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Animal Disease Economic Impacts: A Survey of Literature and Typology of Research Approaches

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Abstract

Animal diseases such as bovine spongiform encephalopathy (BSE) are a threat to the animal product marketing sector and the broader economy. Policy makers and industry stakeholders seek a means of assessing a disease threat's economic impacts when evaluating prevention and mitigation measures. But, differences in the focus of the impact analysis (production level, market prices, welfare), level of analysis (geographically, marketing phase) and proposed policy alternatives all influence the analytical approach. This paper surveys previous research, focusing on methodological approaches and results. Drawing from past research and future economic data needs, a typology is developed to guide researchers when defining the scope and policy alternatives of various research approaches.

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Animal Disease Economics: Review of Research and Typology of Approaches

Animal disease outbreaks such as bovine spongiform encephalopathy (BSE) are a significant economic threat to the animal product marketing sector because the impacts of an outbreak can be quite costly and far-reaching. A recent BSE outbreak in the US and an earlier outbreak in Canada have crystallized concerns that consumers, livestock producers, and allied industries share about the economic impacts of animal disease and the complexity of estimating the size of such impacts. From a public perspective, policy makers seek an accurate assessment of losses due to animal disease when weighing disease prevention and mitigation alternatives.

Immediate impacts of a disease outbreak include a reduction in the productive capacity of the animal products industry and a subsequent reduction in the supply of meat products. At the same time, disease outbreaks may reduce the demand for meat and meat products. Allied agribusinesses bear an initial loss in the supply of meat products, and later, increased costs when locating and certifying safe food supplies. Previous analyses of animal disease impacts, policies and management are wide ranging both in focus (firm level effects vs. regional effects) and method (partial equilibrium analysis vs. input-output analysis). Yet, after a major disease and market event, stakeholders seek a single economic measure of loss, all-inclusive of impacts.

The current study is a synthesis of the approaches and suggests a typology of appropriate methods to address the economic impacts of animal disease in order to assist in defining future research. The objectives of this work are to summarize past work on animal disease (and other related market structure and policy analysis), provide a framework to show the complexity of defining impacts, and finally, present some potential synergies for integrating work done in various fields and at different levels to provide richer findings. The challenge to agribusiness leaders is to motivate the need for more research on the potential managerial implications of animal disease threats, better frame the research that guides public institutions and influences policy development, and thus, illustrate why more managers should take an active interest in the interpretation of research findings by regulatory and policymaking bodies.

A Typology of Approaches and Techniques

Animal diseases are an example of an invasive species, and Evans (2003) categorizes the economic impacts of invasive species into six areas: production effects, market and price effects, trade effects, impacts on food security and nutrition, human health and the environment, and financial costs (Food and Agricultural Organization, 2001). Disease impacts are generally easy to identify but may be difficult to quantify. In livestock, for example, delays in reproduction result

Table 1: Economics of Animal Disease Typology Matrix

Scope of Analysis	Research Objectives	Assessment Methods	Policy Instruments	Research Opportunity
Producer Impacts	Business Loss, Incentives for Control	Budgeting, Stochastic Simulation	Compensation, Testing	Epidemiological & Economic Models, Catastrophic Insurance
Allied Agribusiness Processors Suppliers and Supporting Activities	Lost Shareholder Wealth, Business Loss	Efficiency Analysis, Event Analysis	Production Practices, Certification, Traceability	Economic Geography, Market Structure
Consumer	Welfare Loss, Risk Assessment	Partial Equilibrium, CVM, WTP	Education, Certification, Information	WTP/WTA Assessment, Cross Species Substitution
Sector	Industry Losses	Simulation, Efficiency Estimation	Traceability, Certification	Post Harvest Models, Dynamic Models, Epidemiological Links, Market Structure, Distribution
Regional	Welfare Impact, Industry Specific Loss, Inadvertent Loss	I-O Models, CGE	Travel Restrictions, Compensation, Prescribed Cull	Economic Geography, Linking Economic & Epidemiological, Mitigation & Prevention Costs
National and International	Welfare Impact, Distribution of Loss	Partial Equilibrium, CGE	Regionalization, Rapid Response Plans, National ID, Tariffs/Non Tariff Barriers, Restrictions	Economic Geography, Distribution of Impacts

in fewer offspring, which has long term effects not easily measured in the present. Disease outbreaks often have broader, longer-term multiplier effects that extend beyond principle markets. Table 1 summarizes aspects of the animal disease literature, a literature that considers the direct economic losses of animal disease, and to a lesser extent, broader, long-term impacts. The rows of the matrix represent the level of analysis ranging from the individual producer level to the national level. The columns summarize selected characteristics including common research objectives, typical methods to assess related objectives, policy instruments used to manage impacts (e.g., quarantine), and potential research opportunities to improve methods of analysis and their subsequent estimates.

In short, Table 1 provides a typology of the research objectives and research processes when analyzing animal disease issues -- whether they be managerial, market or policy issues -- according to the livestock sub-sector of interest. As an example from the first row of the matrix, producer (firm level) studies of animal

disease economics are often directed at business losses and incentives for disease prevention/mitigation. Quantifying business losses is straightforward; standard budgeting techniques examine the loss of animals, business interruption costs, and disease mitigation options (e.g., Nott and Wolf). Yet, conducting such analysis (at any level of the market) requires establishing disease scenarios with specific epidemiological parameters for disease incidence and transmission. Stochastic disease elements used in these scenarios generally include:

- Geography – The location of the outbreak, size of the affected area, animal density, and frequency of mobility of affected animals are important variables in determining economic loss.
- Timing – The duration between the initial outbreak and pathogen recognition/response by animal health officials is an important determinant of economic loss. Losses vary proportionally with the time between introduction and response.
- Strategy – The strategy employed to prevent, contain and respond to the outbreak will influence the degree of economic loss. (Doering et al.)

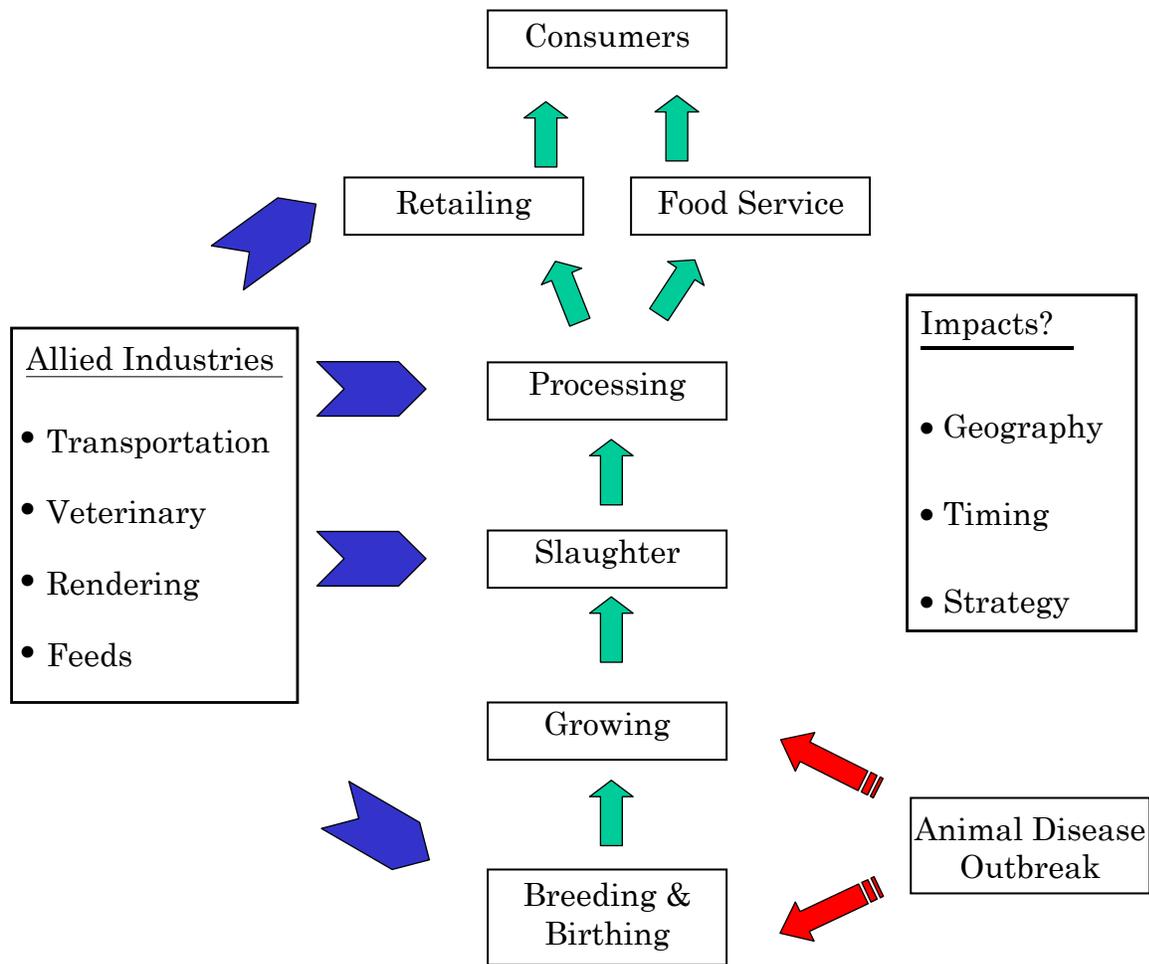


Figure 1: Animal Disease Impacts in the Marketing Channel

Figure 1 indicates how these stochastic disease elements interact with the animal products marketing channel. Disease effects are principally felt at two upstream production stages, the breeding stage and the growing stage. Ripples from these shocks are felt throughout the marketing channel and in allied industries such as transportation. Central to the illustration are production relationships that link the growth and development stages of livestock with the slaughter and fabrication of meat and meat products. In addition, economic relationships link each production stage by allocating scarce resources according to price signals.

Our goal with the literature summary and new categorization is to briefly describe the animal disease economic work conducted at different stages of the animal product sector, and summarize how research and approaches tend to be organized so that it is easier to determine how different research questions might need to be addressed. By understanding the current state of animal disease research, opportunities for integrating findings and approaches to expand the scope and value of empirical research will become evident, and may inform agribusiness leaders as to how they can help frame economic and policy research, thereby assuring a more accurate assessment of impact, as well as policy and regulatory development that takes the full set of managerial implications into consideration.

Producer Level Studies

The producer studies summarized in row 1 of Table 1 focus on the breeding and growing stages of the marketing channel and emphasize epidemiological impacts and idiosyncratic economic effects. More specifically:

- **Breeding & Birthing** – Studies in this production stage focus on impacts to livestock as they are conceived, gestated, and grown until ready for a feeding stage. Disease interruptions are of two types, the stock of breeding animals might be reduced constituting an overall reduction in productive capacity, and the flow of feeding animals may be delayed or interrupted. As an example, Sorenson, Houe and Eneveldsen consider these effects when studying bovine virus diarrhea in dairy herds.
- **Growing Stage** – Once meat animals have gained sufficient maturity, a growing stage prepares them for slaughter. Direct impacts of animal disease at this stage include increased mortality and morbidity, as well as reduced feed efficiency and lower average daily gain (Smith). Geographically, the growing stage tends to be more regionally concentrated than the breeding and birthing stage. Concentration occurs in part because of the relative transportation rates of livestock versus feed, and the technical aspects of livestock feeding reward specialization (Shields and Mathews).

Regional concentration of feeding operations has important implications when studying animal disease impacts and directly shows the interdependence between analysis levels since producer, agribusiness and regional analyses will all be influenced by this market force. Animal disease control strategies include the quarantine and non-transport of livestock, which disrupts input flows through the marketing channel to guard against interregional spread. Disruptions are reflected in higher prices for feeder livestock outside the quarantine zone, and regional differences in feeder prices may be greater than the cost to transport, indicating regional markets are no longer integrated. Regional quarantines may also limit movements of non-livestock enterprises such as tourists to recreational destinations, as was the case in Britain.

Consistent themes are found in the producer level studies. Disease epidemiology is central to the modeling effort and studied intensively, while the economic efficacy of best management practices is generally examined in a benefit-cost analysis. As examples, Bennet considers the direct producer impacts of animal disease, and Chi et al broadens the context to consider control and treatment costs.

Difficult challenges exist when attempting to marry economic models of disease outbreaks and epidemiological models. Clearly, economic modeling should extend beyond a simple accounting of business loss to include treatment and prevention costs (Chi et al). Including economic relationships within disease simulation models, rather than merely assigning economic values to output variables, may improve the quality of information provided to stakeholders. Likewise, economic models should integrate epidemiological information into productive and economic relationships rather than relying on ad-hoc scenarios, but these integrated models require intensive, cross-disciplinary efforts (see for example Groenendaal, et al; Vonk Noordegraaf et al). In addition, opportunities exist to evaluate disease mitigation strategies in stochastic, cyclical simulation models of the meat products sector. Indeed, producer incentives for adopting and maintaining disease best management practices may depend importantly on price expectations or the relative position of the herd in the price cycle.

As Wolf's article concludes (Exhibit 1), when considering disease prevention and mitigation strategies, agent behavior becomes important. Public institutions influence the behavior of private individuals through regulations, mandates and legislation, and can create incentives with indemnity payments. Still, catastrophic insurance for livestock disease is enjoying increased visibility as evidenced by a 2002 conference and upcoming book from USDA-APHIS on livestock insurance issues.

Exhibit 1: Producer and Policy Impacts: The Case of Johne's Disease

Wolf's article illustrates that eradication programs are only adopted by livestock managers when there are positive private returns. In cases where managers don't have sufficient private incentives but social costs of the disease are high, several areas of public expenditure might be justified. These include adding information that allows producers to effectively assess the benefits from potential biosecurity and disease control decisions, research to improve test efficacy or subsidies to the price of disease tests.

- Bounties or indemnity payments must be large enough to encourage compliance without being so large as to encourage "manufacturing" newly diseased animals.
- Previously, the dairy industry successfully removed breeding animals to control supply (2003-04) and one could imagine an industry-funded program such as this that paid a premium for Johne's positive cows (or herds with high prevalence rates), thereby lowering the industry disease prevalence and simultaneously shifting supply back.
- Finally, state policy makers might consider a requirement that all cows be tested Johne's free in order to qualify for the subsidized finance programs to encourage dairy expansion.
- Economists can utilize bioeconomic models to inform policy-makers on the optimal value and method for subsidies so they are effective matching private incentives with optimal social outcomes.

Understanding where the private response may occur can facilitate more accurate disease prevalence paths and therefore more accurate cost and benefit estimates.

Agribusiness Level Studies: Meat Processors

The initial shock of an animal disease outbreak is manifested at the producer level, but ripples are quickly felt by upstream and downstream agribusinesses. As indicated in the second row of Table 1, it's useful to categorize these firms into three types: meat processors, input suppliers and supporting activities. Animal disease outbreaks disrupt agribusiness operations in many ways. Meat processors suffer from a physical loss of meat products, the additional cost of certifying safe food supplies, a potential negative demand shift and perhaps a persistent loss in consumer confidence. Processors are found downstream in the marketing channel, including:

- Slaughter Stage – In the slaughter stage, livestock are harvested and fabricated into meat products. Firms may also sell primal and subprimal cuts to purveyors or processors that transform the raw products into a form meeting customer

needs. Slaughter firms are also beginning to market case ready meats in grocery stores and supermarkets.

Slaughter prices reflect the relative supply and demand for livestock carcasses, while wholesale prices reflect the demand for processed meat products. The value added for this stage of the marketing channel totaled more than \$39 billion in year 2000 (ASM). Initial price shocks due to animal disease can be quite dramatic in this stage of the marketing channel. The late 2003 BSE outbreak in the US dropped choice boxed beef prices by 13% between December 22nd and January 8th, while fed cattle prices fell 20% during the same time period. The negative impact (married with other economic forces) on the slaughter industry persisted throughout 2004.

Because slaughter facilities are concentrated in a few regional locations, animal disease control strategies that limit livestock transport may produce substantial increases in costs. Furthermore, agribusiness may bear the additional costs of certifying safe food supplies. Recent actions by the Food and Drug Administration and the US Department of Agriculture suggest that private entities will be required to more closely track and report animal product shipments, thereby requiring packers to shoulder part of the cost of tracing disease outbreaks.

Wholesalers – Wholesale purveyors provide ready-to-eat meals, case ready meats and frozen products to retailers, including Sysco Corporation, US Food Service, and Performance Food Group. In 1997, the wholesale meat trade had sales totaling more than \$57 billion (US Economic Census). Because the stock in many of these firms is publicly traded, share price reductions may be used as a proxy for perceived, long-term business losses associated with animal disease.

Retailing and Food Service – The retail meat trade represents the end point of the meat marketing channel. The retailing sector can be divided into two subsegments, retail food establishments (i.e., grocery stores and supermarkets) and food service establishments (restaurants, distributors, institutions). Retail food establishments, including specialty food stores and meat markets, grossed more than \$107 billion in meat products sales in 1997 (US Economic Census). The largest retailers in terms of sales include The Kroger Company, Albertson's Inc, Safeway Stores, and Wal-Mart Supercenters (Kaufman).

Retailers will be the first to face the effect of consumers' concerns regarding animal disease. And on the supply side, they are not immune to the effects of supply shortages, and may absorb some of the costs of locating and segregating safe food supplies. As a result, retail meat prices are likely to reflect, to a certain extent, the scarcity of meats, and the consumer response to animal disease outbreaks.

Slaughterers, wholesalers and retailers of meat products each stand to suffer from an animal disease outbreak, but quantifying these economic losses is challenging

relative to producer or consumer studies because of the proprietary nature of business. Quite simply, proprietary agribusiness data is limited and expensive to obtain. Despite these limitations, opportunities exist to study agribusiness losses using event analysis and econometrically estimated efficiency models that exploit plant level data.

Event analysis is a means of characterizing the economic impact of shocks (such as animal disease outbreaks) without detailed analysis of firm productivity, for example, the impact of government price reports (Colling and Irwin), new government regulations on the meat packing industry (e.g., Johnson, Mittlehammer and Blayney) and meat recalls (Lusk and Schroeder). Intuitively, efficient financial markets capture the perceived long-term impact of exogenous shocks in publicly traded share prices. Henson and Mazzochi recently examined the impact of BSE on agribusiness in the U.K. and found it resulted in abnormal negative returns in the beef, pet food, animal feed and dairy sectors. In contrast, non-beef meat firms experienced positive abnormal returns after the disease shock.

Event analysis of equity shares does have limitations. In particular, the share information is available for publicly traded companies, and shocks to private firms may be more difficult to approximate. Agribusiness firms often have highly diversified business units, and it may be difficult to disentangle the economic effects of a particular event from equity price movements because of the firm's financial structure. However, firm level idiosyncratic data (such as that found in the Census Bureau's Line of Business Survey or perhaps from the Grain Inspection, Packers and Stockyards Administration) may be used to disaggregate the economic shock into various agribusiness sectors. Doing so requires the use of complementarity conditions and the estimation of substitution elasticities in a manner similar to Macdonald and Ollinger.

Newly mandated production practice or product certification measures might disrupt agribusiness cost efficiencies. Who bears the costs of regulatory mandates is important and depends on the relative bargaining power of agribusiness and spatial nature of disease incidence and transmission. Consequently, a firm's specific cost and geographic data is a great advantage when exploring potential impacts. Using the Census Bureau's Longitudinal Research Database and USDA-NASS livestock statistics, measures of spatial market structure may be developed similar to Ellison and Glaser, and these measures can be integrated into a distributional study of disease impacts. Decreases in productive efficiency might also be simulated using plant level revenue and cost data from the USDA Grain Inspection, Packers and Stockyards Administration as Paul did when measuring market and cost structure in the US beef packing industry.

Agribusiness Level Studies: Input Suppliers

Input suppliers will also face business shocks from an animal disease outbreak.

- **Feeds and Feeding** – If a disease outbreak leads to widespread mortality and a reduction in the supply of live animals, smaller quantities of feed and feed supplements will be needed. In contrast, if animal disease leads to a simple reduction in feed efficiency, additional feedstuffs will be bid away from other sectors to support livestock feeding. Furthermore, if livestock transportation is restricted, regional feed price relationships will be altered. Regulations of feed and feed products may also be part of a broader disease prevention strategy. For example, the use of bovine blood protein in milk replacer may be abandoned. Secondary effects will occur both for wholesalers of processed feeds and to the purchasers of raw feed ingredients (i.e. corn, soybean meal). Linkages between the livestock and feeding industries have been explored in the general agricultural economics literature (e.g., Chung and Buhr), but no work on regional shocks to either sector have been conducted.

The value of feed mixed on-site was \$6 billion in 1997, and the value of prepared feeds purchased off site was more than \$2 billion in the same year (US Economic Census). According to the USDA's World Agricultural Supply and Demand Estimates, roughly 50% of corn supplies and more than 50% of soybean supplies are used in livestock feeds (USDA-WASDE).

- **Veterinary Services and Medicines** – An animal disease outbreak will necessitate an increase in veterinary services such as testing and vaccinations in the short-run, and, if sufficient numbers of livestock die or are destroyed in terms of remediation, may actually reduce demand for other health services in the long-run. Periodic surveys by USDA/APHIS/VS/CAHMS chronicle ongoing veterinary medicine practices (USDA-APHIS), and the same organization is developing internet based livestock tracking systems.

Agribusiness Level Studies: Supporting Activities

Sectors that indirectly support the livestock sector will also be impacted including:

- **Transportation and Trading Services** – Relatively little research has focused on the transportation of livestock and meat products (shippers, brokers, insurers, traders) with the notable exception of the recent report by Shields and Mathews. If livestock sales, exports or movements were halted to reduce the transmission of a disease outbreak, one would expect higher costs for producers who are unable to move livestock to be marketed (Shields and Mathews). Mathews notes that local truck hauling and long distance hauling transportation generates \$65 billion annually in revenues and employs 62,300 workers.

- Rendering – Disposal of diseased animals may represent a challenge for the industry depending on the size of the outbreak, the associated mortality rate, and the nature of the outbreak. If diseased animals may be used in traditional rendered products, total revenues may increase or decrease depending on how rendered product prices change relative to the increase in supply. However, if diseased animals cannot be used in rendered products, or if transportation restrictions stop the flow of rendered inputs, rendered product outputs could fall. Regulations governing the slaughter of sick, downer livestock and new meat processing regulations are likely to increase demand for rendering services in the near term.

Consumer Level Studies

A negative demand shock is anticipated in an animal disease outbreak; however, additional questions include whether the shock results in a permanent change in consumer preferences, if all meat products bear demand loss equally, and the extent to which losses in consumer surplus are offset by increased purchases at lower prices. Recent consumer studies of animal disease outbreaks applied ex post analysis of lost sales rather than losses in consumer welfare, with BSE in the United Kingdom as a heavily studied example (Ashworth and Mainland; Verbeke and Ward; Henson and Mazzochi; Thompson and Tallard; and Pennings, Wansink and Meulenberg) although a number of European nations have also suffered outbreaks.

BSE has received a higher share of consumer analysis relative to other animal diseases (Exhibit 2). To date, four well publicized outbreaks of BSE or “mad cow” disease have occurred: a 1986 discovery by British scientists in the UK with a subsequent link between mad cow disease and the human version of the pathogen established in 1996; a Japanese outbreak in 2001, a Canadian outbreak in May 2003; and a US outbreak in December 2003.

The consumer response to BSE has varied internationally (Exhibit 2), but additional economic study is needed to discern if changing prices influence demand changes. It should be noted that gained/lost sales is not an economic welfare measure, so that the approach to measuring consumer welfare changes is itself an issue (Paarlberg, Lee and Seitzinger, 2003).

Information and its management are important in maintaining consumer confidence during an animal disease outbreak. As noted by Pope, the Canadian government’s transparency was important in maintaining consumer confidence following the May 2003 BSE outbreak. Negative media coverage can create substitution effects from one meat product to another (Verbeke and Ward) or might be responsible for a negative demand shock in all meats (Burton and Young). Henry

Exhibit 2: Consumer and Policy Research on Mad Cow Disease (BSE)

Animal disease may prove to be a human health risk or may entail a significant consumer response, as is the case with “mad cow” disease. Mad cow disease, also known as bovine spongiform encephalopathy (BSE), has a strong epidemiological link to a fatal human disorder in humans called variant Creutzfeldt-Jakob Disease (vCJD). Between 1994 and 2004, 151 human deaths have been attributed to vCJD, and in Britain more than 180,000 cattle have been diagnosed with BSE since 1988.

Research into Europe’s experience with BSE illustrates how several economic methodologies are used to capture the impact of a large animal disease event. Consumer surveys and secondary demand analysis have been used to quantify reductions in consumer demand for beef, while other researchers have used survey techniques to track the impact of the media on meat consumption.

- Consumer response to BSE outbreaks has been quite varied across nations (Jin, Skripnitchenko, Koo)
- BSE has created a negative structural change in consumer preferences in Europe and Japan (Mangen and Burrell; Jin and Koo; Peterson and Chen).
- Thompson and Tallard find long-term beef demand reductions approaching 25% of their original value in Europe.
- The U.S. Food and Drug Administration (FDA) estimates a loss of \$15 billion in sales revenue, resulting from a 24 percent decline in domestic beef sales and an 80 percent decline in beef and live cattle exports if a US outbreak were to occur. Slaughter and disposal costs of at-risk cattle would be at least \$12 billion.

The third article in this series (Sumner, Bervejillo and Jarvis) summarizes the government response to the consumer concerns raised by BSE outbreaks in Europe, Japan and the United States. Because BSE is not a communicable disease, most of the response has focused on updating cattle feeding standards to prevent disease transmission, revising cattle slaughter regulations, and restriction of imports from countries whose cattle have tested positive for BSE.

argues that factual and thorough scientific information must be provided to consumers during an outbreak and third-party collaboration between government agencies and private industry is an effective means of conveying scientific information to the media.

Information needs have encouraged policy mandates for animal identification systems, and who must bear the cost of tracking systems and how sophisticated

such systems must be is an important policy question. Absent from the discussion is the consumers' willingness-to-pay for source assurance, though work has been performed along this vein with policy issues such as country of origin labeling (Loureiro and Umberger). Following Pope and Henry's discussion of the need for clear information, Latouche, Rainelli and Vermerschhave used contingent valuation when studying consumer response to BSE in France finding consumers are willing to pay for increased transparency. Adda disentangles the effect of past exposure to risk on further risk taking behavior among French beef consumers, finding those with medium-sized consumption levels decreased demand and sought higher quality products after negative BSE news.

Sector Level Effects: Modeling the Entire Meat Marketing Channel

The previous rows of the literature matrix focus on individual economic agents (i.e. producers, businesses and consumers). But often, a single measure that represents the true "economic loss" to a sector, region or country is what is needed. The subsequent rows of the literature matrix take a broader view of economic impacts necessitating the study of technical and economic relationships that link economic agents together. In particular, studies of the animal products sector closely resemble Figure 1's concept of shocks in the upstream stages that are transmitted downstream.

Characteristics of complete meat sector studies are found in the fourth row of Table 1. As an example, a recent FMD outbreak in the United Kingdom has been the subject of several economic impact analyses. A report by the UK's Department of Environment, Food and Rural Affairs suggests a 3.1 billion pound sterling impact on agriculture and the food chain from FMD in 2001, of which 1.9 to 2.3 billion pound sterling are attributed to agribusiness sectors beyond the farm gate. In Canada, Leroy and Klein chronicle the substantial short-term costs to federal and provincial agencies of responding to a single case of BSE, including the public cost of indemnifying cattle feeders against large business losses.

Research suggests that the structure of the meat products sector is changing with the advent of more value-added or ready to eat meals, which will impact how disease shocks to commodity prices and food cost changes are transmitted through the marketing channel. Paul and MacDonald find that disembodied technical change, likely the result of value-added or ready to eat meals, has reduced the demand for agriculture inputs relative to other marketing inputs resulting in weaker impacts of farm level shocks on food prices. However, improving quality and real price declines of agricultural inputs has encouraged greater use. This is a nice example of how relevant agribusiness research might be integrated into economic impact analyses.

Recent models of antibiotic removal from livestock feed have used a sector approach. As an example, Hayes et al estimated the likely economic effects of a subtherapeutic ban of antibiotics on the U.S. pork industry by marrying technical assumptions in pork production with economic relationships in a meat sector model developed by Buhr. This type of modeling allows for both stock adjustments in livestock breeding herds as well as the flow effects associated with exogenous shocks. Buhr and Kim use a similar approach in their examination of dynamic adjustment in vertically linked markets. Additional insight may be gained as epidemiological models are integrated with sector modeling, together with consideration of market structure.

Regional Level Effects: Impacts across All Industries

Economic losses in an animal disease outbreak are not limited to the meat sector and its allied agribusinesses. Rather, entire regions may suffer from the outbreak due to multiplier effects associated with lost sales and wages, and because disease mitigation strategies such as travel restrictions or consumer response alter non-meat business activity (Table 1, row 5).

As mentioned previously, the impact of the 2001 FMD outbreak in Britain totaled 3.1 billion pound sterling on agriculture and the food chain in 2001, but regional impacts were higher. Since the UK has a relatively small livestock sector, it is not surprising that the impact to agriculture would be matched by a decline in tourist expenditures that totaled an additional 2.7-3.2 billion pounds sterling (DEFRA). Blake, et al. extended the discussion of broader impacts by noting that lost tourism represents an even greater impact on a region's GDP losses because of the tourism sector's higher multiplier. By ranking affected sectors, Blake, et al found that hotels and pubs were the biggest relative losers from the outbreak, followed by railway transport, road transport, milk products, and slaughtering/meat processing.

Ekboir estimates \$13.5 billion of potential losses to an FMD outbreak in California in the US. The estimates are generated using IMPLAN input-output analysis and include direct losses to livestock producers, disease control costs including depopulation, and indirect or imputed losses to businesses. Input-output (I-O) models are often used to generate regional economic impacts, and quantification relies on multipliers, which may be imperfect, but could potentially be refined with analyses done at other levels of this matrix. For example, careful attention to potential travel restrictions, the size and distribution of relevant firms (economic geography) and the costs of disease prevention-mitigation strategies are opportunities to refine baseline analysis.

Ekboir's estimates also show that there is great sensitivity to how quickly the disease is transmitted, the particular depopulation policies imposed and the speed with which depopulation occurs (following the discussion on the nature of shocks

Exhibit 3: Regional and International Research on Foot and Mouth Disease

While not a human health concern, foot and mouth disease (FMD) can significantly disrupt the meat industry because it is highly contagious, necessitating limitations on livestock travel, the prescribed culling of infected/exposed animals and restrictions on trade. Further, FMD quarantine may impact local tourism and travel, as was the case with the UK's outbreak in 2001. Sumner, Bervejillo, and Jarvis discuss the policy responses to FMD, and managerial implications, later in this series.

Highly infectious diseases require many restrictions on industries, and as a result economic effects are broad and far reaching.

- Paarlberg, Lee and Seitzinger illustrate the importance of decomposing the disease impacts according to those actually impacted by the disease and those that may actually benefit from reduced competition.
- They also suggest that efficiency gains exist by establishing import restrictions based on the likelihood of animal disease outbreaks rather than an ad hoc, all-inclusive barrier.

Internationally, the Australian Productivity Commission used three hypothetical FMD outbreak scenarios to find that value of exports, in the year following the outbreak, would face reductions ranging from \$3 to \$4.7 billion depending on the scenario.

The domestic market's decrease in revenue is less than the loss of export revenue, but still represents an additional \$2 to \$2.7 billion.

from the producer section). Ekboir does assume meat export losses (domestically from California to other states and internationally) are a substantial portion of total economic impacts (\$6 billion of the \$13.5 total), with only \$1.4 billion attributed to direct production losses, suggesting the importance of attention to national and international trade and management policies.

National and International Level Effects

Due to the spillover effects of animal disease, disease mitigation strategies and the economic size and distribution of impacts are often computed at the national level. National studies include both domestic effects and the extent to which trade flows are altered as a result of the disease outbreak. In many instances, national data is

readily available; yet, this data may not be easily disaggregated to consider sub-national policy tools such as regionalization.

A 2002 Canadian study of a potential FMD outbreak focused primarily on trade impacts, as Canada is a large net exporter of many livestock products (\$8 billion plus in annual exports) (Serecon). The total net impacts of an outbreak would range from \$13.7-45.9 Canadian, depending on whether the outbreak was small-(50 herds over six weeks) or large-(1500 herds over six months) scale. Of the total impacts, more than half are attributed to trade losses, and given the livestock sector's significant role in Canadian agriculture, the long-term costs of an outbreak could represent as much as 80% of Canada's 2001 agriculture cash receipts.

Paarlberg, Lee, Seitzinger (2002) estimate losses to the US of a potential FMD outbreak if the magnitude were similar to that experienced by the UK. Total losses to US farm income are estimated a \$14 billion including a 7% reduction in domestic consumer expenditures. Of the total loss, \$7 billion is due to a negative consumer reaction, \$6 billion dollars is lost exports, while the remainder is attributed to on-farm losses (a small residual that is consistent with Ekboir). The authors suggest a need to decompose these gross effects into the components borne by individual groups including producers affected by the disease and those that remain disease free. In their more recent work, Paarlberg, Lee, Seitzinger (2003) found that some producers may actually benefit from an outbreak provided prices increase and export losses are ignored.

Jin, Skripnitchenko and Koo consider the ex ante effects of the US outbreak of BSE using scenarios that assume reduced domestic consumption (5 to 20%), and decreased export scenarios (50 to 100%). The authors' simulation results indicate the price of beef could decrease by 15%, while the price of beef substitutes would increase about 3% as consumers switch consumption to pork and poultry. The price of fed and feeder cattle is expected to decrease 13.5% and 16%, respectively. The authors' base simulation of a single case of BSE does not consider potential productivity shocks due to culling, or the increased costs of new disease prevention measures.

Future Directions

Understanding how an animal disease event will impact the animal products marketing channel is a complex, multidisciplinary problem. An accurate assessment of losses due to animal disease is useful for policy makers who may weigh these potential losses against the costs of disease prevention and mitigation, and models that provide the most comprehensive assessment of potential losses are most useful to decision makers (GAO). This paper summarizes the economic approaches to quantify economic loss ranging from individual agent impacts (producers, consumers, businesses) to broader, inter-sector impacts (sector, regional and

national/international studies) to provide the reader a baseline of information on what is already discovered. Using an animal disease economics typology, this paper suggests opportunities for integration and consideration among the different veins of analysis.

Several future directions exist for animal disease studies at each of the various market levels, which can subsequently feed better baseline data to broader sector, regional and national analyses. To appropriately model a wide variety of animal disease impacts, a system of economic relationships is needed that accounts for the interdependencies and degree of response (elasticities) among the various production, marketing and consumer sectors of the economy, and which allows for sensitivity analysis of the magnitude and incidence of the initial animal health shock. Interdisciplinary work should encourage the merger of epidemiological models used to trace the growth and demise of disease outbreaks and economic models that capture the direct and indirect economic relationships linking stages, potential structural change and performance of the marketing channel.

As policy makers explore strategic responses to animal disease, the distributions of losses, policy costs and program benefits becomes particularly important, as Paarlberg, Lee and Seitzinger (2003) conclude in their work. Potential economic losses include higher prices or diminished satisfaction for consumers, and producers may face lower sales prices or limited markets. But, some individuals actually fare better after an animal disease outbreak, such as producers who are not quarantined, or consumers who are uninfluenced by animal disease outbreaks (and who are able to buy at lower prices), an issue for future researchers to consider.

The spatial dimension of animal disease also deserves additional attention. Too often data limitations prevent analysis of spatial economics when evaluating outbreak scenarios. The National Animal ID system allows for space to be added as a dimension for analysis, but the location, geographic distribution, and movement of animals must be linked to economic data (e.g., market prices) to show the full effects.

Finally, market structure plays an important dimension in determining the distribution of losses associated with an animal disease outbreak. Studies from the industrial organization literature, particularly those that combine measures of market power in economic space, are useful considering the role that market structure plays in the impacts of animal disease. An interesting question is whether the traceability and product certification costs of new regulations will increase the pace of agribusiness consolidation, or vice versa.

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