Enhancing economic models for the analysis of animal disease

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Summary

This paper discusses how economic tools can be targeted and combined to enhance their usefulness in analyses of animal disease problems. It briefly reviews the most commonly used economic modelling techniques to clarify the applicability of specific economic methods to different problems in animal health analysis. The paper then reviews applications of these methods in the literature and suggests how further research could integrate and improve different economic approaches and link epidemiological and economic methods to address a wider range of issues at different scales of analysis.

Keywords

Animal health economics – Benefit-cost analysis – Computable general equilibrium model – Disease control – Input-output model – Partial equilibrium – Policy model.

Introduction

Analysis of animal disease control increasingly makes combined use of economic and epidemiological models. This paper suggests ways in which economic tools could be enhanced and combined to improve the analysis of animal disease problems. Because different economic techniques are relevant for addressing different concerns, the paper begins with a review of a typology from a companion paper (27) to link policy questions and scale of analysis with appropriate economic techniques. Discussion of these techniques examines recent applications and considers potential extensions to improve their representation of disease impacts. In particular, the paper demonstrates that alternative approaches and synergies between traditional benefit-cost analyses (BCA) and other economic methods can strengthen future analyses of animal health issues. The authors also summarise avenues for future research.

Policy questions and analytical models

The choice of an economic modelling approach reflects a balance between providing desired output and applying a feasible model. Desirability is determined by the questions that stakeholders wish to have answered and normally relates to some economic issue as it is manifested at a particular scale. Economic models may be called upon to quantify the impact of an animal health problem on producer or government costs, product prices, employment, international trade, or non-agricultural sectors and national welfare. Scales of analysis for these questions range from the herd to the national or global economy. In contrast, feasibility is largely determined by the availability of data, time, financial resources, or computational capacities.

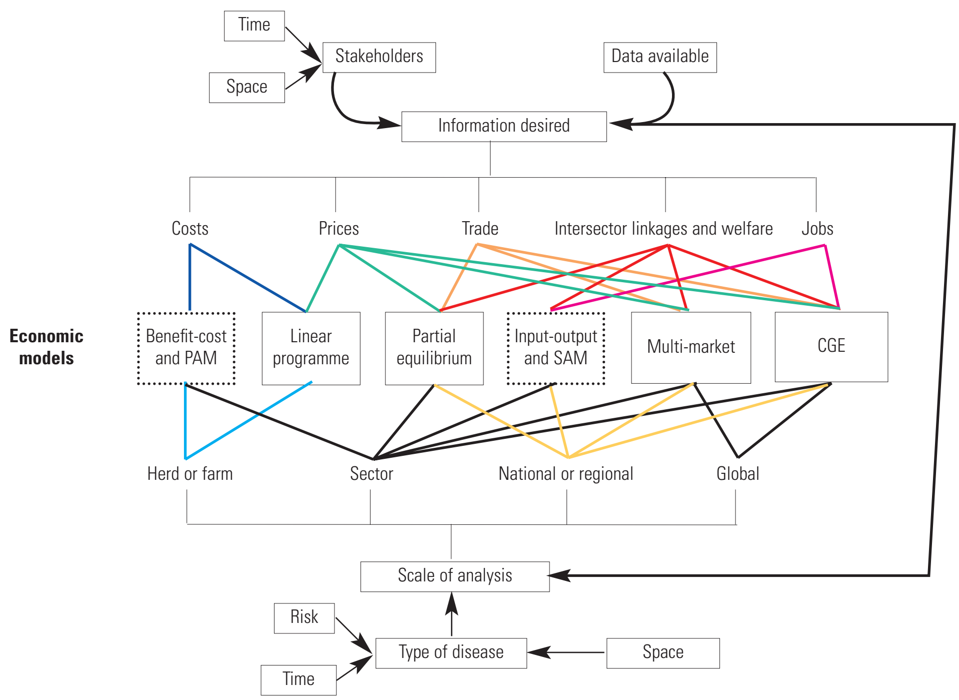
Figure 1 maps a set of commonly applied economic methods onto the issues and scales of analysis for which they are best suited, following the typology defined in the previous companion paper (27). The methods considered include BCA and the policy analysis matrix (PAM), linear programming, partial equilibrium analysis, input-output (I-O) models and social accounting matrices (SAMs), multi-market models, and computable general equilibrium models (CGE). The figure attempts to describe how different economic modelling approaches are differentially able to address various issues at various scales, with aspects of time, space, and risk incorporated as warranted by the disease in question (27).

Table I outlines the relative strengths of each model. Together, the table and diagram reveal the range of economic models available for any scale of analysis and for various economic or policy issues. The pattern of strengths across these models indicates that breadth in the issues that can be addressed comes at the expense of detailed information on impacts at the level of the herd, farm, or government agency. Hence, the authors argue for combining certain economic approaches to enrich the economic analysis of animal disease control. Many approaches are currently underutilised and thus there is scope to add value to the economic models that are typically used.

Applications and extensions of economic models to animal health issues

Traditional approaches: benefit-cost analysis

Benefit-cost analysis has been used extensively to quantify particular costs of animal disease outbreaks through budgets for specific activities. As explained in Rushton, Thornton, and Otte (28), the method can provide valuable information on the effects of disease on the costs and revenues in livestock production or the costs of public intervention. Rushton, Thornton, and Otte (28) distinguish between BCA at the national or sector level and budgeting techniques at the farm or herd level; similarly, Dijkhuizen, Huirne, and Jalvingh (7) differentiate between partial budgeting and BCA. While distinctions can be made concerning the level of aggregation and application of discounting over time, the authors apply the term BCA to all of these forms of analysis (5). Detailed budgets used in a BCA are often linked to an epidemiological model to simulate alternative disease mitigation strategies and determine changes in income under these different scenarios. The sophistication of these combined epidemiological-economic approaches has increased in



CGE: computable general equilibrium models
PAM: policy analysis matrix
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

Table I
Summary of appropriateness of economic models based on certain criteria

Criteria	Benefit-cost analysis/ PAM	Linear/ dynamic programming	Input-output/ SAM	Partial equilibrium/ multi-market models	CGE
Policy issue					
Costs	+++	++	++	+++	+++
Prices	+	++	+	+++	+++
International trade	+	++	++	+++	+++
Inter-sector linkages	+	+	+++	+++	+++
Welfare	+	+	+++	+++	+++
Employment	+	+	+++	+	+++
Scale of analysis					
Herd	+++	++	+	+	+
Farm/government agency	+++	++	+	+	+
Sector	++	+	++	+++	+++
Region or nation	+	+	++	+++	+++
Global	+	+	+	++	+++
Spatial sensitivity	++	+++	+++	+++	+++
Changes over time	+	+++	+	+++	+++
Uncertainty	++	++	++	++	++
Ease of use	+++	+	++	++	+

CGE: computable general equilibrium model
PAM: policy analysis matrix
SAM: social accounting matrix
+: inappropriate
++: somewhat appropriate
+++: very appropriate

recent years. Disney *et al.* (8) examine animal traceability systems in a BCA that combines an epidemiological model of disease spread (state-transition model) with a module that identifies alternative levels of animal identification. The disease model and partial budgets were used to derive data on benefits, while costs were derived from examining the distribution of costs of alternative identification systems. Thus, BCA can provide an effective way to gauge the impact of disease on a given herd or farm. When there is uncertainty about parameters in the model, BCA can incorporate the implied risk through the use of probability distributions rather than point estimates in the stream of benefits and costs. Probability distributions can also be used in any of the subsequent economic techniques discussed in this paper.

One drawback of conventional BCA is that it only examines impacts for a particular activity in isolation. Linkages across scales (say from the herd to the processor) or across sectors (farming to tourism) are not explicitly modelled. The PAM approach of Monke and Pearson (18) represents a means of applying the budget-based methods of BCA to consider linkages between activities. A PAM is a system of partial budgets that identify the revenues and costs along each segment of the marketing chain (e.g. production, transportation and processing). The PAM has not been used for analysis of animal health, but it has the potential to simultaneously address farm-level and sector costs and returns, as well as some distributional effects. While not using the PAM explicitly, Meuwissen *et al.* (15) and Neilen *et al.* (19) apply analyses that are similar in spirit by tracing disease impacts through associated livestock and meat processing activities. The impacts in these related sectors proved to be a full 25% of the total costs in Meuwissen *et al.* (15), while for Neilen *et al.* (19), they ranged from 20% to 22%, depending on the scenario analysed. A PAM approach may capture impacts in a closely related activity, but less obviously linked industries (e.g. tourism) are ignored. Thus, the BCA and PAM are not appropriate when the impacts of spillovers into other sectors are large or when important impacts in the land or labour market could follow the disease shock.

An additional drawback of conventional BCA is that price effects are often omitted from the analysis. As a result, scaling up BCA results from a representative herd to a region or nation will misrepresent costs if widespread disease would affect supply enough to influence prices. While such price effects would not arise from isolated outbreaks, unless they triggered trade sanctions, they would emerge in epidemic situations and thus BCA could misrepresent the impact of a disease outbreak.

Moreover, while BCA has been combined with epidemiological models to gauge the short-term, farm-level impacts of a disease, the method is not well suited to measuring longer-term dynamic effects or impacts at a broader scale. This weakness follows from the reliance on fixed budgets with pre-determined I-O relationships. 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. For example, Perry *et al.* (22) and Randolph *et al.* (25) include multi-period BCAs. Their studies of foot and mouth disease (FMD) control strategies in Thailand and the Philippines, respectively, included epidemiological-economic models with time horizons of 10 to 50 years. Although one can impose a pattern of changes in prices or productivity over time, a BCA cannot allow endogenous changes in behaviour or markets and thus may overstate its impact, especially over the long term when producer responses are more likely and when the disease outbreaks can influence prices.

The shortcomings of BCA can often be addressed by supplementing it with other methods that better capture price effects, dynamics, and spillovers. For example, Garner and Lack (10) combine BCA with an I-O approach to reveal inter-sectoral impacts. Berentsen *et al.* (1, 2), Miller *et al.* (16) and Rich (26) combine BCA with partial equilibrium modelling to capture price effects, while Perry *et al.* (23) use a CGE model with a BCA, potentially allowing improved treatment of price, sector spillovers and dynamic effects. Given the trend towards complementary use of multiple approaches, the authors review these other methods below.

Alternative approaches

Input-output and social accounting models

Input-output models are similar to BCA in their reliance on budgets and accounting relationships, but where BCA measures inputs and outputs in an activity, an I-O table specifies the flow of inputs and outputs among productive sectors of an economy. Input-output tables can be built and used to study the national economy as well as regional and 'village' economies (31). In addition to summarising economic transactions across sectors, I-O tables can model interregional flows and thus have application where interregional linkages are important (24).

In an I-O table, each sector (termed an 'account') is represented by a row and a column (Table II). The row accounts specify the sales made from a given sector to each of the other sectors in the economy while the column accounts denote the value of inputs from each sector required to produce output in a given sector. The principle of double-entry bookkeeping ensures that the row and column sums for a given sector are equal. A SAM extends an I-O table by including accounts for factors of production, institutions, capital, and the rest-of-world; some SAMs also contain commodity accounts which represent intermediate domestic production. The household and factor accounts in a SAM can be disaggregated by skill class, income group, or region. Thus, in addition to modelling the flow of resources across productive sectors, the SAM reflects flows of income to different household groups and their spending, as well as flows of taxes to the government and public expenditure. In the SAM, the capital account represents the distribution of saving and investment within the economy, while a rest-of-world account relays the economy-wide influence of imports and exports.

Input-output tables and SAMs can be used to compute the impacts of various types of exogenous shocks on sector performance. This necessitates converting the I-O table or SAM into a matrix of multipliers that reflect the amount by which production, employment, or income would increase as a result of a one-unit increase in final demand. The reader is directed to Miller and Blair (17) for more details on this technique. Changes in output can thus be computed by considering simulations that change the level of final demand. For example, the multiplier matrix could

Table II
A hypothetical input-output table

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

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. Simulations of disease control efforts can be conducted in this framework by adjusting final demand in the livestock sector according to the magnitude of the outbreak or mitigation strategy. Ideally, an epidemiological model would be used to calibrate the size of the shock to demand. The final demand vector is revised to reflect the shock and is multiplied by the multiplier matrix to determine the impact of the shock. The accuracy of such simulations will depend on the level of aggregation in the I-O table. If livestock is not suitably disaggregated, the analysis will overstate the potential impacts.

Because I-O models are structured to analyse demand shocks, many studies of disease control using I-O models focus on the multipliers to examine effects of export bans imposed for phytosanitary reasons (9, 10, 13). In this context, adding an I-O analysis to a BCA allows one to trace the impact of a disease outbreak on all sectors of the economy and can provide an indication of the direction of employment and income effects that may occur. BCA contributes specific information on the short-run costs of a disease outbreak as an input into an I-O. This approach was used in Garner and Lack (10), Ekboir (9), and Mahul and Durand (13). In each of these analyses, a state-transition model of FMD transmission was used to simulate alternative disease scenarios, which generated final demand shocks used in the I-O multiplier analysis. Garner and Lack (10) and Mahul and Durand (13) utilised regional I-O tables to assess where the disease had the largest impacts and what control method was more cost-effective, with respect to compensation paid, employment losses, and income effects.

While I-O techniques can play an important role in augmenting a traditional BCA, aspects of the analysis are weakened by two fundamental assumptions in the framework. First, production is subject to Leontief technology, which means that there is no substitution between inputs and constant returns to scale. Second, I-O and SAM models are fixed price models and assume that any changes in the economy are only due to shifts in the demand curve; the supply curve is assumed to be perfectly elastic. This assumption is problematic in agriculture where supply constraints are often present, particularly in sectors subject to long production lags such as livestock. As a result, the conventional multipliers produced in an I-O and SAM analysis overstate the true impacts of shocks in final demand. This problem can be addressed through the use of mixed-multipliers that allow inelastic supply response in specific sectors. With the exception of an unpublished analysis by one of the authors (Rich), I-O analyses of animal disease control have not made these adjustments to handle supply constraints in livestock production. In his study, he found that incorporating supply constraints reduced the measured impact of an FMD outbreak on household income by 30%. The appropriate mixed multiplier techniques are formally detailed in Miller and Blair (17).

While the use of mixed multipliers would improve I-O analysis of livestock issues, I-O and SAM models are fundamentally unsuited to capturing changes in prices that accompany shocks to the economy and changes in a sector over time. Consequently, I-O and SAM methods are problematic when looking at medium- and long-term effects. Furthermore, the information about linkages, welfare, and employment that can be extracted from an I-O approach depends on the level of detail in the data. Since I-O tables are usually developed at a high level of aggregation, the range of problems which they can practically address may be quite narrow. Thus, I-O models provide the opportunity to measure short-run impacts across broad sectors of the economy given health incidents that affect the demand side only. Assessment of a broader set of problems may be facilitated with partial equilibrium and/or multi-market models.

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

A partial equilibrium model defines functional relationships for supply and demand for a specific commodity in a specific time and place. As in an I-O model, partial equilibrium analysis reveals very little about the details of the distribution of costs in an activity budget. Instead, the model measures the market-wide impacts of a shock on prices, quantities, and welfare. A multi-market analysis links shocks in one market to changes in demand and supply in related markets, thereby capturing impacts through diverse sectors of the economy. Unlike the I-O approach, shocks in a partial equilibrium framework may affect either supply or demand and their impacts can be assessed over longer time periods.

In a partial equilibrium framework, shifts in supply and demand can arise from a number of sources, including a disease outbreak. The aggregate impacts of the outbreak could be estimated by measuring the prices, quantities, and welfare before and after the shock. For example, an increase in the incidence of a particular disease could reduce the amount of livestock produced at any given price, implying a leftward shift in the supply curve and resulting in an increase in prices and a decline in quantity supplied. Demand shifts could arise if an outbreak negatively affected consumer attitudes, implying a shift in demand to the left and lower equilibrium prices and quantities. These shifts in supply or demand can be calibrated with reference to an integrated epidemiological simulation (e.g. Mangen and Burrell [14]; Rich [26]).

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 have the advantage of explicitly linking related markets and can thus trace the impacts of, for example, a disease outbreak affecting beef supply (e.g. bovine spongiform encephalopathy) on the demand for poultry. The calculation of producer and consumer surplus in multiple markets involves sequentially computing the effects in each of the affected markets (12). Household groups can also be incorporated in multi-market models to allow for the study of distributional issues in demand. As a result, such models are useful in understanding the feedbacks that alternative policy scenarios could have on a sector.

Partial equilibrium modelling is appropriate when it is important to measure changes in prices, linkages across markets, or changes in welfare. Although the data required to construct a large-scale, multi-market model can be substantial, many existing models are available and can be adapted for use in animal health applications.

The World Bank designed a number of multi-market models in the 1980s for studying agricultural policies in developing countries and the Economic Research Service of the United States Department of Agriculture (USDA) has used the USMP (US Math Programming) model since the late 1980s to study agricultural policy and land and water conservation issues. The USMP model 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 (11).

In conjunction with a disease spread model, Schoenbaum and Disney (30) used the USMP model as a method to obtain consumer and producer surplus measures arising from different FMD mitigation strategies. Their epidemiological model simulated the impact of alternative disease control strategies, based on a stochastic state-transition framework and parameters on direct and indirect contact rates. Government costs were determined from partial budgets linked to elements of the disease control model (e.g. number of herds, vaccination costs, etc.). Thus, BCA supplemented the partial equilibrium analysis with activity-level cost data.

Because better modelling of price impacts is directly relevant to assessing costs in a BCA, the combined use of BCA and partial equilibrium models has great appeal. In their analysis of FMD control in the Netherlands, Berentsen *et al.* (2) combined a BCA based on cost data of a disease outbreak with a partial equilibrium model and calculated the indirect costs of foreign bans on meat exported by the Netherlands and subsequent changes in producer and consumer surplus. They applied single sector partial equilibrium models of the pork and cattle markets to calculate the indirect effects resulting from changes in export markets arising from an FMD outbreak, including the imposition of bans by certain trading partners. Joint partial equilibrium and BCA analysis were used to compute producer and consumer surplus and the net present value of the flow of benefits and costs over a ten-year period. Paarlberg *et al.* (21), Rich (26), and Mangen and Burrell (14) provide additional examples of the use of partial equilibrium models in animal disease applications.

Despite the appeal of partial equilibrium models, a drawback of the approach relative to the I-O approach is that the scope of sector-level linkages analysed is often limited. For instance, while the USMP model traces interactions within the agricultural economy, it does not address other non-agricultural sectors or changes in international markets that might result from a disease outbreak. Likewise, important impacts such as changes in employment or household income are often lacking. Thus, its utility as a combined approach with BCA is limited to applications where the main questions relate to the agricultural or livestock sector. For applications that require the economy-wide scope of I-O models and the economic realism of partial equilibrium models, CGB approaches may be needed.

At the same time, partial equilibrium approaches themselves can be enhanced by greater use of multi-market models. The multi-market approach offers a way to capture greater linkages between sectors (including non-agricultural sectors) and is particularly suitable for the examination of dynamic, long-term issues in which BCA and I-O models are less appropriate. Further work will be required to link the data needs of such multi-market models to animal health applications and epidemiological approaches, but the models used by Schoenbaum and Disney (30) and Rich (26) point in this direction. Moreover, spatial issues that are often not analysed in both the epidemiological and economic literature could be addressed along the lines of Rich (26).

Computable general equilibrium models

In terms of modelling the economic effects of animal disease, CGE models combine the strengths of I-O and multi-market models to answer a wide range of questions. Because such models represent the entire economy, as in an I-O or SAM model, the CGE approach can address questions concerning impacts across sectors, categories of households, and employment groups. Moreover, since they include functional relationships between actors in the economy as in a partial equilibrium model, CGE analyses can also address price changes, the reallocation of labour and capital markets, and longer-run impacts. This capacity, however, makes the model highly complex, which means that it is expensive to develop and that the interpretation of results can be problematic. To keep CGE models tractable, they are often constructed with a high level of aggregation that can make them inappropriate for addressing specific questions about animal disease or other shocks with more targeted impacts. When CGE models are used, they are often combined with BCA to provide more detailed information on particular activities. (Readers interested in the details of CGE modelling are directed to the analysis in Sadoulet and de Janvry [29], Dervis, de Melo, and Robinson [6], or Blonigen, Flynn and Reinert [4].)

There have been a number of recent applications of CGE models to animal health issues. Perry *et al.* (23) conducted a sophisticated BCA which combined information on income and costs with a CGE model to calculate the trade effects of alternative FMD mitigation strategies in Zimbabwe. The authors also examined issues of dynamics, through the calculation of benefit-cost ratios as a means to rank alternative disease control strategies and distributional issues. CGE models have also been employed to examine the impact of recent FMD outbreaks in the United Kingdom (UK) and Ireland. O'Toole, Matthews, and Mulvey (20) used the IMAGE CGE model (IMAGE stands for Irish Model of Agriculture General Equilibrium) to assess the impacts of shocks in agriculture, government expenditure, and tourism due to FMD on the Irish economy. Similarly, Blake, Sinclair and Sugiyarto (3) used a CGE model to analyse the most recent FMD outbreak in the UK in 2001. Their study particularly focused on the impact of FMD on tourism in the UK. A 115-sector CGE model was used that was integrated with a separate micro-regional tourism model that provided a more detailed analysis of changes in tourism demand and expenditure from domestic and international tourists as a result of the outbreak.

None of the CGE applications mentioned above was explicitly linked to an epidemiological model. Changes in the economy resulting from a disease outbreak were measured exogenously as a supply and/or demand shock to the economy, rather than through a disease model. The main focus of CGE models has been on the economic impacts of animal diseases, and there appears to be room for improvement in the modelling of epidemiological factors within them. More sophisticated modelling of disease within a CGE model would be facilitated through interdisciplinary collaboration.

Conclusion

Many economic tools can be combined with epidemiological methods to guide decisions concerning the management of animal disease. While BCA is frequently applied to animal health problems, other methods that could address important issues beyond the scope of BCA are also available. The significance of price effects (especially when disease affects international market access) and intersectoral linkages (as in the case of tourism and FMD control) highlights the need for models that capture price dynamics, responses to price changes, and spillovers into other sectors. Thus, there is a need to improve the integration of epidemiological modelling in alternative economic platforms, such as I-O, multi-market, and CGE analysis. These modelling techniques, however, address economy- or sector-wide impacts without giving the kind of precise cost information that follows from BCA. Future research may thus do well to include combined use of different economic models to achieve both in-depth scope and high precision analysis.

Aside from combining methods, applications of BCA, I-O, and partial equilibrium models could be enhanced in many ways. First, BCA approaches can increase their scope by adopting PAM techniques to measure impacts through complete commodity chains. When I-O models are used, the supply constraints inherent in livestock production could be captured via mixed multiplier methods to increase the accuracy of results. Partial equilibrium models of disease control can be expanded in scope through the use of more detailed multi-market methods. All of these approaches can be enhanced through better modelling of spatial interactions and through integration with epidemiological models to internally capture disease effects.

This review echoes many of the same concerns made in past reviews of epidemiology and economics. Following Dijkhuizen *et al.* (7), the authors concur that significant work remains to be done in integrating economics and subsequent data requirements into the types of information systems already in place. All of the models discussed here have their own data requirements, with greater precision necessitating more extensive data. At the same time, there needs to be greater recognition that the data collected for traditional animal health applications (e.g. epidemiological models) should also be relevant and adaptable to economic questions of interest to key stakeholders. While this presents challenges in the organisation and coordination of institutions and information systems, it has the potential of providing significant rewards to policy-makers in terms of improvements in the delivery, cost-effectiveness, and efficiency of animal disease control. While such issues are beyond the scope of this article, the authors would nonetheless conclude that the ability for practitioners to move beyond BCA is often feasible at present given current data sources; such models having the potential to enrich and strengthen a wider range of important policy questions.

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Adaptation des modèles économiques à l'analyse des maladies animales

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Résumé

Le présent article examine les moyens de cibler et de combiner les modèles économiques afin d'accroître leur utilité pour l'analyse des problèmes posés par les maladies animales. Il présente brièvement les techniques de modélisation économique les plus couramment employées pour déterminer dans quelle mesure ces méthodes peuvent s'appliquer aux divers problèmes posés par l'analyse de la santé animale. Il examine ensuite les applications de ces méthodes qui sont exposées dans la littérature et propose des moyens pour que les recherches à venir intègrent en les adaptant les diverses approches économiques et combinent les méthodes de l'épidémiologie et celles de l'économie afin de pouvoir traiter une gamme plus large de problèmes à des stades différents de l'analyse.

Mots-clés

Analyse coût-bénéfice – Contrôle des maladies – Économie de la santé animale – Équilibre partiel – Modèle d'entrées-sorties – Modèle d'équilibre général calculable – Modèle de politique.

■

Perfeccionamiento de modelos económicos para el análisis de enfermedades animales

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Resumen

Los autores exponen el modo en que cabe refinar y combinar herramientas económicas de tal manera que resulten más útiles a la hora de analizar problemas zoosanitarios. También describen sucintamente las técnicas utilizadas con más frecuencia para elaborar modelos económicos, y a partir de ahí estudian en qué medida pueden aplicarse determinados métodos de la economía a distintos problemas de análisis zooosanitario. Acto seguido, tras exponer una serie de ejemplos de aplicación de esos métodos descritos en la bibliografía, proponen vías de investigación para integrar y perfeccionar distintos planteamientos económicos y vincularlos con métodos epidemiológicos con objeto de poder estudiar una mayor diversidad de temas a distintas escalas de análisis.

Palabras clave

Análisis de rentabilidad – Control de enfermedades – Economía de la sanidad animal – Equilibrio parcial – Modelo computable de equilibrio general – Modelo de "insumo-producto" – Modelo normativo.

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