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A review of economic tools for the assessment of animal disease outbreaks

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Summary

This paper demonstrates how currently underutilised economic modelling techniques can enrich the analysis of animal disease problems. Increasingly, analyses of animal health programmes are expected to address a range of economic and social questions. These expectations can be addressed by better integration of epidemiological modelling with economic techniques whose application to animal health has not been thoroughly discussed in past reviews. This paper describes a range of economic models that can be applied in animal health research and provides guidance for determining the appropriate method given the issues at hand. The complexity of some of these approaches underlines the importance of multidisciplinary research and education.

Keywords

Animal health economics – Benefit-cost analysis – Disease control – Mathematical programming – Partial equilibrium – Policy model – Risk analysis.

Introduction

Policy-relevant assessment of animal disease control often requires analyses of the economic impacts of a disease outbreak. In response, models that marry epidemiology and economics are increasingly represented in the literature and researchers are using progressively more sophisticated economic methods (2, 3, 12, 14, 16, 25, 26, 31, 37, 41, 45). Nonetheless, many economic methods remain underutilised and potentially important questions are not addressed. The growing relevance of complex economic methods in the analysis of disease control has created a need for a review of economic modelling techniques as they relate to animal health problems. While many of these tools are not easily accessible to practitioners without specialised training, they demonstrate the potential usefulness of economic analysis and thus highlight the need for greater collaborative and multidisciplinary work among economists, veterinarians, epidemiologists, and other animal health professionals.

This paper presents a typology of economic methods and offers a critical analysis of five types of economic models, with examples given from the literature. The goal is to convey the range of questions that these models can address and to provide a sense of their different strengths. Mechanisms for enhancing economic approaches and areas for future research are discussed in a companion paper (42).

Range and functions of economic models

Quantitative economic models may be especially useful when setting priorities among health problems and when choosing strategies for addressing a specific disease (36). However, priorities and policy options can be suggested by a host of different economic models, each addressing different economic aspects of a problem. Therefore, the specific underlying question is central in determining which economic model to use. Economic questions usually relate to one or more of the following issues: costs, prices, international trade, national welfare, or jobs. Specifically:

a) costs to producers or to government budgets are routinely considered in the economic analysis of animal disease

b) prices may be affected dramatically by disease, influencing costs to producers and consumers. Analyses that ignore these price effects may be misleading

c) international trade is increasingly important in livestock industries and disease status often generates reactions from regulators and consumers which subsequently affect product prices and disease costs

d) national welfare may be affected both directly through impacts on production costs and prices and also indirectly through inter-industry linkages. For example, the effect of foot and mouth disease on tourism in the United Kingdom revealed that substantial animal disease costs may be borne by agents that are not considered in a narrow assessment of costs to producers and Veterinary Services (5)

e) employment in the livestock sector and in other areas can be a critical issue for some regions or countries and is affected by animal disease outbreaks.

The relative importance that stakeholders give to these different economic issues can help to narrow the choice of assessment method.

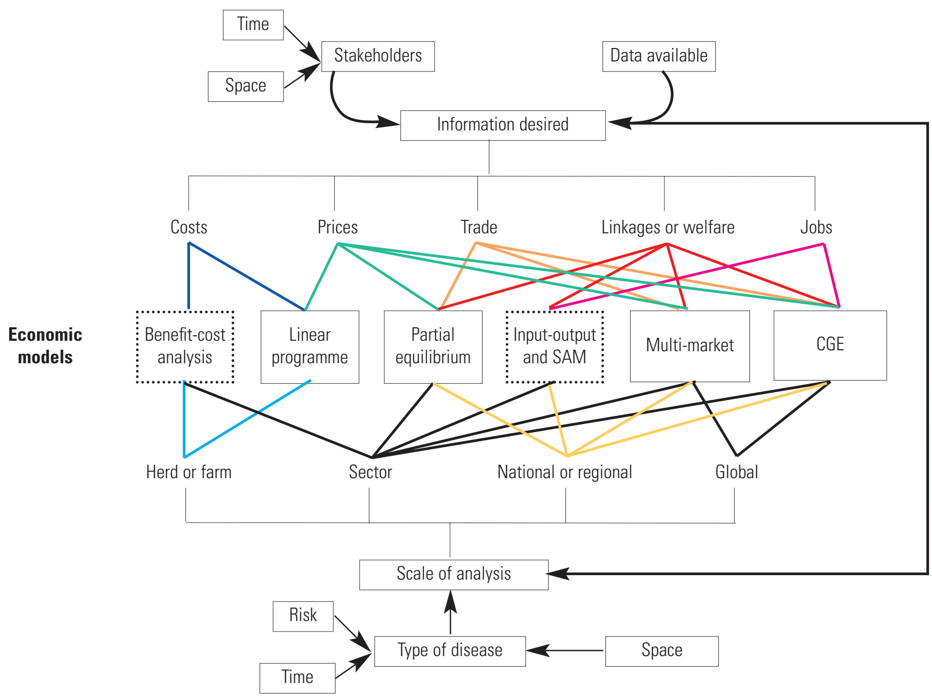
Questions posed about any of these issues typically have a specific scale of analysis implied (e.g. herd, sector, or nation), but scale does not define a specific question. Multiple questions can be posed at any scale and analysis at one scale may be needed to address questions at a different scale. Analysis of an international market, for example, may provide information on prices that is needed to assess the farm-level costs of a disease outbreak. Nonetheless, economic methods are differentially suited to different scales.

The importance of time, space, and risk also bears on the choice of economic method, as these factors are not treated equivalently across methods. Some policy issues and decisions that have short-run (immediate) impacts may be addressed well by some methods, while issues that relate to the long-run effects of an outbreak may require very different analytical approaches. Spatial considerations influence the analysis depending on the interaction among groups and features of the disease. Data allowing spatial issues can be overlaid onto most models as needed.

Like temporal and spatial considerations, the importance of risk varies with the nature of the disease and can influence the choice of economic model. Risk can be particularly important in evaluating the economic impacts of disease control programmes that affect the biological variability inherent in animal production. Moreover, it can be argued that many current animal disease policies related to the international trade of animals and animal products incorporate explicit rules that reflect an implicit stance on disease risk minimisation or disease risk avoidance. Risk considerations can also be overlaid onto most of the economic methods described below, through the incorporation of stochastic shocks using Monte Carlo methods, for example, or through sensitivity analysis on various model parameters. Note that the emphasis here is on the economic side of risk models; decision-tree and pathways analysis that examine the epidemiological aspects of risk are not included here, though they are often an important component of economic analysis.

Figure 1 provides a typology to relate economic methods that can be used in animal disease analysis to the information needs and scale of interest. In the diagram, information desired and scale of analysis depend on stakeholders, data availability, and the risk, time, and spatial aspects of the disease analysed. At the top of the figure, stakeholders and data availability determine the type of information that is desirable and possible to derive. This in turn affects the scale of analysis, noted in the lower half of the figure. Among other things, stakeholder interests may be specified in terms of a time horizon or a geographic concern. The relevant scale of analysis will also depend on the disease type. Issues of uncertainty, time, and space define the disease type for the purpose of economic analysis and influence both the scale and economic question of interest (11).

Six types of economic models are identified in the diagram: benefit-cost analysis (BCA), linear programming (LP), partial equilibrium analysis, input-output (I-O) models and social accounting matrices (SAMs), multimarket models, and computable general equilibrium (CGE) models. Multiple economic models are available for any scale of analysis and for each type of information requested, but none is universally appropriate. Combining the two criteria of scale and information narrows the options, but rarely isolates a single dominant method (31).



CGE: computable general equilibrium
SAM: social accounting matrix

Fig. 1
Typology of economic models for animal disease analysis
Models boxed in solid line are more capable of accommodating time considerations than those boxed in dashed line

Thus, the specific model to apply must be chosen with some reflection. The following review of the methods identified in Figure 1 outlines their advantages and disadvantages and the contexts in which each is most appropriate.

Economic models applicable to animal health issues

Benefit-cost analysis

Overview

Benefit-cost analysis is based on budgets for specific activities and is used frequently to measure the costs of animal disease outbreaks. (Rushton, Thornton, and Otte [43] distinguish between BCA at the national or sector level and budgeting techniques at the farm or herd level; similarly, Dijkhuizen, Huirne, and Jalvingh [11] differentiate between partial budgeting and BCA. Because of the methodological similarity in their reliance on activity budgets, the authors treat these approaches as different forms of BCA [8].) Rushton, Thornton, and Otte (43) provide a thorough review of BCA as applied to animal diseases at the herd and farm levels. In general, BCA examines changes in the profit or income structure of a farm, commercial operation, or public agency. These budgets can be expressed in market prices or shadow prices that reflect non-market values as well.

The budgets in BCA are often combined with an epidemiological model to conduct simulations of alternative disease mitigation strategies to determine changes in profits or programme costs under different scenarios. Some dynamic considerations can be modelled by projecting a series of budgets over time and discounting the projected future revenues and costs at an appropriate rate. Results may be summarised through the computation of the net present value (NPV), which is the discounted stream of benefits minus costs attributable to some project or intervention; the benefit-cost ratio (BCR), which represents the present value of benefits as a share of the present value of costs; or the internal rate of return (IRR), which estimates the effective interest rate earned on the activity. An NPV greater than zero, a BCR greater than one, or an IRR exceeding the reference interest rate each imply that an investment has a positive return. Although BCA may be multi-period, changes in inputs, outputs, or prices over time must be set deterministically by the researcher. The BCA can incorporate risk through the use of probability distributions rather than point estimates in the stream of benefits and costs. The Excel spreadsheet add-on @Risk, for example, allows the use of probability distributions for any value in a budget to incorporate stochasticity in the model.

While BCA has been combined with epidemiological models to gauge short-run, farm-level impacts of a disease outbreak, the method is not well suited to measuring longer-term dynamic effects or impacts at broader scales (Fig. 1). This weakness follows from the reliance on fixed budgets with pre-determined I-O coefficients and no endogenous links to other sectors of the economy. In a multi-period BCA, a researcher may project changes in budgets *a priori*, but the model cannot allow for endogenous changes in behaviour, market conditions, or productivity. Because the BCA framework does not allow producers to find the optimal response to a disease shock (e.g. by changing technology) it may overstate its impact, especially over the long-term when producer responses are more likely.

Aggregating over many farms, the change in production caused by a disease outbreak could influence total market supply and affect prices for both the product and for substitutes and complements. These price effects, which cannot be estimated in a BCA framework, will affect the costs of the outbreak. Scaling up BCA results from a representative herd to a region or nation will misrepresent costs if there are price effects, if there are substitutions in production, or if there are spillovers into other markets or sectors. These dynamic and spillover effects are likely to be more significant over the long-run and when shocks are more widespread. Thus, BCA is more appropriate for the analysis of the short-term effects of isolated disease issues. If linkages to other sectors are limited, price effects are unlikely or easy to forecast, and producer responses can be accurately projected in multi-period budgets, then analysis of impacts at more aggregate scales and longer periods may be possible with BCA.

Applications

Examples of BCA applied to animal health issues are numerous, but typically relate to costs at the herd or farm-level (40). The studies mentioned below (Table I) reveal the capacity to integrate detailed information on disease in the analysis of economic outcomes on a particular farm. Meuwissen *et al.* (27) and Neilen *et al.* (32) traced the budgetary impacts of an outbreak from the farm and through the food processing chain, but not into other parts of the economy. Results based on representative herds or farms can be aggregated up to reflect costs at a higher level, but this is only representative if price effects and spillovers into other sectors are small.

Linear and mathematical programming models

Overview

Linear programming techniques derive the optimal solution to a maximisation or minimisation problem. For a farm-level analysis, the problem could be finding a way to maximise profits that are subject to some physical and market constraints. The constraints typically define relationships between the level of inputs and the level of output. In this way, LP may be based on budget information used in a BCA. However, rather than assuming a certain production behaviour at the farm level (e.g. production of range-fed beef), the constraints in LP may specify budgets for a range of different farm activities, with the optimisation procedures thus determining the optimal combination of production activities.

Because the optimisation process allows for changes in producer behaviour given changes in conditions, LP can better deal with long-term impacts than BCA. For example, an epidemiological model might imply a pattern of changes in biological parameters (e.g. the infection rate) over time, which could change the profit-maximising production technique. While the evolution of constraints must be specified by the analyst, the behaviour of producers will be determined endogenously in the program. The optimisation problem may specify objectives other than profit maximisation and need not be limited to the farm-level. For example, programming models could take the perspective of an optimising government agency, minimising expenditure on veterinary costs to eradicate disease, subject to evolving resource and technical constraints. Alternatively, multiple objectives could be accommodated as explicated in Romero and Rehman (40).

Linear programming can be adapted to assess production risk in decision making. For example, portfolio theory has evolved to address the problem of finding a mix of activities that maximises expected returns while minimising risk (or variance in returns); such problems in LP are known as mean-variance problems (26). An application of portfolio theory in the context of animal disease could include an evaluation of a mix of various veterinary interventions with known costs and improvements in production efficiency. The program chooses the mix of animal health care strategies to maximise the expected return on investment or minimise its standard deviation, subject to resource constraints. The Minimization of Total Absolute Deviations (MOTAD) approach has also been adopted in agricultural applications as a linear approximation to portfolio models (24). In Target MOTAD, the program minimises the deviation from mean income subject to achieving a target level of income.

Applications

Partly because of its data requirements, LP has been applied less frequently to animal health problems than BCA. As the examples in Table II suggest, when LP has been used it has provided either more detail in the modelling of changes over time (4, 19, 23) or analysis of

Table I
Selected applications of benefit-cost analysis to animal disease

Authors	Scale	Time	Risk	Question	Disease
Bates, Carpenter and Thurmond (1)	Herd,aggregated to three counties	Single-period	Stochastic, sensitivity analysis	Farm and government costs of alternative scenarios	FMD
Miller *et al.* (28)	Herd	Single-period; discounting occurs in the companion paper (34)	Not specified	Farm and government costs of alternative scenarios	PRV
Disney *et al.* (13)	Herd, aggregated to nation	Discounting range of alternative time horizons	Stochastic	BCA of different animal traceability programmes to reduce disease	FMD
Perry *et al.* (35)	Herd, aggregated to nation	Discounting range of alternative time horizons	Stochastic	BCA of alternative control, trade, and investment scenarios	FMD
Randolph *et al.* (39)	Herd, aggregated to nation	Discounting range of alternative time horizons	Stochastic	BCA of alternative control and trade scenarios	FMD
Meuwissen *et al.* (27)	Herd, livestock sector, and meat industries	Single-period (annual model with daily time steps)	Sensitivity analysis only	Costs of specific outbreak on different groups	CSF
Nielen *et al.* (32)	Herd, livestock sector, and meat industries	Single-period	Stochastic	Costs of alternative scenarios on different groups	CSF
Horst *et al.* (20)	Herd, aggregated to multiple regions	Five-year simulation period	Stochastic	Costs of alternative scenarios	CSF/FMD

BCA: benefit-cost analysis
CSF: classical swine fever
FMD: foot and mouth disease
PRV: pseudorabies virus

Table II
Selected applications of linear programming to animal disease

Authors	Scale	Time	Risk	Question	Disease
Bicknell *et al.* (4)	Farm aggregated to nation	Changing disease states over time affects producer choices	Not specified	Costs of different types of disease prevention policies	Bovine tuberculosis
Habtermariam* (19)	Herd aggregated to sub-region	Five-year simulation period	Not specified	Benefits of control efforts on disease incidence, jobs, land use	Trypanosomiasis
Galligan and Marsh (15)	National	Five-year simulation period	Portfolio theory	Programme costs of alternative veterinary programmes	Multiple
Stott *et al.* (46)	Farm	Ten-year simulation period, discounted over time	MOTAD, stochastic	Costs of different types of disease prevention on farm income	Bovine viral diarrhoea

MOTAD: Minimization of Total Absolute Deviations
* Koen (23) presents a modified specification of this analysis

risk (15, 46). In principle, both uncertainty and dynamic changes could be addressed in a single analysis, but that has not been frequently done in the applications reviewed here (an exception is Stott *et al.* [46]). Price effects cannot be estimated within an LP framework and data limitations usually prohibit the inclusion of inter-sector linkages.

Partial equilibrium models (single-sector and multi-market models)

Overview

Unlike BCA and LP approaches, the unit of analysis in partial equilibrium models is the market and the measured impacts are for aggregations of producers and consumers. This overview is intended to provide sufficient detail to indicate potential applications to animal health problems, but it does not equip the reader to apply this method. The authors hope instead to motivate multi-disciplinary collaboration.

A partial equilibrium model defines functional relationships for supply and demand for a specific commodity in a specific time and place. Supply and demand are represented as mathematical functions that constitute constraints in an optimisation framework. The technical relations that are explicit constraints on production in LP are embedded in the market supply function of a partial equilibrium model. Similarly, consumer preferences are embedded in the demand function. The objective function to optimise requires that supply and demand be in equilibrium, with the quantity supplied equal to the quantity demanded. When specific assumptions hold, this outcome is expected in practice and maximises social welfare (22, 38). In contrast to LP, which models optimal production at the farm or firm level, partial equilibrium analysis suggests optimal aggregate production and returns for a national or regional economy.

Interpretation of partial equilibrium models requires a basic understanding of the development and meaning of the supply and demand functions. The supply function represents the amount of product producers would be willing to supply at any possible product price. It is derived by assuming a given production technology and profit-maximising behaviour, which results in more being supplied at higher output prices as shown in curve S_0 (Fig. 2). In addition to the product's own price, supply is a function of the prices of inputs needed in production and other factors. In Figure 2, changes in the output price suggest movement along the supply curve, while changes in other parameters (e.g. the price of feed) imply a leftward or rightward shift in the curve.

A demand function represents the amount of a good that consumers would be willing to buy at any possible product price. The demand curve is derived based on the notion that consumption patterns result from individuals attempting to maximise their satisfaction given their budget constraints and prices. In price and quantity space, the demand curve is downward-sloping, since consumers' willingness to pay for additional consumption tends to decline as consumption of the good rises. This declining willingness to pay is consistent with the quantity demanded falling as price rises. Aside from the price of a good, demand is a function of income, consumer preferences, and the prices of substitutes and complements in consumption.

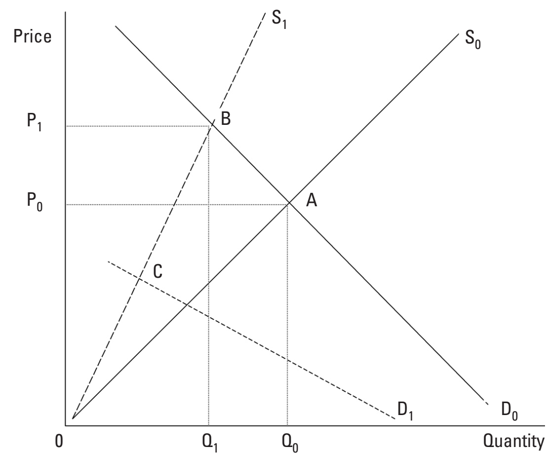


Fig. 2
Partial equilibrium model

Graphically, the point of intersection of the supply and demand functions defines an equilibrium at which producer supply equals the quantity that consumers demand. In Figure 2, demand and supply functions D_0 and S_0 imply equilibrium at point A, with a price of P_0, and quantity Q_0.

Shifts in supply and demand can arise from a number of sources, including a disease outbreak. For example, an increase in the incidence of some disease could reduce the amount of livestock produced at any given price, implying a leftward shift in the supply curve (from S_0 to S_1). With the shift from S_0 to S_1 the equilibrium moves to point B, implying an increase in prices from P_0 to P_1 and a decline in quantity supplied from Q_0 to Q_1. Alternatively, news about an outbreak of bovine spongiform encephalopathy (BSE) might affect consumer preferences, shifting demand to the left (from D_0 to D_1). This will result in a lower price and quantity as the equilibrium moves along the supply curve S_1 from B to C.

Based on welfare theory (22), changes in the equilibrium prices and quantities can be used to derive changes in producer profits (or producer surplus) and in consumer welfare (or consumer surplus). Producer and consumer surplus are powerful concepts in that they enable the identification of the aggregate impact and distributional aspects of a policy or disease shock.

Partial equilibrium analysis can be conducted with respect to one sector (single-sector models) or multiple sectors (multi-market models) and can focus on one or more regions. Multi-market models explicitly link related markets and can thus trace the impacts of a change in one market on output, prices, and incomes in related markets (18). For example, a multi-market model could link an outbreak of BSE to changes in the equilibrium prices and quantities in the beef market and to the associated changes in the prices and quantities in the poultry and feed markets. Household groups can also be incorporated in multi-market models to allow for the study of distributional issues in demand.

Applications

Multi-market models have been widely used for the analysis of agricultural policy, international trade, and environmental issues. The World Bank designed a number of multi-market models in the 1980s for studying agricultural policies in developing countries (7). The USMP (United States Math Programming) model, employed by the Economic Research Service of the United States Department of Agriculture (USDA), is a multi-sector, multi-region model that incorporates over 40 commodities and is linked with updated USDA production and survey data on land use, production, prices, trade, and government programmes (21). The articles indicated in Table III are based either on available multi-market models (26, 41, 45) or stand-alone partial equilibrium analysis (3, 29, 34). These models tend to be applied to estimate national or aggregate impacts of disease as opposed to

Table III
Selected applications of partial equilibrium analysis to animal disease

Authors	Scale	Time	Risk	Question	Disease
Schoenbaum and Disney (45)	National (multi-regional, multi-market)	Single-period (annual effects converted to daily)	Stochastic	Government costs and net welfare of alternative disease control	FMD
Rich (41)	National (multi-regional, multi-market)	Five-year simulation period, discounted over time	Stochastic	Net benefits (trade, prices, welfare, output) of alternative regional disease scenarios	FMD
Berentsen *et al.* (3)	National (single markets: cattle and pigs)	Ten-year simulation period, discounted over time	Sensitivity analysis	Costs and welfare effects of alternative disease control scenarios and trade bans	FMD
Miller, Tsai and Forster (29)	Herd, aggregated to country	20-year simulation period, discounted over time	Not specified	Costs of PRV and national welfare	PRV
Paarlberg, Lee and Seitzinger (34)	National (single market)	Single-period	Not specified	Welfare impact of an outbreak in the USA, similar in magnitude to the UK outbreak	FMD
Mangen and Burrell (26)	National (multi-market, vertically integrated hog market)	Single-period (daily and weekly time steps as inputs); different-length periods depending on simulation	Stochastic	National welfare and government costs of different sized outbreaks	CSF

CSF: classical swine fever
FMD: foot and mouth disease
PRV: pseudorabies virus
UK: United Kingdom
USA: United States of America

farm-level costs. While partial equilibrium methods are appropriate when it is important to measure changes in prices, linkages across markets, or changes in welfare, by themselves they lack the capacity of BCA to obtain detailed farm-level cost information or specific programme costs borne by government agencies.

Input-output and social accounting models

Overview

Like BCA, I-O models are based on budgets and accounting relationships, but rather than specifying the inputs and production in an activity or farm, an I-O table specifies the flow of inputs and outputs among sectors in an economy. For example, the I-O model follows the flow of inputs into, say, the livestock sector from every other sector in the economy (e.g. services, agriculture, manufacturing) and the flow of output from the livestock sector to each of these other sectors. The SAMs extend an I-O analysis by including the distribution of factors of production (land, labour, and capital) to households and other institutions in addition to the productive sectors found in the I-O table. Thus, I-O tables and SAMs are multi-sector models that summarise the economic transactions in an economy.

In an I-O table, economic sectors are aggregated into broad groups known as accounts. Each sector is represented by a row and a column. The rows specify the sales made from a given sector to each of the other sectors in the economy. Table IV presents a hypothetical I-O table with five productive sectors: agriculture, forestry, livestock, manufacturing, and services. Entries in the livestock row specify the value of sales made within livestock and from livestock to agriculture, forestry, manufacturing, and services. In this example, the livestock sector sells US$ 50 of output to agriculture, US$ 5 of output to forestry, US$ 50 within the livestock sector, US$ 15 to manufacturing, US$ 50 to services and US$ 30 to final demand; final demand is defined as the sum of consumption, investment, and net exports (17). The column accounts denote the value of inputs from each sector required to produce output in a given sector. Thus, in the example above, the livestock sector purchases US$ 100 of inputs from agriculture, US$ 10 of inputs from forestry, and so on. In a SAM, the matrix would include accounts for factors of production, institutions, capital, and the rest-of-world.

I-O tables and SAMs can be used to compute the impacts of various types of exogenous shocks, such as a disease outbreak, on sector performance. This requires converting the I-O table or SAM into a matrix of multipliers as described in the companion paper to this manuscript (42) and in greater detail in Miller and Blair (30). In the I-O framework, changes in output are calculated through simulations that alter the level of final demand. For example, the method could be used to show how a one-unit change in demand for meat exports would be transmitted throughout the economy, in terms of changes in the production in each sector. Different disease outbreaks or mitigation strategies could be simulated by adjusting final demand in the livestock sector as suggested by an epidemiological model or an assumed exogenous shock.

I-O and SAM approaches offer the ability to capture linkages between economic sectors, but their accuracy depends on the level of aggregation in the I-O table. If livestock is not suitably disaggregated, the analysis will overstate the potential impacts of a shock. In contrast to partial equilibrium models, I-O models do not allow for changes in prices and are unable to consider dynamic changes in a sector over time. Such price changes are important in agriculture and make I-O and SAM methods less attractive than partial equilibrium approaches when looking at medium- and long-term effects. Another problematic assumption in the I-O framework is that any changes in the economy are only due to shifts in the

Table IV
A hypothetical input-output table (in US$)

Sales to	Purchases from						Total
	Agriculture	Forestry	Livestock	Manufacturing	Services	Final demand*	
Agriculture	200	75	100	30	20	25	450
Forestry	30	20	10	50	40	10	160
Livestock	50	5	50	15	50	30	200
Manufacturing	100	25	10	250	50	25	460
Services	20	10	10	25	100	135	300
Value-added	50	25	20	90	40	100	325
Total	**450**	**160**	**200**	**460**	**300**	**325**	**1,895**

* Final demand: the sum of consumption, investment, and net exports

demand curve rather than from supply constraints. Since supply constraints are often present in agriculture and production lags are pronounced in livestock, I-O models may miss important effects of a disease outbreak. The economic and technical context can suggest whether the assumptions of the I-O approach are justifiable, but the method probably has more limited potential for application than partial equilibrium approaches, particularly for long-run analysis.

Applications

The four studies highlighted in Table V use I-O models or SAMs to examine shocks to demand resulting from export bans that would follow a disease outbreak. Similar to partial equilibrium models, these analyses focus on national aggregate outcomes, but unlike those models, the I-O approach cannot thoroughly address dynamic issues. There is ample scope for I-O and BCA to be combined, particularly in terms of the specific cost information associated with a disease outbreak. This approach was used in Garner and Lack (16), Ekboir (14) and Mahul and Durand (25).

I-O analyses frequently rely on models that were originally constructed for more general applications. Commercial I-O models, such as the IMPLAN® economic impact modelling system and those produced by Regional Economic Models, Inc., have been designed to calculate production, income, and employment multipliers for regions throughout the United States of America. National Ministries of Planning often maintain I-O tables or SAMs.

Computable general equilibrium models

Overview

Computer general equilibrium models are representations of a complete economy that integrate aspects of I-O and partial equilibrium models. A CGE model uses an I-O table or SAM to calibrate the relationships that exist in the entire economy. Extending the I-O analysis, CGE models explicitly express the functional relationships between actors in the economy as in a partial equilibrium model. The CGE approach extends partial equilibrium analysis in that expressions are defined to model the labour, capital, international trade, and currency markets that are beyond the scope of conventional partial equilibrium models. Thus, CGE models potentially give a larger amount of information than other models, though their complexity imposes costs in both the development and interpretation of results.

The theory behind CGE models is highly sophisticated and beyond the scope of this review. Readers interested in a detailed description of the approach are directed to Sadoulet and de Janvry (44) or Dervis, de Melo, and Robinson (10). The basic structure of a CGE model can be described in terms of sets of 'blocks' of equations that specify demand relationships, production technologies, relationships between domestic and imported goods, domestic prices, household income, government revenue, and numerous equilibrium conditions (6). Most CGEs

Table V
Selected applications of input-output/social accounting matrix modelling to animal disease

Authors	Scale	Time	Risk	Question	Disease
Garner and Lack (16)	Multi-regional (three Australian regions)	Single-period	Stochastic	Direct and indirect impacts (output, income, jobs) from alternative disease scenarios	FMD
Caskie, Davis, and Moss (9)	Regional (Northern Ireland)	Single-period	Not specified	Regional and sectoral impact on output, jobs, and income from beef demand shocks	BSE
Ekboir (14)	Regional (California)	Single-period; two periods considered for trade effects	Stochastic	Regional and sectoral income, employment, and output from alternative disease scenarios	FMD
Mahul and Durand (25)	Multi-regional (two regions in France)	Single-period	Stochastic	Regional and sectoral income, employment, and output effects from alternative disease scenarios and trade bans	FMD

BSE: bovine spongiform encephalopathy
FMD: foot and mouth disease

consider transactions at the national level, but they can also be applied to regional and local economies (47).

CGE models have a distinct advantage over I-O and partial equilibrium models in their ability to capture a wide array of economic linkages across sectors. The complexity of CGE models allows policy-makers to gain insights on how a shock to the economy, such as an animal disease outbreak, would transmit throughout all sectors of the economy and the potential reverberations on national income, trade, and employment. However, the amount of information contained in a CGE often makes it difficult to understand and interpret the results (18). Moreover, because CGEs rely on I-O tables, aggregation can be a problem in agricultural or livestock applications. Whereas a multi-market model can include detailed agricultural sector information, CGE models are often confined by the imprecise nature of the I-O data. Hence, as Figure 1 suggests, the application of a CGE approach is most appropriate for questions that can be answered with a high level of aggregation.

Applications

Table VI presents a number of recent applications of CGE models to animal health issues. In most of these analyses, changes in the economy resulting from a disease outbreak were simulated through an exogenous supply shock, rather than through an integrated epidemiological model. (The analysis in Perry *et al.* [37] also used results from the CGE analysis as an input to a BCA that uses an epidemiological model to assess alternative control programs.) This does not preclude such an analysis; rather, the main focus to date of CGE models has been on the economic impacts of animal diseases. In each of these models, results revealed large impacts on sectors other than livestock.

Conclusions

Economics offers a range of tools that could be applied to measure the impacts of animal disease on concerns ranging from farm costs to trade balances to household welfare and unemployment rates. The available tools offer divergent strengths and applications. Benefit-cost analysis, for example, offers precise specification of the immediate impact of a disease outbreak on herd-level costs, but little insight into longer term effects throughout the economy. By contrast, multi-market or CGE models can provide information on wider impacts over different time frames, but obscure details of more immediate effects. With the exception of benefit-cost analysis, most economic methods remain under-used. Greater use of other methods could enhance the applicability of economics to a variety of questions that need to be addressed in the context of animal disease and its evaluation. At the same time, the complexity of the tools presented in this review suggests a strong need to cultivate multi-disciplinary collaboration in the planning process for disease evaluation, data collection, and subsequent data analyses.

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Table VI
Selected applications of computable general equilibrium (CGE) models to animal disease

Authors	Scale	Time	Risk	Question	Disease
Perry *et al.* (37)	National, multi-regional (Zimbabwe)	25-year time horizon used in BCA using CGE results	Stochasticity considered in separate BCA that uses CGE results	Impact of disease through trade bans on national welfare, international trade, jobs and income distribution	FMD
O'Toole, Matthews and Mulvey (33)	National (Ireland)	Single-period	Not specified	Impact of disease shock on agriculture, tourism, government spending, taxes, and economy-wide effects	BSE
Blake, Sinclair and Sugiyarto (5)	National, multi-regional (United Kingdom)	Four-year time horizon	Not specified	Economic impacts (national welfare and intersectoral linkages) from disease outbreak, particularly on tourism	FMD

BCA: benefit-cost analysis
BSE: bovine spongiform encephalopathy
FMD: foot and mouth disease

Examen des outils économiques pour l'évaluation des foyers de maladies animales

K.M. Rich, G.Y. Miller & A. Winter-Nelson

Résumé

Le présent article montre comment les techniques de modélisation économique actuellement sous-utilisées peuvent enrichir l'analyse des problèmes posés par les maladies animales. Les analyses des programmes de santé animale sont de plus en plus tenus d'aborder toute une série de questions économiques et sociales. On peut répondre à ces attentes en intégrant mieux la modélisation épidémiologique et les techniques économiques dont l'application à la santé animale n'a pas jusqu'à présent fait l'objet d'études poussées. L'article décrit plusieurs modèles économiques que l'on peut appliquer à la recherche sur la santé animale et donne des orientations pour guider le choix de la méthode appropriée en fonction des problèmes qui se posent. La complexité de certains de ces modèles souligne l'importance de la recherche et de l'enseignement multidisciplinaires.

Mots-clés

Analyse coût-bénéfice – Analyse du risque – Contrôle des maladies – Économie de la santé animale – Équilibre partiel – Modèle de politique – Programmation mathématique.

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Estudio de las herramientas económicas para evaluar brotes de enfermedades animales

K.M. Rich, G.Y. Miller & A. Winter-Nelson

Resumen

Los autores ponen de manifiesto que ciertas técnicas de modelización económica, actualmente infrautilizadas, pueden enriquecer el análisis de problemas zoosanitarios. Cada vez más se presupone que los análisis de programas de sanidad animal deben abordar una serie de cuestiones de índole económica y social, para lo cual es preciso hallar una mejor articulación entre la elaboración de modelos epidemiológicos y técnicas económicas cuya posible aplicación a cuestiones de sanidad animal no se ha examinado a fondo en estudios anteriores. Los autores describen diversos modelos económicos que pueden aplicarse a la investigación en sanidad animal y ofrecen pautas para elegir el método más apropiado según la cuestión que uno tenga planteada. La complejidad de algunos de estos planteamientos no hace sino subrayar la importancia que revisten la enseñanza e investigación multidisciplinares.

Palabras clave

Análisis de la rentabilidad – Análisis del riesgo – Control de enfermedades – Economía de la sanidad animal – Equilibrio parcial – Modelo de política – Programación matemática.

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