price because the demand is stationary. Estimates for hypersensitive consumers are sensitive to the choke price because their welfare is measured as consumer surplus foregone as their demand shifts. The linear demand used in the model yields a choke price of $6.06 per pound with a base market price of $2.32253 per pound. Calculations using nonlinear demands require a choke price assumption. A choke price higher than that used would give a larger loss in consumer surplus for hypersensitive consumers, while not altering the gain to unconcerned consumers. That means a national consumer welfare loss would occur with a smaller share of hypersensitive consumers, or equivalently, the estimated losses shown in Table 2 would be much greater.

Table 2 also shows the change in consumer expenditure to compare with the welfare changes. For hypersensitive consumers, the expenditure declines are larger than the welfare declines, but of similar magnitude. For consumers that continue to consume beef and veal, the declines in expenditure are much different than the welfare gains. When 5% of the population consists of hypersensitive consumers, consumers that are unconcerned about eating beef gain $3,119 million with an expenditure reduction of $1,260 million. These differences are reflected at the national level. Both situations show falling national expenditure—$4,441 million and $8,204 million. However, the situation with 5% of the population being hypersensitive is a national consumer welfare gain, whereas that with 10% hypersensitive consumers is a national consumer welfare loss.

As discussed using Figure 3, there is ambiguity about whether the decline in consumer surplus measures a welfare loss given that these consumers voluntarily alter their consumption bundle. Is consumer surplus an appropriate measure of the change in consumer welfare when the demand shift is caused by a reaction to the news of an FMD outbreak? Should the consumer surplus declines be counted as part of the economic cost of an FMD outbreak? The argument made is that the loss of consumer surplus measures the cost of the change in the consumer's choice set even though the consumer misunderstands the human health risk from FMD-infected beef. Thus, these losses in consumer surplus should be counted in the national cost.

Summary and Conclusions

With recent FMD outbreaks around the world, questions about the economic cost of a potential U.S. outbreak have been raised. Most analyses measure the gains and losses using changes in sales revenue, export revenue, and consumer expenditures. Such values might not be accurate estimates of changes in economic welfare.

This paper discusses the uses of welfare measures in the context of an FMD outbreak. It argues that standard welfare measures like producer and consumer surplus should be decomposed. The welfare effects of an FMD outbreak on producers differ for those with animals quarantined and slaughtered from those who avoid FMD. The welfare change for producers with animals not quarantined is measured as the change in producer surplus using an FMD-free supply schedule. The welfare change for growers with quarantined and slaughtered animals is measured using the loss in sales revenue.

The change in consumer welfare is complicated when there are consumers who fear human health effects from an FMD outbreak. The welfare changes for consumers that do not have health concerns are unambiguous. Consumers who perceive human health risks voluntarily curtail consumption. There is a welfare loss associated with reduced consumption, but the new consumption bundle is voluntarily selected so it could be argued to represent a higher level of welfare. This paper argues that welfare is indeed lower and can be measured by the change in consumer surplus, indicating the lost opportunity to consume the product.

A numerical model calibrated to 2000 and 2001 beef and veal data is used to illustrate the concepts developed. Three scenarios are considered. Scenario 1 considers only the output reduction caused by a quarantine and slaughter control strategy. Scenario 2 adds an export ban for beef. Scenario 3 additionally includes an assumed pattern of adverse consumer reaction to the FMD outbreak.

The model results indicate that when supply is price responsive, the change in sector sales revenue is a poor estimate of the producer welfare loss. In the case of scenario 1, the welfare loss is underestimated. For the other scenarios, producer welfare losses are overestimated by the change in sales revenue. The bias occurs because sales revenue does not account for the response of producers with animals not quarantined to market price changes. When the supply elasticity is reduced, the change in sales revenue becomes a closer approximation to the welfare loss.

The total change in consumer surplus hides large differences in welfare effects among groups of consumers. Consumers who recognize that FMD poses no significant human health risk experience a welfare gain when the beef price falls. Consumers that are misinformed and curtail beef and veal consumption comprise a small share of consumers in this scenario, but experience large welfare losses. The welfare losses by this small group of consumers can be large enough that, in aggregate, there is a total welfare loss to consumers. In this model, the switch between a national consumer welfare gain and a loss occurs when roughly 7% of consumers are hypersensitive and drop beef and veal from their consumption bundle. This indicates that knowledge of how consumers would react to an FMD outbreak is important to estimating the welfare effects. Surveys of U.S. consumer attitudes toward eating beef and other products following an FMD outbreak could provide essential information for determining the welfare effects.

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