International Food and Agribusiness Management Review
Volume 8, Issue 1, 2005

Economic Modeling of Livestock Disease Outbreaks[1]

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Abstract

The paper surveys articles examining the economic impacts of a livestock disease outbreak and focuses on modeling issues. One set of papers considers setting an import barrier when there is a livestock disease risk. They show that the level of a risk-based import barrier is sensitive to the impact of disease on economic welfare. The remaining articles focus on estimates of the economic impacts. An outbreak is modeled in a U.S. agricultural sector model and shows the importance of lost exports and consumer response to the magnitude of losses. The final paper argues for de-composition of the welfare impacts. Lessons for future research include improved links to epidemiological research, improved inclusion of trade, extension to non-agricultural sectors, and knowledge of consumer response.

Key Words: foot-and-mouth disease, modeling, trade

[1] Presented at *The Economic Impact of Animal Disease on the Animal Product Marketing Sector in the United States*, Farm Foundation Showcase Project, Denver CO. July 11, 2003

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Recent outbreaks of animal diseases around the world have sparked interest in the impacts of such an event in the United States. Whereas agricultural commodity policy analysis has a long history with multiple analyses of most issues, there has been much less work on economic analysis of livestock diseases (Sumner 2003). The public, policymakers, and analysts have limited experience generating, evaluating, and using estimates of national impacts of livestock disease outbreaks.

This paper surveys articles by the authors on the economic impacts of livestock diseases. The intention is to focus on modeling issues confronted and to investigate the implications of modeling decisions for estimates of the impacts of livestock disease outbreaks and policy implications. That is, while the results of the research are presented, this paper focuses on methodological issues confronted in doing the research and how assumptions influence findings. The paper finishes with observations about where future research might expand this work.

Import Barriers Incorporating Livestock Disease Risk

International trade in livestock and livestock products reflects a fundamental tension. Economic theory and empirical studies find benefits to international trade, yet open borders risk trading not only commodities but also disease. International trading rules attempt to balance this tension by affirming a nation's right to protect its plant and animal health and safety through trade barriers while requiring that any such barriers not be disguised protection. Assessing whether a specific import rule meets the criteria has proven difficult.

The 1994 Sanitary and Phyto-sanitary (SPS) Agreement of the Uruguay Round Agreement (URA) strengthened the existing rules. It allows nations to adopt sanitary barriers more restrictive than the norms set by the World Organization for Animal Health (OIE) if justified by a risk assessment (Smith 2003). Furthermore, sanitary barriers are to be no more restrictive than required to meet the appropriate risk.

Determining when a trade barrier is unnecessarily restrictive has proved challenging. The first three papers demonstrate methods for tying the level of a sanitary barrier to the disease risk in imports from other nations. Such trade barriers have the potential to generate additional gains-from-trade while preserving the health of a nation's livestock herd. Numerical illustrations highlight important information required to make these methods operational.

Paarlberg and Lee (1998) examine whether such a linkage can be made. Is there a trade barrier that balances the gains-from-trade from imports with the risk of losses to the United States arising from importing an animal disease? Foot-and-Mouth Disease (FMD) is used as an illustration[2].

The methodology is to construct a partial equilibrium model for beef when the United States imports beef from two potential sources. One source of imports is FMD-free, so consists of nations that represent no FMD risk. Imports from this source are modeled using an excess supply function. The other exporter consists of nations representing a potential FMD risk. Its exports, X_I, are also described by an excess supply function where the base volume of trade with the United States under current policy is zero. Thus, initially, the United States only imports beef from the uninfected exporter.

The behavior of the U.S. beef market is captured by demand and supply functions. The U.S. demand function specification is standard for a single commodity partial equilibrium model. The specification of the U.S. beef supply function, S_u, is modified to include an argument for the number of outbreaks, N. As N increases supply of beef falls, $(\partial S_u/\partial N) < 0$. In this model outbreaks shift the supply of beef to the left. The number of outbreaks of FMD in the United States is linked to the volume of imports from the infected exporter, X_I. As imports from the infected exporter rise, so does the number of outbreaks, $(\partial N/\partial X_I) > 0$.

As a substitute for the existing U.S. policy of banning imports from nations not free of FMD, the United States is allowed to set a discriminatory two-part tariff. One part of the tariff is the traditional tariff. The other part of the tariff is an additional barrier incorporating the FMD risk from the infected exporter. The total barriers facing each exporter are set by maximizing U.S. welfare measured as producer surplus and consumer surplus plus tariff revenues.

In this formulation the additional *ad valorem* barrier against the infected exporter (R_I) is set by the following intervention rule:

$$(1)\ R_I = -(\partial S_u/\partial N)(\partial N/\partial X_I)(P_u/P_I)$$

where P_u and P_I are the U.S. beef price and the beef price from the infected exporter.

There are two critical terms. The term $(\partial S_u/\partial N)$ measures the beef output loss from each outbreak. The second term $(\partial N/\partial X_I)$ ties the number of outbreaks to the import flow from the infected exporter. This term is the risk of importing FMD.

[2] Using a specific disease and its associated characteristics helps set limits on the type and scope of the issues and provides some concreteness. However, due to the complexity of an actual disease the numerical results can only be interpreted as illustrative.

Implementation of the model requires setting values for the two terms in expression (1). These values are not known for the United States since there has been no FMD outbreak in the United States since 1929. Thus, other information must be used to establish plausible values. Empirical estimates for the loss from an FMD outbreak ($\partial S_u/\partial N$) are taken from the study by McCauley et al. (1979) and range from a low loss of 1.4 percent of output, to a medium output loss of 9 percent, to a high output loss of 15.5 percent. Estimates of the risk of an FMD outbreak being triggered by imports are based on the British experience prior to and after their 1966/67 outbreak as reported by the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA/APHIS 1994). The British experience is used because that nation imported beef from nations representing an FMD risk. The estimated risk is found by dividing the number of British outbreaks in a period traced to imports by the total import tonnage for that period. The earlier period indicated one outbreak per every 215 thousand tons of imports, termed a high risk. The later period showed one outbreak occurring for every 24.7 million tons, termed a low risk. The large decline in risk is due to changes in import procedures for handling imported beef following the 1966/67 outbreak.

Inserting the information into the model and solving gives prices, quantities, and trade barriers. The results indicate that under the low risk scenario, the additional trade barrier levied against the infected exporter ranges from 0.76 percent with the 1.4 percent output loss to 8.09 percent with the output loss of 15.5 percent. In the high risk scenario, all of the trade barriers against the infected exporter are prohibitive.

The model allows calculation of the risk threshold where the barrier against the infected exporting country becomes prohibitive. For an output loss of 1.4 percent the threshold is a risk of one outbreak per 447 thousand tons imported. If outbreaks occur more frequently than that threshold, the trade barrier is prohibitive. If the output loss is set at 15.5 percent, the risk threshold for a prohibitive trade barrier is 1 outbreak for every 4.785 million tons of imports.

A second paper by Paarlberg and Lee (2001) expands the methodology to include multiple risk categories. This requires using expected welfare as the objective for setting trade policy. This expansion in methodology reflects proposed changes in U.S. meat and animal import rules to comply with the adopted Uruguay Round Agreement (USDA/APHIS 1996). In the proposed rule changes nations are classified into one of six risk categories. The altered methodology provides a richer intervention rule, but retains the features of the earlier rule.

Multiple risk categories mean altering the manner in which an FMD outbreak affects U.S. supply. The earlier paper used the number of outbreaks and tied that number to import volume from the exporter of potentially infected beef. In the second paper an argument indicating the expected severity of an outbreak, α, replaces the number of outbreaks. That loss occurs with a probability of π which depends on the probability of imports from each individual risk category triggering a U.S. outbreak, π_i. Those probabilities are linked to the flow of imports from each risk category.

The objective for the United States is to find the risk-based premia that maximize U.S. expected welfare. U.S. welfare is defined as producer surplus and consumer surplus plus policy revenue, G_u , less control costs, C. For a given control strategy, t, the premium facing nations in risk category i, R_{it}, is:

$$(2)\ R_{it} = -\ [G_u(P_u,\alpha_t) - G_u(P_u) - C_t(\alpha_t)](\partial\pi\ /\partial\pi_i\ )(\partial\pi_i\ /\partial X_i).$$

The first set of terms indicate the change in U.S. welfare that occurs when there is an outbreak. Because U.S. welfare under an outbreak is lower, the sign of this term is negative. The last terms link trade from risk category i to the probability of a U.S. outbreak. They indicate how the probability of a U.S. outbreak is affected by the risk from each risk category and the linkage between risk and trade volume in each risk category.

Empirical implementation requires identifying plausible values to use in expression (2). The FMD risk by category consists of two parts. One part is the risk of FMD in the herd of the exporting nation. In the proposal, USDA/APHIS assigns risk probabilities to the risk categories ranging from 1 /100 to 1/1 million (USDA/APHIS 1996). The second part is the risk that the product remains infected following processing and shipment. A value for this risk is not identified in the proposal so the magnitude of this risk is assumed to be 1/1000 to facilitate scaling of the data values[3]. Thus, the numbers generated are purely illustrative and not a description of what U.S. policy is or should be.

The output losses expected from an FMD outbreak in the United States come from research by Aulaqui and Sundquist (1979) done as part of the McCauley, et al. 1979 study. They examine the path of outbreaks across a 15-year cycle for three control strategies. When the disease is endemic the average annual output loss over the 15 years is 6.3 percent and that value is used for the endemic scenario. Under a policy of stamping-out the average annual output loss falls to 1.0 percent. The lowest average annual output loss occurs under a strategy of vaccination – 0.2 percent. Thus, the empirical results are interpreted as indicating the long-run average barrier.

[3] The risk of the product remaining infected with FMD is not known and could differ considerably from the value assumed. Further, handling and processing procedures, such as de-boning, can affect this value. Other risk mitigation procedures affect this risk and this value can be a means of recognizing such effects. This is illustrated by the Petry, Paarlberg, and Lee article where the transmission risk is affected by a testing requirement.

Control costs are also introduced. No control costs are assigned when FMD is assumed to be endemic. With the stamping-out control strategy the administrative costs used by Aulaqui and Sundquist (1979) are inflated to 1996 values using the consumer price index. For vaccination additional costs are added. It is assumed that to be effective, 90 percent of U.S. cattle must be vaccinated twice per year. The vaccine cost is set at $0.60 per animal with a $0.20 per animal charge to administer the vaccination.

The model is solved for the U.S. beef price, U.S. beef output, U.S. beef use, U.S. beef imports from each exporting risk category, and the trade barriers against each risk category. The empirical results seem to correspond quite well to existing U.S. policy despite all of the assumptions made to empirically implement the illustration.

Regardless of the control strategy, the additional premia levied against negligible and slight risk nations are small. The largest of those premia is levied against slight risk nations in the endemic scenario – $38.09 per ton. The premia against all other risk categories under the three control programs are prohibitive with one exception. That exception is when the United States vaccinates. Under a vaccination control strategy low risk nations do not face a prohibitive tariff so some imports are allowed from low risk nations in that case.

This methodology is applied to U.S.-Mexico live swine trade (Petry, Paarlberg, and Lee 1999). Because the U.S. swine herd is infected with Porcine Respiratory and Reproductive Syndrom (PRRS) while Mexico claims it is PRRS free, very restrictive barriers against U.S. swine sales to Mexico were imposed. The methodology allows analysis of whether the barriers set conform to the PRRS risk in U.S. swine.

One set of information needed is the effect of a PRRS outbreak on the Mexican swine herd. The output loss expected in Mexico from PRRS is determined by constructing two national herds. One herd is affected by PRRS and the other is not. The output of animals for each herd is determined with differences arising via the effects of PRRS on rates of abortion, farrowing deaths, pre-weaning deaths, and finishing time. The experience of the United States with PRRS is used to determine the losses and the Mexican swine herd is assumed to expect the same impacts if PRRS becomes established. The estimated losses in Mexican swine due to PRRS range from 2.4 percent to 13 percent.

Another piece of information is the risk of infection for the Mexican swine herd. The risk of Mexico importing PRRS from the United States depends on U.S. infection rates, transmission risks, and testing requirements. U.S. infection risks are set at 54.8 percent for slaughter hogs and 31.3 percent for feeder and breeder animals (Rothenberger 1997). Breeding animals and feeder pigs are assumed to have a risk of infecting Mexican animals of 1 since they are integrated into the Mexican herd. Slaughter hogs have less chance to interact with the Mexican herd so their transmission risk is assumed to vary between 1/100,000 and 1/1 million. Testing animals for PRRS alters the transmission probabilities. The failure rate for the test is 0.005. Testing slaughter hogs for PRRS cuts the total risks to the Mexican herd from slaughter hogs to 1/ 36 million and 1/364 million. The cost of the test is set at $1.22 per animal.

The empirical results indicate that trade in live swine occurs only when there is testing and that trade is confined to slaughter hogs. Breeding animals and feeder pigs face prohibitive trade barriers and the existing restrictive trade barriers on those types of pigs are appropriate. Testing breeders and feeders for PRRS does not alter that conclusion. The results suggest slaughter animals should be treated as distinct and testing for PRRS does make a difference for slaughter hogs. When no test is required prohibitive barriers are imposed. The PRRS test lowers the transmission probabilities enough to allow non-prohibitive premia. Those premia vary from $1.32 per hog to $3.80 per hog.

Welfare benefits for Mexico occur when imports of tested hogs for immediate slaughter are allowed. Under the low transmission risk and low output loss case, Mexico gains $105 million in social welfare compared to the existing restrictive policy. On the other extreme, if the transmission risk is high and the largest output loss is used, the net benefits of liberalizing trade for Mexico are but $7 million.

There are lessons about sanitary risk and trade policy that emerge from these papers. One lesson, is that methodologies can link the magnitude of trade barriers to the risk of importing livestock diseases. Such methods can assist in determining when an existing barrier might violate World Trade Organization SPS rules by being unnecessarily restrictive. These methods can also be used to justify barriers based on risk. The papers demonstrate potential added gains-from-trade could be obtained without compromising the health of a nation's livestock sector. The illustration using PRRS shows that separate sanitary rules for slaughter animals with a testing requirement provides trade benefits for Mexico over the current restrictive policy. Another lesson is that two sets of information are critical. One set of information is quality risk values and expected output losses. Epidemiologists, veterinarians, and animal scientists have a comparative advantage providing this information. The other information is quality measurement of the welfare impacts of a disease outbreak, and here the economist can play a role. The next section investigates our attempts to improve understanding of the market, revenue, and economic impacts using FMD as an example.

Estimating the Economic Impacts of an FMD Outbreak in the United States

Determining the economic impacts of an animal disease outbreak is critical for national policy on trade rules, over which control strategy to adopt, how aggressively to intervene, and compensation payments. Economics provides methodologies to make such estimates, but assumptions by modelers about the shocks to include and their magnitudes, about commodity coverage, about how trade is modeled, as well as parameter values all affect results. In short, understanding the implications of assumptions made about how to measure the impacts is critical to the interpretation of results.

This section covers two papers that estimate the economic consequences of an FMD outbreak in the United States. The first paper uses a U.S. agricultural sector model to determine the revenue impacts of a U.S. outbreak similar to that experienced in Britain during 2001. The second paper examines the question of how to measure the changes in economic welfare from an FMD outbreak.

Estimating the impacts on farm revenue from an FMD outbreak in the United States of a similar magnitude to that in 2001 in Britain is the focus of Paarlberg, Lee, and Seitzinger (2002). The estimates are made with an agricultural sector model of the United States. That model considers four market levels and links these levels vertically. Final goods are those assumed eaten by consumers and include: beef, pork, poultry meat, lamb and sheep meat, dairy products, eggs, wheat, coarse grains, rice, and soybean oil. Intermediate goods in animal agriculture include: cattle, swine, lambs and sheep, and birds. Animal agriculture uses feeds as intermediate goods. Feeds are wheat, coarse grains, soybean meal, and forage and pasture. Thus, crop production for wheat, coarse grains, soybeans, and rice is modeled. Finally, crops use land where total crop area is treated as fixed.

The model relies on the complementarity conditions from a mathematical programming problem. Such models are commonly used in international trade to describe the behavior of an economy (Jones 1981). The primal problem is to maximize the value of national output subject to the economy's resource constraints while the dual problem is minimizing the cost of generating the output. As demonstrated by Sanyal and Jones (1982) such a model can be modified to include intermediate goods.

In its general form, the model assumes that industries are perfectly competitive with profit maximizing agents that produce using constant returns to scale technologies. Let W be a vector of primary factor prices, P_c be a vector of demand prices, and P_p be a vector of producer prices. The use of primary factors per unit of output is described by $A(W, P_c)$ which only depends on factor prices under the constant returns to scale assumption. Per unit use of intermediate inputs also only depends on factor prices and is indicated as $Z(W, P_c)$. The complementarity condition from the primal problem describes each industry as earning zero profits:

$$(3)\ A(W, P_c)W + Z(W, P_c)P_c = P_p.$$

Note that $Z(W, P_c)$ gives the per unit derived demands for intermediate inputs. The matrix $A(W,P_c)$ gives the per unit derived demand for primary factors of production. Market clearing for primary factors comes from the complementarity condition of the dual problem:

$$(4)\ A(W, P_c)Q = R$$

where Q is the output vector and R is the fixed supply of primary factors. Derived demands of intermediate inputs are defined as the vector D:

$$(5)\ D = Z(W, P_c)Q.$$

The model closure begins by specifying a demand system for final goods where the vector of consumption, C, depends on the vector of demand prices and a scalar expenditure, E:

$$(6)\ C = C(P_c, E).$$

The final task for closure involves specifying market clearing identities and excess demand or excess supply equations to capture international trade.

Government commodity support programs are exogenous. Multiple programs are included. Production Flexibility Contract (PFC) payments are included as de-coupled, lump sum transfers to wheat, coarse grains, soybean, and rice growers. These same producers receive a coupled payment equal to the difference between the loan rate and the market clearing price to represent Loan Deficiency Payments (LDPs). Market Loss Assistance (MLA) payments are excluded in the formulation, but could be added as de-coupled transfers. Finally, Commodity Credit Corporation (CCC) dairy product removals are included to capture U.S. Government efforts to defend the fluid milk price.

The FMD outbreak is introduced as three potential sub-shocks. The first sub-shock is the removal of animals from the marketing chain via a control strategy of stamping-out. The supply of animals (intermediate inputs) is exogenously reduced. The percentage reductions are based on the animal losses in Britain due to FMD as of May 21, 2001 and are: cattle/milk, - 5 percent; swine, -2 percent; and sheep and lambs, -9 percent[4]. By itself this sub-shock has the effect of cutting animal supply and feed demand. Animal and meat prices rise while crop prices fall.

[4] The final magnitudes of animal losses in Britain were somewhat larger than those assumed, but the use of the final losses does not greatly affect the results. Also animal production systems in the United States differ from those in Britain. The use of the British values is only to give a sense of scale to the shocks and not intended to imply that a U.S. outbreak would mirror the British experience.

The second sub-shock is to ban U.S. exports of cattle, swine, lambs and sheep, beef, pork, lamb and sheep meat, and dairy products. This is the trade policy response usually followed for an FMD outbreak. The impact of banning exports in isolation from the other shocks is to lower prices of livestock products, animals, and crops. Effectively there is excess supply in the U.S. market at the original prices.

The third sub-shock is to consider a potential adverse consumer reaction. Some consumers may misunderstand the human health risks of FMD and curtail consumption. The extent to which this might happen in the United States is unknown so an assumed value is used[5]. This sub-shock is modeled as a 10 percent decline in demand for beef, pork, and lamb and sheep meat, and dairy products combined with a 10 percent increase in demand for poultry meat. Thus, there is a livestock product demand reduction combined with a shift to more poultry consumption.

The combined effect of these sub-shocks reduces U.S. farm revenue $14 billion. Of that reduction, $6 billion comes from the ban on U.S. exports and $7 billion is from the assumed consumer response. In comparison to the effects of the export ban and the consumer reaction, the revenue impact of the animal removal is small. Of course, that small impact is measured at the sector level and falls on a small number of producers.

As a percentage of U.S. total farm revenue, the $14 billion revenue decline represents a loss of 6.2 percent. If calculated relative to the production value for the commodities included in the model, the decline is greater at a loss of 9.5 percent. If just the change in revenue for animal agriculture is calculated, revenue in animal agriculture is 20.4 percent lower.

The losses in production revenue by activity can also be calculated. For livestock products, beef, pork, and dairy products, producer revenues fall 20, 24 and 16 percent, respectively. Sheep and lamb meat revenues are 10 percent lower. Egg revenues are slightly lower, 2 percent, since egg prices decline as there is no assumed demand boost. Poultry meat revenues benefit from the demand boost and because the United States maintains exports. Poultry meat revenues are 5 percent greater. Falling meat revenues are reflected in sales revenues for animals. Cattle revenues fall 17 percent while swine revenues are down 34 percent. Sheep and lamb revenue is 14 percent lower. The pattern between the pork and swine revenue changes as well as between sheep/lamb meats and animals reflect magnification effects between output and input prices found in vertical systems.

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[5] Subsequent experience with Bovine Spongiform Encephalopathy (BSE) shows the uncertainty with consumer response. In Europe and Japan BSE outbreaks caused a decline in beef demand. In Canada indications are that beef demand rose. In the United States there appears to be little impact from confirmation of a cow with BSE (Pritchett, Thilmany, and Rosenstiel).

Except for the revenue on forage and the imputed value of pasture, changes in crop revenues are small. This reflects the role of government commodity programs. Since pasture and forage do not have price support their revenue falls 15 percent. The other commodities have such support and revenues rise slightly as output increases when pasture and forage land moves to supported crops.

An FMD outbreak in the United States would affect more than just production revenue. Export revenue falls 13 percent. Consumer expenditure also falls – nearly 7 percent. In contrast, U.S. Government spending on commodity programs rises 8 percent as LDP's increase.

Because prices are changing throughout the market channel, it is useful to adjust the revenue for changes in input cost. For livestock products revenues fall but so do animal costs. The change in value-added is a decline of 15.9 percent. For animal agriculture feed costs fall. The value-added for livestock growers is 12.9 percent lower compared to a 20.4 percent decline in sales revenue. Crop producers experience a slight fall in land cost. Commodities protected by programs show little change in revenue. Adjusting crop revenues by the change in land cost gives a decline of 7.0 percent which is due to losses in revenue and imputed value for forage and pasture.

Two policy recommendations flow from these results. One recommendation is that consumer education about the lack of human health consequences from FMD can sharply reduce the costs of an outbreak. Second, convincing foreign buyers to regionalize the United States keeps a portion of U.S. exports flowing. That strongly dampens the costs of an FMD outbreak.

Several lessons for researchers and policymakers emerge. One lesson is that the type and magnitude of the shocks assumed are critical to interpreting the estimated impact. Ignoring the export ban in the analysis generates a $6 billion difference and raises prices which alters the welfare conclusions. The assumed 10 percent demand reduction by U.S. consumers represents a $7 billion impact. The losses from animal removals are comparatively small.

Another important lesson is that modeling meat trade as net trade is not satisfactory and produces erroneous results. Meat imports and exports must be treated as distinct and the structure of import policies affects total supply adjustment.

Inclusion of the vertical linkages from consumer to producer is important in identifying the transmission of shock along the marketing chain. This point is emphasized in the paper by Pritchett, Thilmany, and Rosenstiel.

While the public and policymakers find changes in revenue and expenditure concepts they can grasp, economists do not interpret changes in revenue and expenditure as welfare measures. For example, the model results show a decline in expenditure. Is that a benefit to consumers or does it reflect lost consumption? For economic welfare it is important to know whether that decline occurs due to a lower price, lower consumption, or both. Thus, welfare changes are most often calculated as changes in producer and consumer surplus. Consumer surplus indicates the difference between the marginal willingness to consume and the price that the consumer must pay for each unit consumed. Producer surplus indicates the return to quasi-fixed inputs. That is, the difference between revenue and the variable cost of production.

Risk-linked trade interventions depend on changes in U.S. national welfare due to an outbreak. Thus, an issue investigated by Paarlberg, Lee, and Seitzinger (2003) is the relationship between changes in welfare measures and changes in revenue and expenditure like those reported for the agricultural sector model.

The paper argues that both producers and consumers must be de-composed to obtain accurate indications of welfare changes. Producers should be separated into those with animals that cannot be marketed following an outbreak and those whose animals are salable. Consumers should be de-composed into those where a structural change occurs in their preferences and those whose preferences remain unchanged.

When producers are separated into groups a divergence in welfare measurement occurs. Producer surplus assumes producers can alter output and adjust variable costs so the measure reflects either variable cost savings for lower output or variable cost increases for higher prices and outputs. Producers with animals that can be marketed retain that ability to adjust output and costs so producer surplus as a welfare measure retains its validity. Producers whose animals are not salable, either because the animals are infected or are within an exclusion zone, do not have output or cost flexibility. They incur the total costs of producing the animals, both fixed and variable, but have an animal of no market value. Thus, the measure of the change in their welfare is sales revenue foregone. The change in producer welfare for the sector is the change in producer surplus for the first group of producers and the foregone sales revenue for the second group.

Consumers are separated into two groups as well. One group experiences no change in demand structure because they know FMD offers negligible human health risk. Their welfare change can be measured by the change in consumer surplus.

The second group of consumers misunderstands the health risk and foregoes consumption. Thus, demand for the product by these consumers vanishes. Paarlberg, Lee, and Seitzinger (2003) argue that this group's welfare loss should be measured as total original consumer surplus. Doing so creates a methodological issue because the total consumer surplus is sensitive to the choke price for demand. A linear demand gives a unique choke price and provides a value for lost consumer surplus. Non-linear demands, such as constant elasticity functions, do not give a choke price. Generally the researcher selects a value for the choke price, but which value is used can dramatically alter the estimates. Higher values for the choke price boost the estimates of lost consumer surplus and magnify the welfare cost of the outbreak.

To demonstrate the modeling issues raised Paarlberg, Lee, and Seitzinger (2003) construct a partial equilibrium model of the U.S. beef and veal market using linear functions. They assume 1 million animals are removed from the market due to an FMD outbreak. Exports of beef and veal are banned. Two alternative potential consumer reactions are allowed. The base scenario assumes 5 percent of U.S. consumers stop eating beef and veal due to the FMD outbreak. A more extreme scenario assumes 10 percent of U.S. consumers stop eating the products.

Given these shocks, alternative measures of welfare changes are compared. With a supply elasticity of 0.61 from Marsh (1994) the change in sector producer surplus as usually calculated is -$1.286 billion. The change in total sector sales revenue is greater at -$2.0035 billion. Aggregating the welfare measures as argued gives a sector producer welfare loss of $1.4436 billion which lies between the other measures. The results suggest that using the change in sector sales revenue as done in the agricultural sector model overstates the producer welfare change. It should also be noted that as the supply elasticity falls to zero, the two measures converge.

The importance of de-composing the welfare change is more apparent for consumers. When 5 percent of consumers give up beef and veal consumption, those sensitive consumers lose consumer surplus of $2.56 billion. Consumers whose preferences are unaffected by the FMD outbreak gain welfare of $3.119 billion because the price of beef is lower due to loss of trade and the domestic demand reduction. The aggregate change in consumer welfare for the United States is a small increase of $559 million. The change in U.S. consumer expenditure is -$4.441 billion so the value calculated in the U.S. agricultural sector model is much different than the change in consumer welfare. Boosting the share of consumers that forego beef and veal consumption has two effects as the inward shift of the market demand is larger. One effect is that more consumers experience a welfare loss. The second effect is that the beef price falls more so the smaller number of unconcerned consumers obtain a larger gain. The first effect dominates. With 10 percent of consumers sensitive to FMD, those consumers lose $5.121 billion. Consumers that keep eating beef and veal gain $4.428 billion. The total effect is that U.S. consumer welfare is $693 million lower. The decline in total U.S. consumer expenditure of $8.204 billion is again much different than the total loss in consumer welfare.

Future Directions

The modeling work in the papers discussed here highlights broad areas which could be enhanced. One area is that of control options. Estimates of control costs are included in most of the empirical work, but those costs are based on older information and also need to be linked more strongly to the magnitude of outbreak. Stronger links to epidemiological work would improve the estimates. Ekboir, Jarvis, and Bervejillo (2003) use an epidemiological model for FMD developed in Australia to determine impacts of an FMD outbreak in the South Valley of California on the dairy industry in that state. They then use these results as input into a model of the California economy to determine the economic losses. Similar work needs to be done for the United States as a whole and would strengthen quantifying the impacts of an outbreak. Improved links to other sectors would improve empirical estimates. Capturing the vertical and horizontal linkages in supply chains is a critical component. Extending the analysis beyond agricultural commodities is also important. Poe (2002) shows that of the $12-13 billion estimated cost for the 2001 British FMD outbreak, $8 billion fell on the tourist industry. The costs to the agricultural sector were less than half of those for the tourism industry. General equilibrium modeling provides a vehicle to include the impacts of a livestock disease on other sectors of the economy.

Additional improvements in modeling animal and meat trade would help improve the quality of estimates. Existing models treat animals and meats as homogenous goods despite evidence of intra-industry trade. Recognition of intra-industry trade is vital to determining the impact of a livestock disease outbreak. Capturing intra-industry trade is facilitated by modeling meats as differentiated products. Source differentiated meat import demands have been estimated (Yang and Koo 1994). The need is for product differentiation by source, cut, and quality. Improved introduction of import rules for meats is necessary because such policies condition the supply adjustment following a disease outbreak. Animal trade has unique features yet to be reflected in the modeling. Some animal trade is in breeding animals to improve genetics. Some trade, like cattle moving from Mexico to the United States, is due to economies of specialization in production. Hogs and cattle move from Canada to U.S. packers due to spatial location of slaughtering and animal production. In the recent case of Bovine Spongiform Encephalopathy beef and cattle faced different trade barriers as exports of beef from Canada to the United States were liberalized sooner than was trade in cattle.

Consumer reactions to livestock diseases are critical to accurately measure the economic impacts. Yet we know little about such potential reactions. To what extent do consumers know the transmission risk? Do they respond to a disease transmissible to humans differently from a disease like FMD? Is their response sensitive to the consequences? That is, do consumers perceive differences between

Bovine Spongiform Encephalopathy and e coli? To accurately determine the welfare impacts of a livestock disease we need quantitative answers to such questions.

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