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Achieving an optimal allocation of resources for animal health surveillance, intervention and disease mitigation

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Summary

The primary role of animal health economics is to inform decision-making by determining optimal investments for animal health. Animal health surveillance produces information to guide interventions. Consequently, investments in surveillance and intervention must be evaluated together. This article explores the different theoretical frameworks and methods developed to assess and optimise the spending of resources in surveillance and intervention and their technical interdependence. The authors present frameworks that define the relationship between health investment and losses due to disease, and the relationship between surveillance and intervention resources. Surveillance and intervention are usually considered as technical substitutes, since increased investments in surveillance reduce the level of intervention resources required to reach the same benefit. The authors also discuss approaches used to quantify externalities and non-monetary impacts. Finally, they describe common economic evaluation types, including optimisation, acceptability and least-cost studies.

Keywords

Animal health – Economic efficiency – Intervention – Least-cost study – Mitigation – Optimal investment – Surveillance – Value.

Introduction

Animal disease creates two categories of economic cost. First, mortality and morbidity directly affect the quantity of goods and services produced, thus reducing people's scope for consumption. Secondly, scarce resources with positive opportunity costs are allocated to mitigation. To these direct effects may be added wider impacts, due to mitigation itself, including spillover to other sectors, impacts on upstream and downstream businesses and costs accruing from human illness caused by foodborne and zoonotic disease. Recently published estimates have established that 31 foodborne hazards caused a major burden of 600 million foodborne illnesses and 420,000 deaths in 2010 (1). Moreover, the impacts of disease on animal welfare, consumer confidence, nutrition, reputation, and the environment can cause adverse indirect effects (externalities). For example, food scares triggered by the emergence of highly pathogenic avian influenza led to a significant decrease in demand for chicken in Thailand in 2004 (2).

In economically efficient disease management, the overall economic costs resulting from the negative biological effects and the mitigation expenditures needed to avoid these negative effects should be minimised (3). Mitigation is defined as the process of making the effects of disease less severe by avoiding, containing, reducing or removing it and encompasses two vital elements: surveillance and intervention (4, 5).

Animal health surveillance is, 'the systematic, continuous or repeated, measurement, collection, collation, analysis, interpretation and timely dissemination of animal health and welfare related data from distinct populations [...] to describe health hazard occurrence and to contribute to [...] risk mitigation actions' (6). It uses expenditure (e.g. materials, labour) to provide crucial information for policy-makers to plan, implement and evaluate interventions that aim to protect human and animal health and welfare. Surveillance has gained traction due to its important role as an early warning mechanism that enables a rapid response for (re-)emerging or exotic diseases. Surveillance also plays

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an important role in the characterisation of endemic diseases to assess the situation and support intervention strategies to manage disease and to document freedom from disease (7, 8).

While effective, international surveillance improves the chances of detecting disease early and responding in an adequate manner, carrying out interventions is usually the responsibility of national service providers. Where there are scarce financial resources, competencies and capacity, the effectiveness of outbreak response measures and interventions in general can be limited. Outbreak investigation, detection, treatment, vaccination, selective breeding, or culling all cause expenditure in the form of materials, operations and labour (5).

Therefore, to determine the efficiency of resource allocation for disease mitigation, the combined expenditures for surveillance and interventions must be taken into account and compared to the resulting loss avoidance, which would potentially take the form of reduced consumption of animal goods and services, capital losses, and negative externalities. Depending on the nature of the disease in question, an interdisciplinary approach including public health, livestock, wildlife and food sectors may be required (9). In this article, the theory underpinning the economic analysis of surveillance and intervention is presented for livestock populations, with a discussion of expansion to other sectors and applications, and the limitations of popular economic tools.

Economic theory of disease mitigation, including surveillance

Disease losses and expenditures

The relationship between losses (*L*) caused by disease in animal production systems (e.g. abortion, reduced yield), and expenditure (*E*) used in disease management (e.g. drugs, veterinary services) was described in the 1990s as a 'disease loss-expenditure frontier', where $L + E$ together define the costs of disease (*C*) (3, 10). The authors stipulated that, from an economic point of view, 'disease management involves a choice between levels of *L* and *E*' and that the relevant objective is the minimisation of *C*. The economic optimum for disease mitigation was identified as the point when an additional monetary unit of control expenditure would return the same amount in the form of reduced losses (10). The model was criticised and expanded by Tisdell (11), who provided the theoretical basis to include multiple diseases and relaxed the assumption of diminishing marginal returns that had previously been established. The theory of McInerney and colleagues was used by Bennett (12), who disaggregated *E* into the 'increase in expenditures on non-veterinary resources due to a disease (*R*)', 'cost of veterinary inputs used to treat disease (*T*)', and 'cost of disease prevention measures (*P*)'. This resulted in the equation $C = (L + R) + T + P$, which was used to estimate the so-called direct disease costs of 30 endemic livestock diseases in Great Britain (12). Subsequently, this model was expanded to include such costs in terms of a qualitative animal welfare score and monetary and non-monetary human health impacts (13). A related framework breaks down losses into 'visible' (e.g. mortality, morbidity) and 'invisible' (e.g. changes in herd structure) losses, and expenditures into 'additional costs' for mitigation activities (e.g. treatment), as well as 'lost revenue' (e.g. sub-optimal use of technology), taking into account both the animal and human health sectors (14, 15). All these models share the feature that they differentiate between biological effects due to disease and the human reaction to disease, and explain that the economic objective is to reduce the overall cost.

Surveillance, intervention and loss avoidance in animal populations

Given the increasing importance of surveillance in disease mitigation and the growing demand from policy-makers for information on the value of surveillance, the above relationships were conceived of, or conceptualised, as a relationship with three variables: surveillance, intervention and loss avoidance (5). Importantly, surveillance and intervention can either be technical substitutes or complements in disease mitigation. If they are complements – for example, in a testing (surveillance) and culling (intervention) strategy – they are used in a given ratio and collapse into the term expenditure, '*E*', described above. If they are substitutes, the use of one mitigation resource will reduce the use of the other. The common use of surveillance as an early warning mechanism and the expectation that effective surveillance information enables improved intervention support this notion.

In Figure 1, curves A1, A2 and A3 illustrate the possibility of substitution between surveillance and intervention for three out of potentially many feasible levels of avoided losses. Assuming diminishing returns to resource use, the curves are convex to the origin, requiring more intervention resources to compensate for each unit reduction in surveillance, and vice versa.

To determine the optimal level of disease mitigation, it is necessary to (16):

i) estimate output loss avoidance curves with and without mitigation (A1, A2, ...A*n*)

ii) estimate technical relationships between loss avoidance and the use of surveillance and intervention resources *iii)* translate loss avoidance and resource use into (monetary) values

iv) identify least-cost combinations for surveillance and intervention

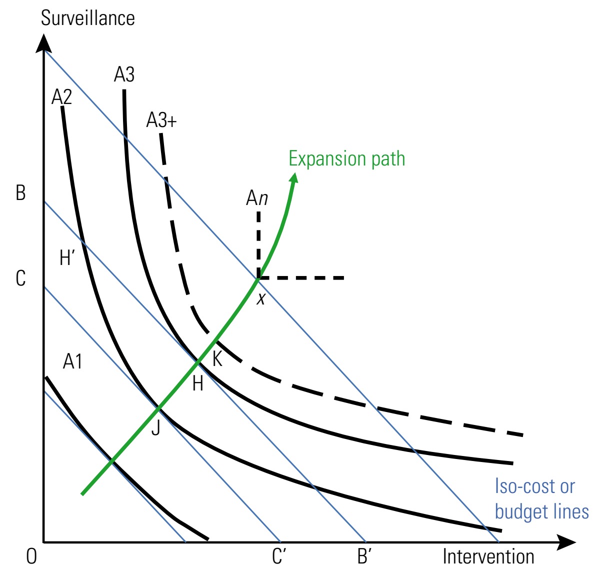
v) identify least-cost combination(s) consistent with the avoidance loss that maximises people's economic welfare, i.e. the point where the marginal benefit of loss avoidance equals the marginal cost of the least-cost combination of surveillance and intervention.

The estimation of output loss avoidance curves, with and without different combinations of surveillance and intervention, necessarily includes the consideration of one or more scenarios and therefore requires the use of epidemiological models to predict indicators, such as prevalence or incidence, over time in relation to the mitigation strategies assessed. Once available, the technical relationships expressed as surveillance and intervention units and a reduction in prevalence or incidence need to be translated into economic values.

The 'expansion path' in Figure 1 describes identical tangent points on iso-mitigation curves, with the gradient corresponding to the price ratio for surveillance and intervention. Each point of tangency defines the least-cost combination of surveillance and intervention for the given price ratio. The iso-cost lines represent all combinations of surveillance and intervention, adding up to the same total amount of mitigation expenditure. If policy-makers allocate a specific sum of money to disease mitigation, any such iso-cost line represents a 'budget line', which sets the limit for monetary expenditure on all combinations of surveillance and intervention at their current prices. The optimal level of disease-mitigation activity lies where the least-cost combination of surveillance and intervention meets the tangent in their price ratio or, in other words, where the marginal benefit equals the marginal cost. Other levels of A can be obtained for the same total expenditure, but are sub-optimal. For example, the optimal location on budget line BB′ is at H for A3 avoided losses, although H′ is also feasible for lower A2 avoided losses. Such a point can only be identified if information is available on the technical relationships between loss avoidance, surveillance and intervention, and their associated values (16).

Expansion of principles to account for externalities

The existence of externalities influences the optimal level of investment (5). In Figure 1, if H is optimal with respect to avoided animal (production) losses but there are also positive externalities (e.g. reduced risk of human infection, beneficial effects on animal welfare), the budget line BB′ is insufficient to achieve optimal economic efficiency, and



A1, A2, A3, A3+ and A*n* distinct levels of losses avoided

J, H, K and x mark least-cost combinations of surveillance and intervention corresponding to distinct levels of loss avoidance

Explanations referring to the letters B, B′, C, C′, H and H′ can be found in the text

Fig. 1
Economic interpretation of surveillance, intervention and loss avoidance
Source: Modified from Häsler (16)

there is a case for increased funding. Hence, with the value of externalities added, A3 becomes A3+ in Figure 1, and a case can be made for mitigation resources to be increased on the expansion path to reach the optimum net benefits for society at point K on curve A3+. If A3 instead incorporates a negative externality, such as negative environmental effects due to disease mitigation (e.g. ground water pollution due to mass culling of animals), then BB′ funding is deemed excessive, because the net benefit to society is reduced by the negative value of the (unintended) environmental consequences. In such a case, CC′ budget expenditures for A2 avoided production losses may correspond to the true economic optimum (16).

The existence of positive externalities is particularly relevant when considering the optimal level of investment for zoonoses mitigation and 'One Health' approaches to surveillance and intervention. In 'One Health surveillance', for example, early warning of potential public health threats through surveillance of the animal population, improving the design of public health policies and interventions, and generating disease knowledge for risk assessment can result in avoided losses and improved outputs for the public health sector (17).

Depending on the viewpoint and scale of the analysis, positive and negative externalities of animal disease and its mitigation can be explicitly included and estimated for private and public perspectives, as described, for example, by Peck and Bruce (18), in this issue. Another approach towards calculating human and animal monetary losses at the societal level takes age-specific groups into account, as well as treatments and consequences (19, 20).

When health risk reductions cause a substantial increase in animal production, the resulting market impacts (e.g. changes in market prices of farm outputs or product prices in other dependent agricultural sectors) need to be included in the model. Depending on the extent of cross-market impacts, these societal effects can be addressed using either the economic surplus method (21) or more complex multi-market agricultural models or computerised general equilibrium models (22).

Non-monetary benefits

Surveillance and intervention activities can also generate a wide range of non-monetary benefits, which all have a value but which are difficult to express in monetary terms. For some of these, e.g. human health and suffering, a set of widely accepted and standardised metrics are available, such as disability-adjusted life years (DALYs) or quality-adjusted life years (QALYs) (23). However, to inform decisions on resource allocation, decision-makers still need to know how much a DALY or QALY is worth to decide whether an investment is acceptable. The National Institute for Health and Care Excellence (NICE) in the United Kingdom (UK) established a threshold for the QALY of £30,000; a figure which was recently shown to be too high (24). In environmental valuation, a range of techniques have been developed to capture the value of ecosystem services in monetary terms, such as the market-price method, hedonic pricing, or travel-cost method. As an example, the average expenditure of UK citizens on angling fish was used as an estimate of the market price attributed to the maritime ecosystem when assessing the societal benefit of the surveillance and control of notifiable fish diseases (25). In some cases, the values attributed to non-market goods (commonly referred to as 'the willingness to pay' for these goods) can only be assessed through empirical surveys, most often with contingent valuation. As an example, contingent valuation was used to assess the willingness of Ugandan farmers to pay for extended governmental local husbandry services (26).

Other values accrue from mitigation activities. Surveillance creates intellectual and social capital, technical reassurance and feelings of safety, contentment and 'peace of mind'. Moreover, the information generated by surveillance can be positively valued by private stakeholders, as it helps them to adapt their disease prevention practices and production strategy (27). Such effects are rarely captured when assessing the economic value of surveillance. They can be gathered through empirical studies using stated preference methods, which are widely used in marketing research (28). Choice experiments (also referred to as 'conjoint analysis') consist of asking survey participants to weigh their interest for certain defined health services in relation to other services, based on a set of defined attributes (29). In animal health, for example, choice experiments were used to assess the UK farmers' willingness to pay for bovine tuberculosis vaccines (30) and consumers' willingness to pay for different *Salmonella* infection control methods in pork (31). In Vietnam, this method was adapted to price the different attributes of avian influenza surveillance programmes (e.g. associated control measures, cleaning the environment, effects on the poultry market) from the poultry farmers' perspective (27).

Linking private decisions to surveillance effectiveness

In some cases, the effectiveness of a health programme depends on decentralised decisions made by private actors in animal value chains. This can be the case for large-scale vaccination programmes but also for passive surveillance, which is based on private actors reporting their disease suspicions to the competent authorities (32, 33). In such cases, *ex ante* economic evaluations would benefit from preliminary estimations of the likely compliance of the target population. In practice, however, this factor is given little consideration. The willingness of private actors (e.g. farmers and local veterinarians) to participate in an animal health programme is usually addressed through qualitative or semi-quantitative surveys (34, 35, 36). Choice experiments can prove useful, not only to assess the non-monetary effects of health programmes, but also to estimate the correlation between their characteristics (e.g. the type of implemented measures and their positive and negative externalities) and the likelihood of being adopted effectively by private end-users (27, 29).

From principles to practice

At present, data on the relationships described above are limited, leading to empirical economic analyses of surveillance, intervention and mitigation being carried out for any disease on a case-by-case basis (8). A short overview of popular techniques for such analyses is given here.

Optimisation studies

In optimal economic efficiency, the net benefit accruing to society from allocating scarce resources to disease mitigation is maximised. A method often used in optimisation studies is linear programming, a mathematical technique for optimising an outcome, such as maximising profit or minimising cost in a given system (37, 38, 39). It normally consists of an objective function (e.g. net benefit) to be maximised or minimised, a set of activities (e.g. sample taking, removal of sick animals), and a set of constraints, which specify a so-called 'feasible area' over which the objective function is to be optimised (40). This technique is gaining popularity in animal health. For example, Kompas *et al.* (41) developed a stochastic optimal control model to determine the optimal level of surveillance activity against a disease incursion. The model minimised the value of the direct and indirect costs of the disease, as well as the cost of surveillance and the disease management and eradication programme applied to the potential entry and spread of foot and mouth disease in the United States.

When the economic consequences of an outbreak and the associated response are known to be severe (e.g. due to fears among consumers, high mortality, pain and discomfort, trade bans), an analysis may focus on maximising the technical and economic performance of surveillance only, keeping the intervention fixed (8). Such an approach has, for example, been applied by Guo *et al.* (42), who used technical surveillance performance parameters in simulation models, in combination with a multi-criteria, decision-making model, to identify technically and economically efficient surveillance set-ups.

Acceptability studies

Another criterion refers to acceptability; it allows us to judge whether the benefits stemming from a mitigation policy at least cover its costs, thus making a strategy justifiable. Cost–benefit analysis (CBA) aims to evaluate, in monetary terms, all types of costs and benefits of surveillance and intervention, direct and indirect, including market and non-market values, in order to find out if a strategy generates a positive net value. Direct costs and benefits are related to the direct results of disease mitigation activities (e.g. resource use, animal health), while indirect costs and benefits are related to externalities. This method is popular in animal health economics (43), but only a few studies have explicitly included surveillance, intervention and loss avoidance.

When conducting a CBA, it is important to bear in mind that loss avoidance is the product of combined surveillance and intervention, and that the analysis must include data on intervention and surveillance expenditures and the mitigation outcome. Because the impact of surveillance cannot be measured directly as a mitigation outcome, it is only possible to quantify the loss avoidance resulting from the combination of surveillance and intervention, and to compare it to the expenditure for surveillance and intervention. Therefore, it is recommended that researchers calculate a residual margin over the intervention cost, which constitutes the maximum additional expenditure potentially available for surveillance without the net overall benefit from mitigation becoming zero. This margin can then be compared to the expenditures of various surveillance options. The one maximising the net benefit would be the best from an economic point of view. An illustration of this concept can be found in Häsler *et al.* (44).

Moreover, it is important to consider the timeframe for the analysis. For example, if the end-point of the programme is the elimination of disease from a population, the analysis does not have to take into account post-elimination surveillance costs to monitor freedom from disease. However, if the time span of the investment to be assessed includes the post-elimination period, the costs of long-term surveillance to sustain disease-free status and the costs of potential re-incursions of the disease also have to be considered (7).

In cost-effectiveness analysis (CEA), apparently the need for valuation of the outcomes can be avoided, which therefore saves resources in the analysis. For instance, an effectiveness measure such as timeliness may be considered to be a proxy for the final outcome or benefit, such as loss avoidance and reduced intervention expenditures due to earlier outbreak detection (which would be measured explicitly in a CBA). However, a CEA can inform resource allocation meaningfully only if its effectiveness measure has an interpretable value. Therefore, before conducting a CEA, it is necessary to think carefully about how the findings can be interpreted and whether the value of an effectiveness measure can be compared to the additional costs. In any situation, the choice of a cost-effectiveness threshold by decision-makers depends on the perspective of the analysis, the value that people attribute to the effectiveness of the outcome, their risk attitude and resource availability (45). These factors will result in setting different cost-effectiveness thresholds for the given outcome. For example, the context may be defined by legal, social or political factors, the disease situation in the country and the availability of technical expertise and capacity.

Least-cost studies

Least-cost analysis aims to identify the cheapest option among different possible options that produce the same outcome. In this type of analysis, the cost of the option is the dominant determining factor; the outcome or value of the outcome is fixed. The valid application of the method depends on establishing that the cost is indeed the determining factor, and that the result is indeed the same for the surveillance and/or intervention options being compared. In its strictest sense, least-cost analysis of mitigation measures applies where the outcomes are established and the design and protocol are specified, by, for example, legislation (e.g. a definition is provided of the types and number of farms and samples required, and laboratory testing and analysis procedures are described). In such a case, it can be expected that a mitigation programme will achieve the desired effect. Different options to be compared can then only look at changes in the implementation (e.g. using cheaper materials from a different manufacturer, using synergies between programmes), and select the option that complies with the given requirements at the minimum cost.

Discussion

Economic principles show where empirical knowledge is essential, before efficient choices about allocating mitigation resources can be made. However, due to institutional preferences and time and resource restrictions, the theoretical concepts available may not be fully applied. Conceptualising mitigation strategies from an economic perspective and ensuring that the relevant data are collected or accessed are important prerequisites to quantify the relationships involved and identify optimal management levels.

It is highly likely that zoonoses and animal diseases with the potential to affect food security, livelihoods and human well-being in general will continue to emerge. It has been demonstrated that emerging infectious diseases are increasing significantly (46), and that preventing pandemic emergence events, with a focus on animal populations, is more cost effective than reacting to disease outbreaks (47). Consequently, surveillance and response systems for emerging infectious diseases need to be enhanced and maintained at the national and international level.

Applied research, linked across the human, livestock and wildlife sectors, is needed to inform preparedness planning and the development of evidence-based approaches to zoonotic disease prevention and control. The impact of emerging diseases can be mitigated by establishing and maintaining the relevant infrastructure and capacity of public animal and human health systems, as well as of associated sectors (9). However, sustaining high levels of service delivery, as well as ensuring preparedness across government institutions, has implications in terms of fixed costs. Under budget cuts, governments are more likely to shift some of this responsibility to private-sector institutions in various models of private–public partnerships. Whether such shifts will have an impact on the capacity for preparedness and outbreak response is yet to be determined.

The animal health decision-making process is closely linked to the political economy, which defines investments in animal health and drives factors that affect mitigation programmes, such as social and cultural acceptability (48, 49). Moreover, many decision-making structures still operate within sectors that have distinct boundaries, agendas and – most importantly – dedicated budgets. Such political realities and cultural aspects often affect the formulation of technical targets of disease mitigation and are sometimes independent of economic criteria. Thus, to assess, select and implement the most economically efficient options, an ecomic, and if appropiate, interdisciplinary and intersectoral approach is needed.

Combinations of epidemiological and economic models tend to be increasingly used to evaluate and compare health policies. Indeed, epidemiological models allow us to link changes in the effectiveness of surveillance or intervention options with subsequent reductions or increases in health risk and losses. They are particularly interesting in *ex ante* evaluations, or in the face of limited epidemiological data when trying to compare the outputs of different investment options (38, 50, 51). Epidemiological models provide information concerning the effects of defined surveillance and mitigation options on the efficiency of animal production systems and their economic implications. However, they do not usually account for the changing responses of stakeholders in the animal value chain to the subsequent modification of their environment (changes in animal health risks and/or economic risks and new institutional constraints arising from state intervention). The integration of stakeholders' decisions into epidemiological economic models remains mostly theoretical (52). Some frameworks have been proposed but their practical application is hampered by the lack of empirical behavioural data (53, 54).

Thus, guidance on the optimal allocation of resources to animal health management does not only require systematic consideration of the relationships between surveillance, intervention and mitigation outcomes – taking into account the disease's effects on lost current and future production and their magnitude, as well as expenditure on resources to curtail losses – but must also consider the dynamic decision-making behaviour of the people involved in these systems.

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Optimiser les ressources allouées à la surveillance et aux interventions zoosanitaires et à l'atténuation des maladies animales

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Résumé

L'économie de la santé animale a pour rôle primordial d'étayer la prise de décisions en définissant les meilleurs investissements en santé animale. Les activités de surveillance de la santé animale permettent de réunir les informations nécessaires pour guider les interventions. Par conséquent, il est nécessaire d'évaluer en même temps les investissements dans la surveillance et ceux dans les interventions. Les auteurs exposent les différents cadres théoriques et méthodologiques permettant d'évaluer et d'optimiser l'utilisation des ressources allouées à la surveillance et aux interventions et en font ressortir l'interdépendance technique. Les cadres présentés mettent en rapport les investissements dans la santé avec les pertes dues aux maladies et définissent les relations entre les ressources allouées à la surveillance et celles allouées aux interventions. La surveillance et les interventions sont généralement considérées comme des substitus tecniques, dans la mesure où toute augmentation des investissements dans la surveillance réduit d'autant le volume des ressources allouées aux interventions, pour un bénéfice équivalent. Les auteurs examinent également les approches utilisées pour quantifier les externalités ainsi que les impacts non monétaires. Enfin, ils décrivent plusieurs types d'évaluations économiques courantes, dont l'optimisation, l'acceptabilité et les analyses du moindre coût.

Mots-clés

Analyse du moindre coût – Atténuation – Intervention – Investissement optimal – Rentabilité – Surveillance – Valeur.

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Óptima asignación de los recursos a las actividades de vigilancia e intervención zoosanitaria y a la mitigación de las enfermedades animales

B. Häsler, A. Delabouglise & S. Babo Martins

Resumen

La economía de la sanidad animal tiene por función básica fundamentar la adopción de decisiones por el expediente de determinar cuáles son las inversiones óptimas desde el punto de vista zoosanitario. La vigilancia zoosanitaria genera información con la cual orientar las intervenciones. Por consiguiente, es necesario evaluar conjuntamente las inversiones en vigilancia y las destinadas a intervenciones. Los autores examinan los diferentes métodos y marcos teóricos que se han elaborado para evaluar y optimizar el gasto de recursos en labores de vigilancia y en intervenciones, así como su interdependencia técnica. En este sentido, presentan una serie de marcos que definen la relación entre inversiones en sanidad y pérdidas por enfermedades y la relación entre recursos para vigilancia y recursos para intervenciones. En general se considera que la vigilancia y las intervenciones son técnicamente interdependientes, toda vez que una mayor inversión en vigilancia reduce la cuantía de los recursos para intervenciones que hacen falta para obtener el mismo beneficio. Los autores también reflexionan sobre los métodos empleados para cuantificar los factores externos (externalidades) y las repercusiones no monetarias. Por último, describen los tipos más frecuentes de evaluación económica, como los de optimización, aceptabilidad o análisis del costo mínimo.

Palabras clave
Análisis del costo mínimo – Eficiencia económica – Intervención – Mitigación – Inversión óptima – Valor – Vigilancia.

References

1. Havelaar A.H., Kirk M.D., Torgerson P.R., Gibb H.J., Hald T., Lake R.J., Praet N., Bellinger D.C., de Silva N.R., Gargouri N., Speybroeck N., Cawthorne A., Mathers C., Stein C., Angulo F.J. & Devleesschauwer B. (2015). – World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med.*, **12** (12), 1–23. doi:10.1371/journal.pmed.1001923.

2. Kraipornsak P. (2010). – The outbreak of avian influenza and chicken consumption in Thailand. *Res. Bus. Econ.*, **2**, 1–18. Available at: www.aabri.com/manuscripts/09340.pdf (accessed on 19 October 2016).

3. McInerney J. (1996). – Old economics for new problems – livestock disease: presidential address. *J. Agric. Econ.*, **47** (3), 295–314. doi:10.1111/j.1477-9552.1996.tb00695.x.

4. Häsler B. & Howe K. (2012). – Evaluating the role of surveillance in national policies for animal health. *EuroChoices*, **11** (2), 39–44. doi:10.1111/j.1746-692X.2012.00233.x.

5. Howe K.S., Häsler B. & Stärk K.D.C. (2013). – Economic principles for resource allocation decisions at national level to mitigate the effects of disease in farm animal populations. *Epidemiol. Infect.*, **141** (1), 91–101. doi:10.1017/S095026881200060X.

6. RISKSUR Consortium (2016). – Risk-based animal health surveillance systems. Glossary. Available at: www.fp7-risksur.eu/terminology/glossary (accessed on 1 May 2016).

7. Häsler B., Howe K.S. & Stärk K.D.C. (2011). – Conceptualising the technical relationship of animal disease surveillance to intervention and mitigation as a basis for economic analysis. *BMC Health Serv. Res.*, **11** (1), 225. doi:10.1186/1472-6963-11-225.

8. Stärk K.D.C. & Häsler B. (2015). – The value of information: current challenges in surveillance implementation. *Prev. Vet. Med.*, **122** (1–2), 229–234. doi:10.1016/j.prevetmed.2015.05.002.

9. Merianos A. (2007). – Surveillance and response to disease emergence. *Curr. Top. Microbiol. Immunol.*, **315**, 477–509. doi:10.1007/978-3-540-70962-6_19.

10. McInerney J.P., Howe K.S. & Schepers J.A. (1992). – A framework for the economic analysis of disease in farm livestock. *Prev. Vet. Med.*, **13** (2), 137–154. doi:10.1016/0167-5877(92)90098-Z.

11. Tisdell C. (1995). – Assessing the approach to cost-benefit analysis of controlling livestock diseases of McInerney and others. *In* Research papers and reports in animal health economics. Working Paper No. 3. Department of Economics, University of Queensland, Brisbane.

12. Bennett R. (2003). – The 'direct costs' of livestock disease: the development of a system of models for the analysis of 30 endemic livestock diseases in Great Britain. *J. Agric. Econ.*, **54** (1), 55–71. doi:10.1111/j.1477-9552.2003.tb00048.x.

13. Bennett R. & IJpelaar J. (2005). – Updated estimates of the costs associated with thirty four endemic livestock diseases in Great Britain: a note. *J. Agric. Econ.*, **56** (1), 135–144. doi:10.1111/j.1477-9552.2005.tb00126.x.

14. Rushton J., Thornton P.K. & Otte M.J. (1999). – Methods of economic impact assessment. *In* The economics of animal disease control (B.D. Perry, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **18** (2), 315–342. doi:10.20506/rst.18.2.1172.

15. Rushton J., Queenan K., Stevens K. & Häsler B. (2015). – Social sciences: human behavior and disease emergence in humans and animals. *In* Proc. of the 3rd International One Health Congress, 15–18 March, Amsterdam, the Netherlands.

16. Häsler B. (2011). – Economic assessment of veterinary surveillance programmes that are part of the national control plan of Switzerland. PhD thesis submitted to the University of London.

17. Babo Martins S., Rushton J. & Stärk K.D. (2015). – Economic assessment of zoonoses surveillance in a 'One Health' context: a conceptual framework. *Zoon. Public Hlth*, **63** (5), 386-395. doi:10.1111/zph.12239.

18. Peck D. & Bruce M. (2017). – The economic efficiency and equity of government policies on brucellosis: comparative insights from Albania and the United States of America. *In* The economics of animal health (J. Rusthon, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1), 349–358. doi: 10.20506/rst.36.1.2629.

19. Budke C.M., Carabin H. & Torgerson P.R. (2011). – Health impact assessment and burden of zoonotic diseases. *In* Oxford textbook of zoonoses: biology, clinical practice, and public health control, 2nd Ed. Oxford University Press, Oxford, 10.

20. Majorowski M.M., Carabin H., Kilani M. & Bensalah A. (2005). – Echinococcosis in Tunisia: a cost analysis. *Trans. Roy. Soc. Trop. Med. Hyg.*, **99** (4), 268–278. doi:10.1016/j.trstmh.2004.06.011.

21. Ott S.L., Seitzinger A.H. & Hueston W.D. (1995). – Measuring the national economic benefits of reducing livestock mortality. *Prev. Vet. Med.*, **24** (3), 203–211. doi:10.1016/0167-5877(95)00477-E.

22. Upton M. (2009). – Tools for assessing the price and market impact of livestock policies. *In* The economics of animal health and production (J. Rushton, ed.). CAB International, Wallingford, UK.

23. Drummond M.F. (1997). – Methods for the economic evaluation of health care programmes, 2nd Ed. Oxford University Press, Oxford.

24. Claxton K., Martin S., Soares M., Rice N., Spackman E., Hinde S., Devlin N., Smith P.C. & Sculpher M. (2013). – Methods for the estimation of the NICE cost effectiveness threshold. CHE Research Paper 81. Centre for Health Economics (CHE), University of York, York, 436 pp.

25. Moran D. & Fofana A. (2007). – An economic evaluation of the control of three notifiable fish diseases in the United Kingdom. *Prev. Vet. Med.*, **80** (2–3), 193–208. doi:S0167-5877(07)00051-7 (pii)10.1016/j.prevetmed.2007.02.009.

26. Mwaura F., Muwanika F.R. & Okobai G. (2010). – Willingness to pay for extension services in Uganda among farmers involved in crop and animal husbandry. *In* Proc. of the 3rd African Association of Agricultural Economists, 19–23 September, Cape Town, South Africa.

27. Delabouglise A., Antoine-Moussiaux N., Phan T.D., Dao D.C., Nguyen T.T., Truong B.D., Nguyen X.N., Vu T.D., Nguyen K.V., Le H.T., Salem G. & Peyre M. (2016). – The perceived value of passive animal health surveillance: the case of highly pathogenic avian influenza in Vietnam. *Zoon. Public Hlth*, **63** (2), 112–128. doi:10.1111/zph.12212.

28. Louviere J.J., Hensher D.A. & Swait J.D. (2000). – Stated choice methods: analysis and applications. Cambridge University Press, Cambridge. doi:10.1017/cbo9780511753831.

29. Hall J., Kenny P., King M., Louviere J., Viney R. & Yeoh A. (2002). – Using stated preference discrete choice modelling to evaluate the introduction of varicella vaccination. *Hlth Econ.*, **11** (5), 457–465. doi:10.1002/hec.694.

30. Bennett R. & Balcombe K. (2012). – Farmers' willingness to pay for a tuberculosis cattle vaccine. *J. Agric. Econ.*, **63** (2), 408–424. doi:10.1111/j.1477-9552.2011.00330.x.

31. Mørkbak M.R., Christensen T. & Gyrd-Hansen D. (2011). – Consumers' willingness to pay for safer meat depends on the risk reduction methods – a Danish case study on *Salmonella* risk in minced pork. *Food Control*, **22** (3–4), 445–451. doi:10.1016/j.foodcont.2010.09.024.

32. Gramig B.M., Horan R.D. & Wolf C.A. (2009). – Livestock disease indemnity design when moral hazard is followed by adverse selection. *Am. J. Agric. Econ.*, **91** (3), 627–641. doi:10.1111/j.1467-8276.2009.01256.x.

33. Saak A.E. (2012). – Infectious disease detection with private information. International Food Policy Research Institute, Washington, DC.

34. Elbers A.R., Gorgievski-Duijvesteijn M.J., van der Velden P.G., Loeffen W.L. & Zarafshani K. (2010). – A socio-psychological investigation into limitations and incentives concerning reporting a clinically suspect situation aimed at improving early detection of classical swine fever outbreaks. *Vet. Microbiol.*, **142** (1–2), 108–118. doi:10.1016/j.vetmic.2009.09.051.

35. Bronner A., Hénaux V., Fortané N., Hendrikx P. & Calavas D. (2014). – Why do farmers and veterinarians not report all bovine abortions, as requested by the clinical brucellosis surveillance system in France? *BMC Vet. Res.*, **10** (1), 93. doi:10.1186/1746-6148-10-93.

36. Calba C., Antoine-Moussiaux N., Charrier F., Hendrikx P., Saegerman C., Peyre M. & Goutard F.L. (2015). – Applying participatory approaches in the evaluation of surveillance systems: a pilot study on African swine fever surveillance in Corsica. *Prev. Vet. Med.,* **122** (4), 389–398. doi:10.1016/j.prevetmed.2015.10.001.

37. Stott A.W., Lloyd J., Humphry R.W. & Gunn G.J. (2003). – A linear programming approach to estimate the economic impact of bovine viral diarrhoea (BVD) at the whole-farm level in Scotland. *Prev. Vet. Med.*, **59** (1–2), 51–66. doi:10.1016/s0167-5877(03)00062-x.

38. Kobayashi M., Carpenter T.E., Dickey B.F. & Howitt R.E. (2007). – A dynamic, optimal disease control model for foot-and-mouth disease: I. Model description. *Prev. Vet. Med.*, **79** (2–4), 257–273. doi:10.1016/j.prevetmed.2007.01.002.

39. Bates T.W., Carpenter T.E. & Thurmond M.C. (2003). – Benefit-cost analysis of vaccination and preemptive slaughter as a means of eradicating foot-and-mouth disease. *Am. J. Vet. Res.*, **64** (7), 805–812. Available at: www.ncbi.nlm.nih.gov/pubmed/12856762 (accessed on 24 November 2013). doi:10.2460/ajvr.2003.64.805.

40. Carpenter T.E. & Howitt R. (1979). – A linear programming model used in animal disease control. *In* Proc. of the 2nd International Symposium on Veterinary Epidemiology and Economics (ISVEE), 7–11 May, Canberra, Australia (W.A. Geering, R.T. Roe & L.A. Chapman, eds). Australian Government Publishing Service, Canberra.

41. Kompas T., Nhu Che T. & Ha Van P. (2006). – An optimal surveillance measure against foot-and-mouth disease in the United States. Crawford School of Economics and Government, Australian National University (ANU), Working Paper 06–11. ANU, Canberra, Australia. Available at: http://saber.eaber.org/system/tdf/documents/Crawford_Kompas_2006.pdf?file=1&type=node&id=21813&force= (accessed on 20 October 2016).

42. Guo X., Claassen G.D.H., Oude Lansink A.G. & Saatkamp H.W. (2014). – A conceptual framework for economic optimization of single hazard surveillance in livestock production chains. *Prev. Vet. Med.*, **114** (3–4), 188–200. doi:10.1016/j.prevetmed.2014.02.003.

43. Howe K.S. & Christiansen K.H. (2004). – The state of animal health economics: a review. *In* Proc. of the Annual Conference of the Society for Veterinary Epidemiology and Preventive Medicine, Martigny, Switzerland, 68–80.

44. Häsler B., Howe K.S., Presi P. & Stärk K.D.C. (2012). – An economic model to evaluate the mitigation programme for bovine viral diarrhoea in Switzerland. *Prev. Vet. Med.*, **106** (2), 162–173. doi:10.1016/j.prevetmed.2012.01.022.

45. Owens D.K. (1998). – Interpretation of cost-effectiveness analyses. *J. Gen. Internal Med.*, **13** (10), 716–717. doi:10.1046/j.1525-1497.1998.00211.x.

46. Jones K.E., Patel N.G., Levy M.A., Storeygard A., Balk D., Gittleman J.L. & Daszak P. (2008). – Global trends in emerging infectious diseases. *Nature*, **451** (7181), 990–993. doi:10.1038/nature06536.

47. Pike J., Bogich T., Elwood S., Finnoff D.C. & Daszak P. (2014). – Economic optimization of a global strategy to address the pandemic threat. *Nature*, **451** (16), 990–994. doi:10.1073/pnas.1412661112.

48. Safman R. (2009). – The political economy of avian influenza in Thailand. STEPS Centre, Brighton, UK. Available at: http://steps-centre.org/publication/the-political-economy-of-avian-influenza-in-thailand/ (accessed in May 2016).

49. Vu T. (2009). – The political economy of avian influenza response and control in Vietnam. STEPS Centre, Brighton, UK. Available at: http://steps-centre.org/publication/the-political-economy-of-avian-influenza-response-and-control-in-vietnam/ (accessed in May 2016).

50. Carpenter T.E., O'Brien J.M., Hagerman A.D. & McCarl B.A. (2011). – Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of a simulated outbreak in California. *J. Vet. Diagn. Invest.*, **23** (1), 26–33. doi:10.1177/104063871102300104.

51. Rendleman C.M. & Spinelli F.J. (1994). – The costs and benefits of African swine fever prevention. *Am. J. Agric. Econ.*, **76** (5), 1255.

52. Boni M.F., Galvani A.P., Wickelgren A.L. & Malani A. (2013). – Economic epidemiology of avian influenza on smallholder poultry farms. *Theoret. Popul. Biol.*, **90**, 135–144. doi:10.1016/j.tpb.2013.10.001.

53. Chilonda P. & Van Huylenbroeck G. (2001). – A conceptual framework for the economic analysis of factors influencing decision-making of small-scale farmers in animal health management. *Rev. Sci. Tech. Off. Int. Epiz.*, **20** (3), 687–700. doi:10.20506/rst.20.3.1302.

54. Rich K.M., Denwood M.J., Stott A.W., Mellor D.J., Reid S.W. & Gunn G.J. (2013). – Systems approaches to animal disease surveillance and resource allocation: methodological frameworks for behavioral analysis. *PLoS ONE*, **8** (11), e82019. doi:10.1371/journal.pone.0082019.