Insights for the assessment of the economic impact of endemic diseases: specific adaptation of economic frameworks using the case of bovine viral diarrhoea

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Summary
Generic frameworks for the economic analysis of farm animal disease are now well established. The paper, therefore, uses bovine viral diarrhoea (BVD) as an example to explore how these frameworks need to be adapted to fit the characteristics of a particular disease and the specific objectives of the analysis. In the case of BVD, given the relative strength of tests available to correctly identify virus-positive animals, thus enabling them to be culled, the emphasis has been on cost–benefit analysis of regional and national certification/eradication schemes. Such analyses in turn raise interesting questions about farmer uptake and maintenance of certification schemes and the equity and cost-effective implementation of these schemes. The complex epidemiology of BVD virus infections and the long-term, widespread and often occult nature of BVD effects make economic analysis of the disease and its control particularly challenging. However, this has resulted in a wider whole-farm perspective that captures the influence of multiple decisions, not just those directly associated with disease prevention and control. There is a need to include management of reproduction, risk and enterprise mix in the research on farmer decision-making, as all these factors impinge on, and are affected by, the spread of BVD.

Keywords
Animal health economics – Behavioural economics – Bovine viral diarrhoea – Economic welfare – Loss–expenditure frontier – State-transition model.

Introduction

Generic frameworks suited to the economic assessment of endemic farm animal disease (e.g. 1, 2, 3) are now well established and have been applied to a range of endemic diseases, including bovine viral diarrhoea (BVD). For reviews see (4), (5) and (6). However, it is vital that these generic frameworks are suitably adapted to fit both the objective of the analysis and the specific characteristics of the disease in question. The case of BVD brings particular challenges in these regards, which have not previously been fully addressed. In many instances, tackling these challenges provides insights of potential value for economic analysis of diseases other than BVD. This paper is therefore focused on this point.

Clear objectives for economic assessment of farm animal disease help to define the scope of the analysis and ensure that the appropriate methodologies are selected. A valuable table, adapted from (7), sets out a typology for the economics of animal disease (Table I). It serves to illustrate the breadth of important research questions encompassed in the general area of the economics of animal health, which are all relevant to BVD, as well as the range of sectors involved and the extent of interdisciplinary collaboration required. However, to date, the greatest emphasis for BVD has been at producer level and at national/regional levels in support of certification. These analyses have been carried out to persuade producers to adopt specific strategies or change their behaviours in other ways that have been shown to provide the greatest private and/or public benefit, e.g. through the reduction of disease incidence and/ or disease impact. There have also been a number of

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Table I
Economics of animal disease typology matrix
Source: adapted from Pritchard *et al.* (7)

Scope of analysis	Research objectives	Assessment methods	Policy instruments	Research opportunity
Producer impacts	Business loss, incentives for control	Budgeting, stochastic simulation, operational research	Compensation, testing, knowledge exchange	Epidemiological & economic models, insurance
Allied industries, farm services and input suppliers, etc.	Lost shareholder wealth, business losses and gains, e.g. veterinary product sales and services, private health schemes, etc.	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	Regionalisation, rapid response plans, national ID, tariffs/non-tariff barriers, restrictions	Economic geography, distribution of impacts

CGE: computable general equilibrium model
CVM: contingent valuation model
I-O: input–output
WTA: willingness to accept
WTP: willingness to pay

economic studies (8, 9) to demonstrate that BVD has been, and remains, a cause of significant economic loss to cattle farmers across the world.

Epidemiological features of importance for economic analysis

The syndrome caused by BVD virus (BVDV) is one of a group of economically important livestock pathogens known as pestiviruses (10). The virus engenders a wide range of pathogenic features (11), which often go unnoticed or are misattributed. This makes it particularly difficult both to capture the full extent of the economic impact and, even if they are available, to use the results to persuade producers to change behaviour on BVD interventions for individual or societal benefits. One reason for misattribution is that BVDV causes immuno-suppression (12), giving rise to general effects such as increased enteritis and pneumonia amongst calves, and infertility and abortion in cows (13).

The transmission mechanisms of the virus also contribute to its occult nature and influence both output loss and the decisions taken about how best to target control expenditure (14). BVDV is transmitted in several ways, but mainly from persistently infected (PI) animals to susceptible ones through direct contact. If the susceptible animal is a cow in the first trimester of pregnancy, then virus may be transmitted to the fetus. This may cause abortions resulting in reduced fertility. If the calf that was infected in the uterus survives, it will be PI, as its immune system has no ability to limit BVDV multiplication. A PI animal may or may not show signs of ill thrift and may go on to produce a PI calf or calves of its own. Unless diagnosed by blood test and culled as part of a control programme, its status may not become apparent. However, PI animals are susceptible to sudden death from mucosal disease (15). In contrast, transiently infected cattle, which are infected by PI animals, show only mild and temporary impairment in production followed by permanent immunity but frequent reproductive issues. The propensity of PI animals to exit the herd, together with the development of immunity within a herd and regular entry of susceptible calves, will cause the disease profile, and hence output losses, to fluctuate over time, even within a closed herd. This dynamic component adds to the challenge for the economic analyst. Moreover, there are two strains of BVDV, which complicates the analysis further. BVDV-1 is dominant in Europe, while BVDV-2 is common (about 50% of isolates) in North America, where it is associated with more acute symptoms (16) and hence is likely to have a different level of economic impact.

Between-herd spread is likely both through direct contact with PI animals across farm boundaries and by purchase of PI replacement stock. It follows that good bio-exclusion practices are an important aspect of prevention that can also bring benefits by mitigating other disease risks (17). Although vaccination is an option, it may not eliminate BVD as it has no effect on PI animals already present and cannot prevent the birth of susceptible calves or the introduction of other susceptible animals likely to come into contact with any PIs. Farmers and veterinarians often fail to appreciate the limitations of the various vaccines available and the importance of using them properly as part of a wider animal health programme (18). It is therefore important that economic analysis is conducted and communicated to them in ways that best address these and the other problematic aspects of the disease.

Herd prevalence is generally high in Europe. In countries where no national eradication programme exists, about 50% of herds may contain at least one PI animal (15). These prevalences contribute to the high economic impact of BVD that is so widely reported.

Dynamic aspects

The above features of BVD aetiology and epidemiology have given rise to several mathematical simulation models that attempt to capture the key stochastic and dynamic processes involved. These models enable the exploration of important relationships between risk factors and prevention/control interventions, and such explorations are a prelude to economic analysis. (For examples, see [19, 20, 21, 22 & 23].) Some have been used to examine the economic consequences of BVDV (e.g. [24, 25]).

State-transition (modified Markov Chain) models provide a simple spreadsheet-based platform for combining epidemiological and herd-structure features that are important to the progression of infectious disease (26). Stott *et al.* (27) describe how the stochastic functions in the spreadsheet may be used to draw samples of herds of alternative epidemiological status to seed multiple runs representative of current observed prevalence. The state-transition model (STM) may then be used to explore the progression of the disease and hence associated financial loss under alternative control strategies and farm circumstances. Counterfactual prevalence assumptions can then expose the progressive impacts of alternative national/regional policy interventions such as eradication programmes. These are likely to exhibit quite different impacts on individual farm businesses at the start (pioneers with susceptible herds exposed to risk from PI animals in the wider population) and end (persistence of laggards holding PI animals) than in the middle of the programme (28). Where a long-run steady state exists in an STM, this may provide a convenient platform from which to summarise financial outcomes and benchmark alternative scenarios (29). However, this creates a temptation to neglect the cash flow and associated risk implications characteristic of dynamic BVDV epidemics (27), which is an important and arguably under-researched aspect of the economics of BVD and its control.

In terms of economic impact, the key dynamic aspects of BVDV epidemics in breeding herds are reproductive impairment and reproductive failure. Varo Barbudo *et al.* (30) modelled these reproductive aspects explicitly based on a survey of reproductive performance and management in 106 commercial Scottish beef suckler (cow-calf) herds. This work confirmed that hidden losses due to impacts of BVDV on reproduction, although extremely variable, are likely to be considerable, perhaps doubling previous estimates of the total costs of BVD in such herds. Moreover, disease impacts were masked by use of long breeding seasons, suggesting that continued presence of BVDV in Scotland could frustrate programmes of sustainable intensification (31) aimed at improving the efficiency of food production while lowering its carbon footprint. As regards dairy herds, Heuer *et al.* (32) provide a recent demonstration of the economic impacts of BVDV in New Zealand dairy herds, their similarity to results from elsewhere in the world and the strong relationships between some indicators of poor reproductive performance and high BVDV antibody titres in the bulk milk tank. Given the importance of reproductive management for sustainability in the dairy herd (33), it would be useful to more explicitly explore the relationships between management of reproduction and BVD prevention/control in future research.

Economic analysis

A central contribution of the generic economic frameworks for assessment of endemic animal disease is to shift the emphasis of analysis away from estimating average total costs (output losses plus control expenditure) towards establishing avoidable losses, i.e. the difference between current total cost and minimum total cost (34). Such analyses demand an understanding of the production function relationships linking increasing disease control expenditures with reducing output losses (4) and are therefore more demanding of epidemiological data and models. However, they establish the opportunity cost of current practice and identify the means by which such costs might be saved. These are of course key issues for decision support at both farm and regional/national level.

As BVD includes such a complex and occult disease syndrome, few empirical economic analyses of it based on the loss–expenditure frontier (LEF) method of McInerney

(1) have been attempted, with an exception being Chi *et al.* (17). The latter used the framework to make a comparative assessment of four production-limiting diseases (enzootic bovine leukosis, paratuberculosis [Johne's Disease] and neosporosis as well as BVD) in Canadian dairy farms. Although the relatively small (90-herd) cross-sectional study had limitations, it did demonstrate how important it can be to aggregate the benefits of generic prevention measures across the range of disease losses avoided.

Although applying the LEF method to a large sample of herds can establish the aggregate extent of avoidable loss and hence aid resource allocation at regional/national level, it may fail to identify the most appropriate prevention and control strategies under specific circumstances at individual farm level. Stott and Gunn (35) therefore adapted the generic benefit function framework of Tisdell (2) to appraise alternative farm-level decisions about the prevention/control of simulated BVD epidemics in suckler herds. The approach is summarised in Figure 1. This shows relationships between cumulative investments in 'biosecurity' (i.e. a range of additive options; see [35] for details) and the output losses saved as a consequence (benefit). Maximum net benefits vary widely from under £2/cow/year from a £5/cow/year investment for an unvaccinated herd of unknown health status (function 1) through to over £26/cow/year from a £6/cow/year investment for a vaccinated herd known to be free of BVDV at the start of the simulation (function 4).

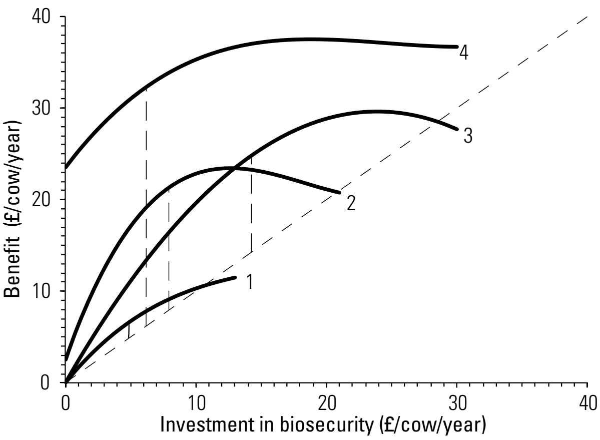

Fig. 1

Benefit functions for investment in biosecurity against the incursion of bovine viral diarrhoea virus (BVDV) for a typical 50-cow suckler herd under standard epidemiological and economic conditions

Functions 1 and 2 represent BVDV status unknown at the start of the 10-year simulated epidemic, while functions 3 and 4 are for herds tested free of BVDV at the outset. Functions 2 and 4 assume vaccination is used while 1 and 3 do not. The hatch line sloping at 45° is the cost function (break-even). Vertical hatch lines show the point of maximum net benefit (slope of benefit function equal to 1, i.e. marginal cost = marginal benefit = £1)

Source: Stott and Gunn (35)

Note that extra investment in biosecurity (beyond a basic minimum not included in the benefit function) is justified even when vaccine is used. Greater investment in disease prevention is justified when a herd is known to be virus-free, as it helps ensure that it stays that way. It can be seen from Figure 1 that more biosecurity, not less, is justified when vaccine is used in a herd where BVDV status is unknown (function 2 vs 1). The reverse is true for herds tested free of the virus (function 3 vs 4). This highlights the importance of the interaction between vaccination and certification and hence the potential for synergy between individual farm and regional (health scheme) BVDV response strategies. All these observations demonstrate the practical insights that bio-economic analysis can bring. Outcomes are of course dependent upon the assumptions made, some of which are hard to verify in specific practice. However, the rules of thumb (if not the specific financial outcomes) provide the basis for interaction with stakeholders and hence the iterative development of the models and associated decision support.

Uptake by farmers

It is clear from the previous example that economics is not about money but concerned with understanding rational choices about the allocation of scarce resources between competing activities in ways that best meet decision-makers' goals (36). This begs the question as to whether economic analysis of BVD is influencing farmers' decision-making and so achieving the net benefits it promises. A key problem here was highlighted by Gates (37), who reported that only 27% of beef farmers and 25% of dairy farmers with seropositive herds identified in a prevalence survey thought that their cattle were affected by BVDV. However, even if farmers are not aware that their herds are affected, they are aware of the generic importance of biosecurity, so the prevalence of BVD can be reduced by focusing on encouraging farmers to implement good biosecurity practices. As biosecurity is central to BVD prevention (38), changing farmer behaviour in this respect is key.

Toma *et al.* (39) explained 64% of the variance in biosecurity behaviour of 900 British cattle and sheep farmers using behavioural economics methods. They demonstrated the relative importance and inter-relationships between drivers of biosecurity actions, such as knowledge of specific measures and perceptions of their importance. These insights could guide policy-makers towards the most effective behavioural change campaigns amongst farmers, especially if linked to economic analysis to estimate the benefits of such campaigns.

Veterinary practitioners perceive their clients to be reluctant to invest in biosecurity and feel that additional proof of efficacy and/or economic benefit is required (40). However, Heffernan *et al.* (41) uncovered a potentially important alternative view that calls into question sole reliance on economic analysis as the driver of uptake of biosecurity and, presumably, other animal disease prevention strategies. In their interviews with 121 cattle and sheep farmers in Wales and South-West England, most were dismissive of the many measures associated with biosecurity. Farmers justified their views in terms of blame, citing external people responsible for inadequate border control and ineffective policy and regulation of epidemic disease. In the case of endemic diseases such as BVD, 'bad' farmers were seen as the problem. This result demonstrates how important it is to use a wide definition of economics in animal health that encompasses behavioural change and not to rely exclusively on the quantitative estimates of the costs and benefits of a disease and its control – the classic cost–benefit studies.

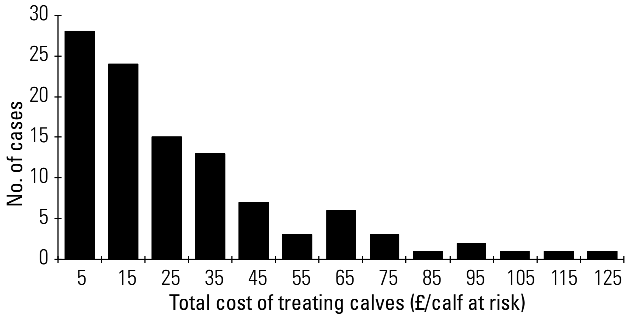

Fig. 2

Unpublished results based on the study of Stott and Gunn (44) **showing the distribution of enteritis costs in a sample of 105 separate episodes in suckler herds, recorded in detail by four veterinary practices working in northern Scotland**

Risk

In many exchanges with farmers and veterinary practitioners, the authors have encountered another problem with farmers' perceptions of economic analysis of BVD and other endemic diseases. To farmers, published and promoted average total costs of endemic diseases, and even avoidable losses derived from them, appear implausibly high. In the case of BVD this could be attributed to its multifaceted and occult nature. However, the distributions of disease costs are often positively skewed, i.e. published means are higher than their medians (42). For example, the mean total health-control cost per cow per year in a survey of 248 French dairy farms was €86, the median €81 and the maximum €252 (43). This observation exposes another often neglected aspect of the economics of animal health, namely, that outbreaks of disease represent an important aspect of production risk and this may be a more important motivator for the farmer than the average avoidable losses or the associated opportunity costs of sub-optimal prevention and control. Figure 2 shows the distribution of the costs in suckled calves of enteritis, which is often associated with a BVDV infection. The mean cost of an episode in this study (44) was approximately £30/calf at risk. However, 64% of the farmers concerned experienced episodes leading to costs that were less than this. They might reasonably be expected to consider the mean cost to be exaggerated. However, the most costly episodes were three to four times greater than the mean, exposing the businesses concerned to substantial financial loss. About 5% of episodes were in this high-cost category, i.e. there was a small but significant risk of important consequences for the whole farm from a condition that might otherwise be considered routine.

The BVD example clearly shows how important it is that animal health economics exposes risks to farm businesses in ways that properly support farmers' decision-making. Rushton (45) reviews the risks in the context of the economics of animal health and the tools available to incorporate it into associated economic analysis. The issue has particular importance for BVD outbreaks, as not only does this disease, like other endemic diseases, contribute via production losses to variation in farm profits (a measure of risk) but, if the herd is naïve, perhaps following removal of PI animals by testing and culling, then ironically the potential for greater variation in loss (risk) may be increased (see Fig. 3). In this example, up to 10% of risk (variance in farm income) was due to BVDV in a naïve herd, but this proportion fell as target farm income increased. In a herd of unknown BVDV status the 'risk' was no more than

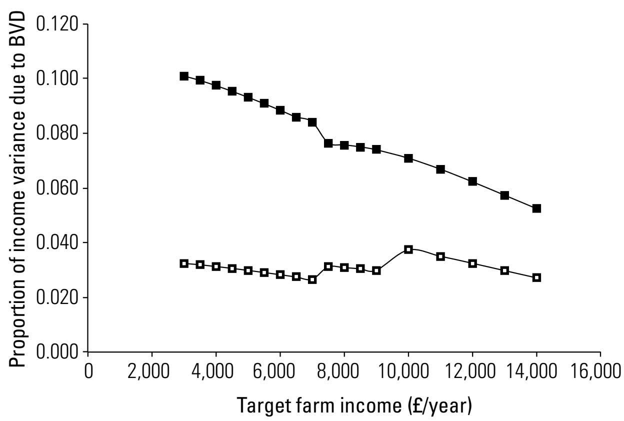

Fig. 3

Predicted effect of bovine viral diarrhoea (BVD) status on risk (proportion of income variance due to BVD) in a typical Scottish mixed farm including a 50-cow suckler herd, young stock, a sheep flock and a barley enterprise

Risk was minimised by a MOTAD LP model (minimisation of the total absolute deviations linear programming model) that could alter enterprise mix and other details of farm management, including BVDV prevention, provided a set farm income target was achieved. As income target rose higher, risk strategies had to be adopted, decreasing the relative importance of risk due to BVDV. The solid markers denote a farm free of BVDV at the start of a ten-year simulation. Open markers show an otherwise identical herd of unknown BVDV status. Further details are in (27)

4% and independent of farm income. The dependence of BVD risk on target farm income in a naïve herd demonstrates that, as income rises, greater investment in biosecurity in such herds will be justified, as it will minimise overall risk, thus reducing the proportion of risk due to BVD. This demonstrates the wider benefits of private health schemes or national eradication programmes that confirm BVDV-free status and hence provide the motivation for greater investment in biosecurity. This investment is likely to generate additional benefits not included in the model; for example, both public and private benefits from greater protection against diseases other than BVD are likely. Moreover, to achieve the same target income as an otherwise equivalent herd of unknown BVD status, a BVD-free herd can be farmed on a smaller scale and at a lower intensity. This reduces production risks and lowers carbon footprint.

National control programmes

The wider benefits of freedom from BVDV at farm level illustrated by the last example help to justify investment in BVDV eradication programmes (Stott and Gunn [35]). The benefits of reliable tests for BVD are, however, offset by the difficulties of ensuring universal uptake by farmers in voluntary schemes (28). There has therefore been increased emphasis in Europe in recent years on compulsory national control schemes (15). For example, Presi *et al.* (46) report the testing of all Swiss cattle for BVDV and the culling of all PI animals. Prevalence of virus-positive newborn calves fell from 1.8% to under 0.2% in two years. Economic analysis plays an important role in demonstrating the *ex ante* benefits, thus helping policy-makers to justify public investment in national BVDV eradication programmes. For example, Valle *et al.* (47) showed positive net benefits for eradication in Norway, while Stott *et al.* (29) provided support for the Irish eradication programme. As these programmes progress they will provide data for a wide range of interdisciplinary work on the epidemiology and economics of BVD prevention and control. This could help to improve the cost effectiveness of future schemes through, for example, more detailed work on alternative resource allocations in response to test results during a campaign rather than simple cost–benefit analysis of eradication versus the status quo. Such interactive approaches will be greatly strengthened by developments in phylogenetic analysis, which provides information about the diversity of virus strains involved in an epidemic, thus helping to trace the routes of viral transmission (48).

Welfare aspects

It is important in the case of BVD, as with many animal diseases, to include not only the costs/benefits to farmers in economic analysis but also the benefits to other stakeholders. Weldegebriel *et al.* (49) used an economic welfare methodology to examine the distributional effects on actors in the milk market of a successful hypothetical programme to eradicate BVDV from the Scottish dairy herd. As expected, milk supply to the market increased as a consequence of eradication, leading to a fall in milk price. This benefited milk consumers (£11 million in discounted economic surplus) but was a small detriment to producers whose herds were already disease free (£2 million). However, the lower milk price was more than offset by the greater volume of milk available for sale from previously infected herds (£39 million gain), leading to an overall gain of £47 million for Scotland. The example highlighted the important effects that national eradication programmes can have on commodity markets, leading in this instance to considerable net gains tempered by small losses in one sector. Considerations of equity and how these might be incorporated into incentive schemes associated with national disease control programmes deserve further economic research.

Conclusion

Bovine viral diarrhoea provides a useful case study of the use of economics in animal health. Economic analysis has played an important role in the instigation of regional and national BVDV eradication programmes and demonstrated the considerable direct and wider benefits, both public and private, that such programmes can provide. It has highlighted the importance of generic biosecurity activities at farm level and exposed some of the important behavioural issues concerned. The generic and widespread effects of BVDV impacts at farm level have highlighted the importance of incorporating animal disease decision support into wider farm management systems. There is much scope for further development in this area, not just to ensure maximum benefit from BVD prevention for the farm business, but also to provide a basis for development of sustainable intensification that meets growing global demand for more food production, of great quality, at less risk, and with reduced impact on the environment.

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Éclairages sur l'évaluation de l'impact économique des maladies endémiques : adaptation spécifique des cadres économiques au cas de la diarrhée virale bovine

A.W. Stott & G.J. Gunn

Résumé

Les cadres généraux de l'analyse économique des maladies affectant les animaux d'élevage sont désormais bien établis. Les auteurs utilisent l'exemple de la diarrhée virale bovine pour définir les adaptations à apporter à ces cadres afin d'intégrer les caractéristiques d'une maladie donnée et les objectifs spécifiques de l'analyse. Dans le cas de la diarrhée virale bovine, compte tenu de la robustesse des tests disponibles pour détecter les animaux infectés (qui seront abattus), l'accent est mis sur l'analyse coûts-bénéfices des dispositifs régionaux et nationaux de certification sanitaire et d'éradication. Ces analyses soulèvent des questions intéressantes quant à l'engagement et à la persévérance des éleveurs à l'égard des dispositifs de certification et à la mise en œuvre équitable et rentable de ces dispositifs. La complexité de l'infection due au virus de la diarrhée virale bovine et le caractère durable, répandu et souvent inapparent de ses effets rendent particulièrement difficiles les analyses économiques de cette maladie et de son contrôle. Ces analyses ont toutefois permis de mieux appréhender la situation dans la perspective d'une exploitation, en tenant compte des effets de décisions multiples qui ne se limitent pas à celles directement destinées à prévenir et à contrôler la maladie. La gestion de la reproduction, la gestion des risques et les choix de diversification doivent impérativement être intégrés dans la recherche sur les processus décisionnaires des éleveurs, car tous ces aspects affectent et sont affectés par la propagation de la diarrhée virale bovine.

Mots-clés

Diagramme états-transition – Diarrhée virale bovine – Économie comportementale – Économie de la santé animale – Frontière entre pertes et dépenses – Prospérité économique.

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Aportaciones para evaluar el impacto económico de enfermedades endémicas: adaptación específica de modelos económicos al caso de la diarrea viral bovina

A.W. Stott & G.J. Gunn

Resumen

Hoy en día ya existen modelos genéricos sobradamente contrastados para analizar en clave económica las enfermedades de los animales de granja. Partiendo de esta realidad, los autores utilizan el ejemplo de la diarrea viral bovina (DVB) para determinar el modo de adaptar esos modelos genéricos para que encajen con las características de una enfermedad en particular y con los objetivos específicos de un determinado análisis. En el caso de la DVB, teniendo en cuenta la relativa solidez de los ensayos existentes para identificar correctamente a los animales infectados (para su posterior sacrificio), los autores se centraron en analizar la relación costo-beneficio que presentan algunos dispositivos regionales y nacionales de certificación sanitaria o erradicación. Estos análisis, a su vez, abren interesantes interrogantes sobre el nivel de adhesión y perseverancia de los productores respecto de los programas de certificación y sobre el grado de equidad y rentabilidad con que se aplican esos dispositivos. La compleja epidemiología de las infecciones por el virus de la DVB y el carácter duradero, extendido y a menudo oculto de sus efectos dificultan especialmente el análisis en clave económica de la enfermedad y de las medidas para combatirla. Sin embargo, estos análisis han permitido aprehender desde una perspectiva más amplia la situación de la explotación en su conjunto, teniendo en cuenta la influencia de múltiples decisiones, y no solo de aquellas directamente relacionadas con la prevención y el control de la enfermedad. En toda investigación sobre el proceso decisorio de los productores es necesario tener en cuenta la gestión de la reproducción, la gestión de los riesgos y el tipo de actividades de la explotación, pues todos estos factores influyen en la propagación de la DVB y son influidos por ella.

Palabras clave
Bienestar económico – Diarrea viral bovina – Economía conductual – Economía de la sanidad animal – Frontera entre pérdidas y gastos – Modelo de transición de estados.

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