SURVEILLANCE AND INTERVENTION EXPENDITURE: SUBSTITUTION OR COMPLEMENTARITY BETWEEN DIFFERENT TYPES OF POLICY

Barbara Häsler
Royal Veterinary College and Leverhulme Centre for Integrative Research on Agriculture and Health, UK

Jonathan Rushton
Royal Veterinary College and Leverhulme Centre for Integrative Research on Agriculture and Health, UK

Katharina D. C. Stärk
Royal Veterinary College and Centre for Rural Policy Research, University of Exeter, UK

Keith S. Howe
Royal Veterinary College, and Centre for Rural Policy Research, College of Social Sciences and International Studies, University of Exeter, UK

Animal disease diminishes the well-being of humans, and can lead to significant economic losses under certain circumstances. In this paper, we discuss a framework that has been designed to guide the economic assessment of surveillance and intervention strategies and inform the allocation of resources for disease mitigation. This framework presents a way to help allocate resources to surveillance and intervention based on economic principles, though its application requires extensive research and data collection to translate the principles into practice. Incorporating economic analysis in the decision making process also requires close collaboration between economists, epidemiologists, animal health scientists and policy makers at all stages.

Introduction

Animal disease is an economic cost

Animal disease diminishes the well-being of humans. In livestock and fish, disease can cause a reduction in the quantity or quality of animal outputs such as milk, meat, eggs, wool or hides, leading to production losses, or inefficiencies. At the same time, disease reduces the availability of animals for work and leisure, whether they be sports animals (e.g. horses for racing), working animals (e.g. sniffer dogs, draught animals) or simple companions.

In certain contexts, these negative effects have even wider consequences. In low- and middle-income countries — where livestock is a source of income, social security, food, asset or dowry — diseases can pose a serious threat to livelihoods. But highly pathogenic or infectious animal diseases can have devastating impacts on productivity in high-income countries, as well.

Zoonotic and foodborne diseases transmitted either directly through contact with infected animals (e.g. rabies infection) or through the ingestion of contaminated food or water can cause human illness and, in the worst case, death. This leads to reduced productivity, lost income and human suffering, and in many cases involves family members or friends who assume the role of unpaid caregiver. While some diseases are limited to short bouts of illness, others are chronic (e.g. *Campylobacter jejuni* disease, which is the most common antecedent to Guillan-Barré syndrome, an acute neuropathy that may result in severe disability), thereby resulting in a permanent economic loss.

Apart from the debilitating consequences associated with human illness, substantial economic costs may also arise from food scares. If a disease can be contracted from contaminated food products, people may fear for their own health. The possibility of people contracting new-variant CJD from cattle affected by BSE is one dramatic example of this situation, as are fears arising from the spread of microbial pathogens such as salmonella, influenza viruses or pathogenic *Escherichia coli* (*E. coli*) bacteria. In countries where there are no substitutions for the food in question, consumers either put themselves at risk of foodborne disease when consuming the food due to the lack of alternatives, or they may increase their risk of malnutrition by excluding nutritious foods from their diets.

Animal disease can also have negative effects on the ecosystem, resulting in further losses in human well-being. For example, the collapse of honeybee colonies seems to be caused by multiple complex factors, including the presence of varroa mites and viruses (Le Conte, et al., 2010). Growing evidence suggests that there has been a general decline in pollinators in many regions across the world, with negative impacts for wild plants and crops (Potts, et al., 2010).

Disease mitigation is an economic cost

Our reaction to disease generates other kinds of economic costs. Public and private institutions — including public and animal health services, industry bodies, and farmers — aim to limit losses by avoiding, containing, reducing or removing a hazard, all of which require scarce resources. The ability to offset the negative effects of disease depends primarily on the technical possibilities, which can only be applied in full if supported by effective communication and behavioural responses. A prerequisite is that the science (i.e. technical characteristics) of any particular disease must be well understood. Then, remedies can be developed based on the knowledge and understanding acquired.

Common steps taken in animal disease mitigation can be classified into three broad groups.

- Mitigation measures that target live animals, such as culling, treating or vaccinating animals (interventions[1]); collection of health or disease data to inform disease mitigation (surveillance[2]); avoidance of contact with pathogens through quarantine, bio-exclusion, movement and trade bans (prevention[3]).
- Post-harvest treatment of animal products to keep a potential hazard[4] below a defined threshold, so that its ingestion does not cause harm to people (e.g. pasteurisation of milk, preservation of meat through heating, cooling, drying and/or addition of preservatives, or removal of any food produce found to be contaminated with unacceptable levels of hazards.
- Campaigns that alert people to zoonotic and foodborne disease, and inform them about how it can be avoided. For many foodborne diseases, these efforts aim to promote the hygienic and safe handling of food among consumers. For diseases transmitted directly, campaigns provide advice on how to reduce the risk of infection. For example, to prevent rabies — commonly transmitted through bites and scratches from infected dogs — campaigns may include seminars on how to prevent bites and treat wounds immediately after a bite, as well as warnings to seek medical advice after a possible exposure (perhaps resulting in vaccination).

All of these remedial actions require the use of scarce resources that would be unnecessary in the absence of disease. Such resources have an opportunity cost — value that could be produced if those same resources were used in alternative ways. Therefore, resources used for disease control are also a component of the full economic cost of disease.

In many countries, animal health policy receives a significant amount of public and private resources to mitigate losses caused by endemic, emerging and exotic diseases. Below are two examples.

- In 1999, a highly pathogenic avian influenza outbreak in Italy triggered a stamping-out and pre-emptive slaughter policy that resulted in the death of over 13 million birds and compensation payments for poultry holdings of an estimated EUR 100 million. These costs do not include the disruption caused to hatcheries, feed mills, abattoirs and processing plants; nor do they include the costs of rendering, disposal, cleaning and disinfection (Capua and Marangon, 2000).
- England spends about GBP 100 million on the mitigation of endemic bovine tuberculosis, with compensation and surveillance costs comprising the largest share (Burke, 2013).

Although these figures demonstrate on-going efforts to mitigate the negative effects of animal disease, they do not provide any information about the economic efficiency of these measures or, equivalently, the magnitude of the losses that could be avoided. Formal economic analysis is therefore needed to assess the economic values of different mitigation strategies, and to inform decisions about resource allocation.

1. The process of implementing measures directed at mitigation
2. The on-going collection, validation, analysis, interpretation and dissemination of health and disease data that are needed to inform key stakeholders to permit them to plan and implement more effective, evidence-based public health policies and strategies relevant to disease mitigation and to demonstrate the absence of disease or infection or food borne hazards
3. The total exclusion of disease from a susceptible animal population
4. Any biological, chemical or physical agent in, or a condition of, an animal or animal product with the potential to cause disease

Economic analysis of animal disease mitigation

In summary, animal disease diminishes human well-being in two ways. First, through the value losses incurred because of the negative effects of the disease itself; and second, through additional resource costs incurred during attempts to offset those value losses (when the resources used could have been used to generate value elsewhere in the economy). The economic cost of animal disease is frequently presented as an aggregate figure that includes both the disease's impact and the impact caused by the reaction to the disease (Rushton, 2013). Aggregate figures of neither losses nor expenditures provide the information needed to inform priorities for research, or for the selection of appropriate mitigation strategies.

In assessing the rationality of any resource-using decision, the key criterion is whether the value of outputs recovered will be at least sufficient to cover the additional resource costs. When considering a given policy, the cost of resources committed to mitigation should therefore be compared with the value of resulting recovered outputs. Ideally, the net benefits to society should be maximised (Mclnerney et al., 1992).

In the literature on animal health economics, this basic principle has been applied by McInerney, et al., who defined a loss expenditure frontier method for identifying endemic disease control strategies that minimise total costs (with costs defined as output losses plus control expenditures) (McInerney, 1996; Mclnerney, et al., 1992). This approach identifies the best balance between losses and expenditures under diminishing returns. Importantly, the total minimum costs will not correspond to the minimum level of losses; in other words, disease eradication is not the best option from an economic point of view. Tisdell expanded on this proposed concept in addressing the control of several diseases at the same time, the possibility of diminishing marginal returns at higher levels of expenditure, and the need for a minimum investment to avoid value losses (Tisdell, 1995). Bennett and IJpelaar suggested an addition to the framework, adding the impact of disease on animal welfare and human health, and using it to estimate disease costs of 34 endemic livestock diseases in the United Kingdom (Bennett and IJpelaar, 2005). A similar concept, suggested recently, takes into account all the broader negative effects of animal disease, and the impact caused by our reaction to disease (Rushton, 2013). A further application of the basic framework established by McInerney, et al. is presented here to incorporate two integral parts of disease mitigation — surveillance and intervention.

Demand for disease mitigation in times of increasing financial constraints

In the past, disease was mainly seen as a livestock problem, because it decreased the productivity of animals and therefore the goods available for human consumption. Because major epidemic and important endemic diseases have been mitigated in most developed countries, the focus has gradually shifted to diseases with less evident economic, farm-level impacts and complex epidemiological patterns (Otte and Chilonda, 2000).

To sustain non-existent or low levels of disease, many governments make substantial investments in early warning surveillance and response systems (Häsler, et al., 2011). At the same time, larger livestock populations, increased production intensity, changes in trade volumes and patterns, and the use of new habitats have produced an environment that facilitates the evolution and spread of pathogens, including those with antimicrobial resistance genes (Daszak, et al. 2000; Dobson and Carper, 1996; Greger, 2007; Jones, et al., 2008; McMichael, 2004; Morse, 1995; Palumbi, 2001). Large-scale epidemics like avian influenza or swine influenza regularly prompt renewed demand for more effective surveillance and intervention systems. At the same time, governments are forced to reduce their animal disease mitigation expenditure in response to growing financial constraints. For these reasons, there is a need for effective and efficient animal health surveillance systems that generate outputs in relation to the health status of the animal populations, thereby allowing for the appropriate management of any emerging or existing risks.

The nature and financing of disease mitigation strategies must therefore be carefully assessed, using suitable approaches and taking into account best available evidence. In the next sections, we discuss a framework that has been designed to guide the economic assessment of surveillance and intervention strategies, and to inform the allocation of resources for disease mitigation.

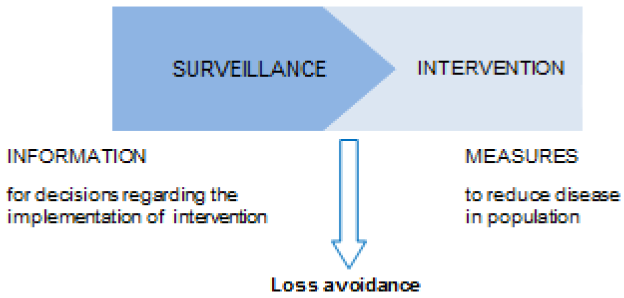
The relationship between surveillance and intervention

Surveillance and intervention as economic substitutes or complements

Surveillance involves the systematic collection, collation and analysis of data related to animal health, and the communication of this information to people who have the authority to act on it. Surveillance is used for early warning when disease (re)occurs, to detect infection or disease, to measure the prevalence of pathogens or hazards found in animal populations or along the food chain, to inform intervention aimed at to reducing or eradicating disease, and to document freedom from disease, infection or chemical contaminants in food products. In a broader sense, surveillance can be considered as a scientific, factual tool that informs policy decisions and the allocation of resources for disease mitigation (Thacker, 1996).

In other words, surveillance provides information for decisions concerning the implementation of interventions. Intervention is the process of implementing measures directed at mitigation. Together, surveillance and intervention achieve loss avoidance — the outcome that ultimately interests us (Figure 1).

Figure 1. The relationship between surveillance, intervention and loss avoidance



We are therefore looking at a three-variable relationship, where surveillance and intervention can be considered as economic complements or substitutes. If surveillance and intervention resources are complements, they are used in a given ratio and must be treated as one input. This is the case, for example, in testing and culling strategies. If they are economic substitutes, using more of one input will require using fewer resources for the other. This is for example the case when we do surveillance to detect disease early, thereby saving intervention resources. In practice, these considerations imply that surveillance cannot be properly evaluated without simultaneously considering intervention.

Intuitively, enhanced surveillance should facilitate more timely, and thus less extensive, intervention. Investments into early warning surveillance are commonly based on the expectation that early detection of disease will lead to rapid response and therefore smaller (less costly) outbreaks. This is in line with the popular "prevention is better than cure" principle, and has resulted in initiatives such as the Global Early Warning System (GLEWS)[5] for major animal diseases (including zoonoses) by the Food and Agriculture Organisation of the United Nations (FAO), the World Health Organisation (WHO), and the World Organisation for Animal Health (OIE) — in addition to multiple early warning surveillance systems worldwide.

The economic analysis of surveillance and intervention as economic substitutes

A necessary, though insufficient, condition for optimal economic efficiency is that the combined cost of surveillance and intervention be minimised for a given disease mitigation objective, such as a reduction in prevalence or incidence (e.g. "reduce prevalence of disease x in population y by 10%", or "eradicate disease from population z"). In economic analysis, prevalence or incidence reduction must be translated into corresponding economic values of loss avoidance.

Avoided value losses may be obtained from different combinations of surveillance and intervention efforts. In general, allocating more resources to surveillance should lead to better information about a disease threat. Interventions can then be better targeted, thereby reducing the need for intervention. For example, surveillance information identifying animal populations at high risk of disease allows vaccination efforts to focus on those particular populations, rather than all animals in an area or country. For any disease of interest, it is therefore necessary to collate information of possible levels of loss avoidance using mitigation resources, and to understand the technical trade-offs between surveillance and intervention for these levels. The implications of this novel concept are described in detail elsewhere (Howe, et al., 2013) and are summarised here.

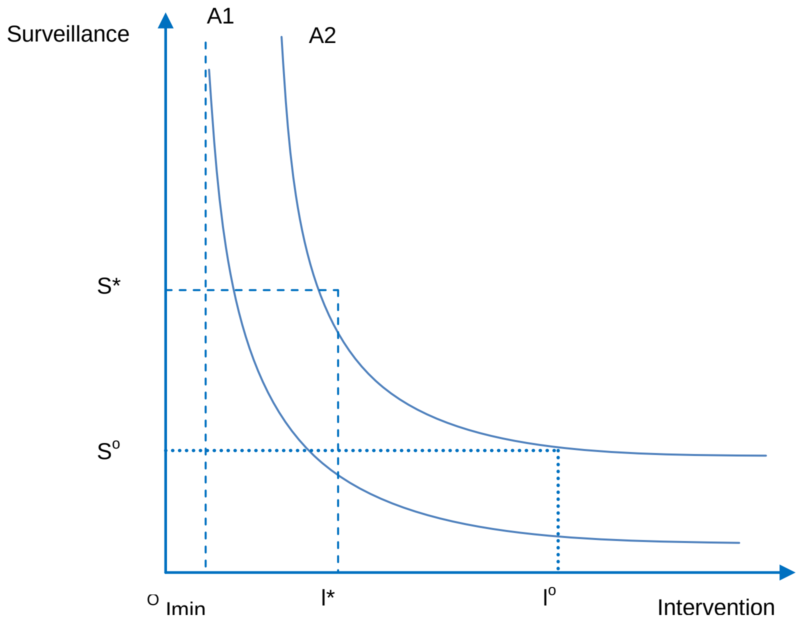
In Figure 2, curves A1 and A2 illustrate the possibility of substitution between surveillance and intervention for two (out of potentially very many) feasible levels of avoided losses. It is hypothesised that some minimum intervention resources need to be used irrespective of the level of surveillance, in order to avoid losses indicated as *Imin* in Figure 2. If there is no possibility for action after detecting disease — for example, if there are no technical options or simply no resources to contain the disease — the value of surveillance lies only in the knowledge of disease occurrence, though it may also result in a head start in launching epidemiological and microbiological investigations to understand disease dynamics and develop intervention options. Because diminishing returns to resource use are expected, the shapes of both curves show that increasing commitments of intervention resources must compensate for each unit reduction in surveillance, or vice versa.

With knowledge about the technical relationships between surveillance and intervention, combinations of surveillance and intervention can be determined for a specified level of loss avoidance. For example, the loss avoidance in curve A2 can be achieved by conducting either a lot of surveillance and limited intervention (S* and I*), or limited surveillance and a lot of intervention (S° and I°). Because resources are not obtained for free, it is important to know not only the combinations that are technically possible (e.g. the combinations S*/I*/A2 and S°/I°/A2), but the costs of provision for both surveillance and intervention, as well. If surveillance and intervention can be used interchangeably, it makes sense to prefer the cheaper resource. It is therefore necessary to estimate first the financial costs of surveillance and intervention for providing personnel, testing equipment, drugs, vaccines, cleaning and disinfection equipment, laboratory services, and other resources needed. If, for instance, the cost of intervention resources rise relative to those for surveillance, surveillance resources should be increased — and intervention resources decreased — in order to retain the same

5. http://www.glews.net/

level of avoided losses. This concept is particularly important when there is a financial budget constraint that defines maximum expenditures on disease mitigation programs.

Figure 2. Two defined levels of loss avoidance (A1<A2) achieved by varying levels of surveillance (S) and intervention (I)

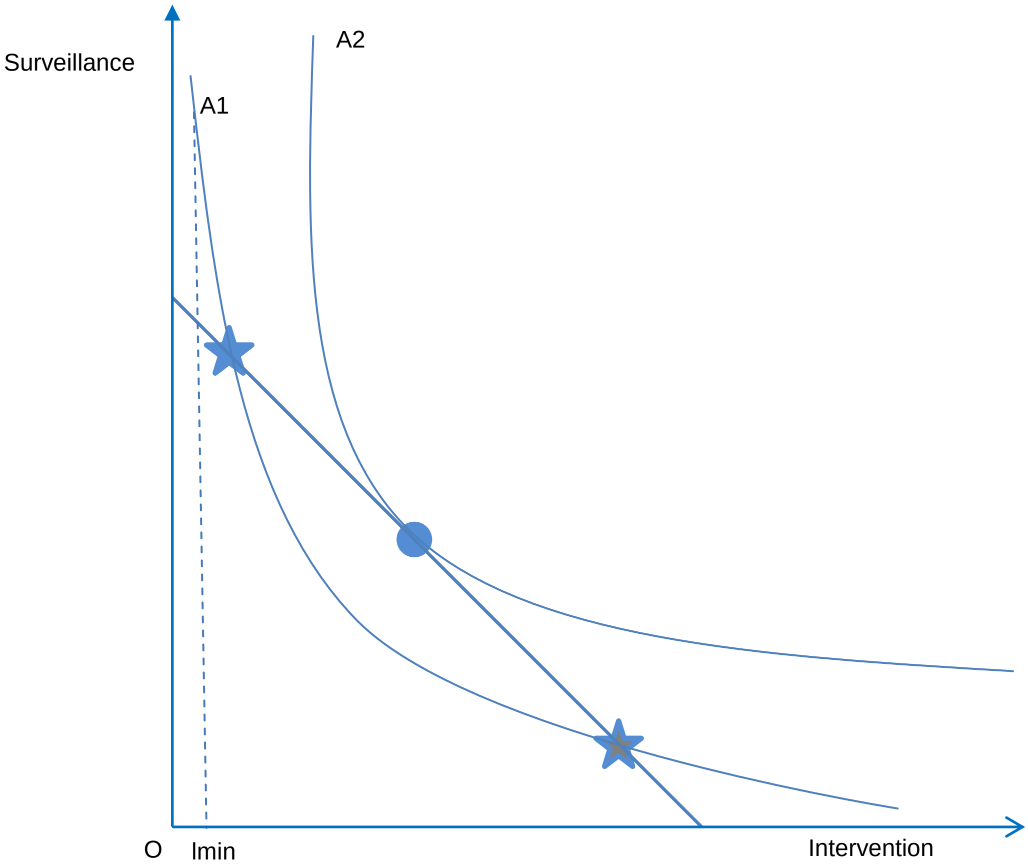


In Figure 3, the grey straight line is a budget line that represents all combinations of surveillance and intervention that sum up to the same total amount of mitigation expenditures. With the ideal combination of surveillance and intervention resource use, a higher level of benefit can be achieved. The least-cost combination of surveillance and intervention use would be where the budget line touches curve A2 (marked with a dot). Other combinations along the budget line are possible as well, but must yield lower values of loss avoidance (marked with stars in Figure 3).

Once least-cost combinations are plotted in relation to levels of loss avoidance (A1 to An), an expansion path can be identified. The net benefit for society is maximised at the point where the marginal loss avoidance (i.e. marginal benefit) equals the marginal costs on the expansion path. To identify this economic optimum for disease mitigation, it is necessary to understand the technical relationships between loss avoidance and the use of surveillance and intervention resources. One must also translate loss avoidance and resource use into monetary values such as benefits and costs, determine least-cost combinations for surveillance and intervention, and identify the least-cost combination(s) consistent with the avoidance loss that maximises economic welfare.

It is important to stress that an understanding of these relationships is critical to making the best use of available resources for surveillance and intervention. Without sufficient information about the relationships described, economic analysis of surveillance and intervention are limited to criteria of acceptability, as used in cost-benefit analysis or the selection of least-cost options.

Figure 3. Illustration of how a higher level of benefit can be achieved* with the ideal combination of resource use



* Dot compared to grey stars.

From principles to practice

Three important prerequisites are needed to determine the economic optimum for disease mitigation using the economic principles described:

- *ex ante* assessment to inform a decision regarding the future implementation or continuation of a disease mitigation program;
- availability of economic and epidemiological expertise to apply the relevant principles and techniques and integrate respective models; and,
- availability of data required for the economic and epidemiological models.

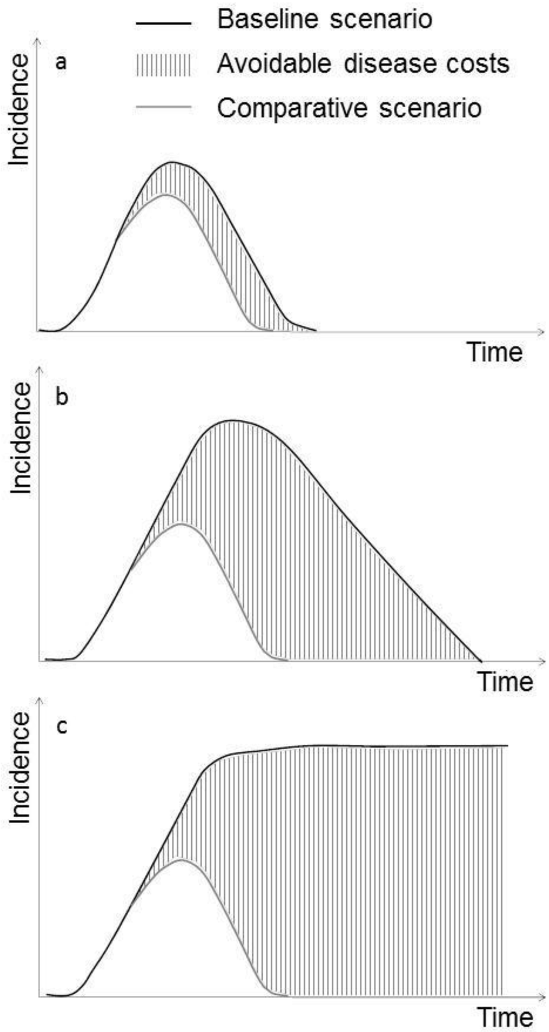
As a basic rule, economic analysis of a national mitigation program needs to account for the losses avoided and the expenditures of all essential activities (Häsler, et al., 2011). These include the effects of morbidity and mortality in livestock holdings and associated upstream and downstream businesses (e.g. breeders or slaughterhouses), which are expressed in monetary terms using market prices. These also include the effects of disease on human health, animal welfare or the environment, with values that can be expressed only with indirect estimation methods. The financial costs of all surveillance and intervention activities — including salaries, testing equipment, sanitary measures, drugs and vaccines — must be estimated, as well.

Loss avoidance

To assess the true economic value of disease mitigation, it is critical to assess the avoidable losses, as advocated by McInerney (1996). This concept is explained here using the example of an outbreak of an exotic disease, such as avian influenza in a country's poultry population. Once the first poultry holding is affected, a certain level of losses will necessarily arise due to morbidity and/or mortality. Because of the time delay between the introduction of a disease and the confirmation of the outbreak, some minimum losses simply cannot be avoided — even with highly sensitive surveillance and effective response. If there are no mitigation measures, the losses will increase, most likely following the shape of an epidemic curve until the outbreak eventually dies out. For certain other pathogens, the outbreak will not be self-limiting, but will instead turn into endemicity with constant losses. Mitigation measures will change the evolution of the outbreak, thereby allowing for a certain level of avoided losses. This is illustrated schematically in Figure 4, where avoidable losses (hatched area) are reflected in the difference in magnitude of an outbreak illustrated for three hypothetical scenarios, namely a) a situation where there is a small difference in magnitude of outbreak without and with mitigation, b) a situation where there is a large difference in magnitude of outbreak without and with mitigation, and c) a situation where the outbreak without mitigation results in endemicity.

The ability to estimate these losses under different mitigation scenarios is very limited due to the scarcity of empirical data, and the large variability of mitigation approaches and contexts across different countries. Epidemiological simulation modelling can provide a solution to this problem by providing estimates for the physical losses expected from epidemics with and without mitigation measures. These estimates can then be translated into monetary values. A wide range of epidemiological simulation models has been developed to inform economic analyses of mitigation programs (Perry, et al., 2001), often using incidence or prevalence in a population over time as proxies. Simulation models can also be used to address specific circumstances, such as national policies, management practices and constraints defined by legislation. On the downside, due to the complex nature of disease transmission and spread, and the limited data on the effectiveness of surveillance and intervention activities, any predictions will be subject to uncertainty.

Figure 4. Avoidable losses under three distinct outbreak scenarios



Valuation of loss avoidance

Once reliable proxies of loss avoidance are available, they must be translated into economic values, including the benefits arising from lower output losses or fewer negative externalities such as human illness.

Any of the losses described in the introduction can be quantified for inclusion in economic analysis. The impact of animal disease on production can be measured using well-validated techniques that reflect production economics principles (Rushton, 2009; Doll and Orazem, 1992; Heady, 1952; Beattie, et al., 2009), and its impact on human health can be measured using approaches from health economics (e.g. Drummond, et al., 2005). But other losses are not so easily quantified. People’s distress, induced by the sickness or death of family members or valued companion animals, is an example of a value loss that is difficult to quantify. Similarly, people in many societies are becoming increasingly concerned for animals’ own welfare. The perceptions that intensive livestock production causes animals to suffer, or that working animals are physically abused, also constitute a loss of well-being. Like output losses in livestock populations, all such intangible or indirect losses are open to estimation in monetary terms, albeit with greater difficulty and through indirect methods.

Willingness-to-pay (WTP) or contingent valuation (CV) methods have been widely used to assess the value of ecological systems, health attributes and safe food. These techniques were developed to assess non-market environmental benefits (e.g. clean water and air), but have increasingly been used in health economics. Their objective is to estimate the value that individuals attribute to a good or service by asking them what they are willing to pay, sacrifice or exchange for it. The underlying approach is based on the assumption that the maximum amount an individual is willing to pay for a commodity reflects the value it holds for them. Miller and Unnevehr (2001), for example, conducted a household survey to investigate consumers' WTP for enhanced pork meat safety. They found that roughly 80% of the consumers were willing to pay at least USD 0.10 more for certified safer pork. Another study used a hypothetical market scenario in the United Kingdom to investigate people's WTP to support legislation to phase out the use of battery cages in egg production in the European Union by 2005 (Bennett, 1998). The survey showed that consumers, on average, were willing to spend GBP 0.43 more per dozen eggs (with a market price of around GBP 1.40 per dozen), purporting to indicate the value respondents attributed to improved animal welfare. The main criticism of the WTP is that it does not give reliable valuations, since the choices are often hypothetical and people tend to overestimate their willingness to pay. Another drawback is that non-users of a good or service might find it difficult to attribute a value to it because their knowledge about it is very limited.

Calculation of surveillance and intervention expenditures

The need for extensive data collection can make it both time consuming and expensive to estimate surveillance and intervention expenditures. But obtaining data on physical inputs and their prices is generally straightforward, thanks to figures available from past mitigation efforts.

We recommend that for both surveillance and intervention, expenditures are calculated for labour, operations and expenses for all activities. Surveillance steps that contribute to surveillance costs are as follows: planning, preparation, sampling, laboratory testing, data management, data analysis, communication, monitoring and controlling, and improvement and adaptation of current programs. Intervention steps that contribute to intervention cost include planning, preparation, implementation, data management, data analysis, communication, monitoring and controlling, and improvement and adaptation of the current program.

Summary and further challenges

In summary, the economic analysis of disease mitigation can require substantial data and skill, depending on the disease, context and the mitigation purpose. Standardisation of the process is complicated by a very large heterogeneity in production systems, public health policies, availability of infrastructure and capacity, national priorities, and existing rules and regulations. Information about technical relationships is rarely collected in a systematic way. Typically, empirical data are only available for very specific combinations of surveillance and intervention, if at all. However, there is a range of epidemiological models available that can be modified in a way to simulate relevant technical relationships and therefore inform economic analysis. Ideally, economic and epidemiological models should be developed together from the start, in order to promote compatibility and increase accuracy.

Scientific challenges arise from a lack of data and integrated epidemiological/economic models, intrinsic uncertainty, variability, and the difficulty of quantifying certain loss values. These challenges are in stark contrast to the needs of decision makers, who often request tools that are simple, practical, and easy to use. Decision makers also have to address the demand for more effective and refined surveillance systems, a demand provoked by both the popular "prevention is better than cure" mentality and large scale epidemics. A higher sensitivity or shorter detection delay may be justified for diseases where past experience has shown the value of early detection, but there seems to be a tendency to apply the same principle to any type of new, exotic or re-emerging disease. For example, during the European *E. coli* O104:H4 in 2011 (Karch, et al., 2012) outbreak mentioned above, Dr. Patrick Walls told Food Safety News that "a better surveillance system and a better early warning system is what we need."[6] But he also cautioned that there is a substantial cost to improving surveillance, and that the finite resources for health care should be spent where they deliver the most.

The above framework presents a way to help allocate resources to surveillance and intervention based on economic principles. Its application requires extensive research and data collection to translate the principles into practice. For diseases with epidemic potential, this should be done during "peacetime", in order for decision makers to be prepared for the next outbreak.

What we can currently do

Case studies that applied the above framework (Häsler, et al., 2012a; Häsler, et al., 2012b; Häsler, et al., 2012c) were limited by the fact that desirable levels of disease had been determined by decision makers before these studies were conducted. Consequently, resource allocation decisions had already been taken, and the models and data available did not allow for the assessment of the substitution possibilities between surveillance and intervention activities. It was only possible to estimate whether the benefit resulting from mitigation was at least as big as the financial expenditures on surveillance and intervention, an acceptability criterion commonly found in cost-benefit analysis (CBA). Until the framework described above is generally accepted, and economic and epidemiological models are constructed for *ex ante* analysis to determine the optimal level of disease mitigation, economic assessments will be confined to the application of acceptable or cheaper alternative methods.

In the transition to improved application of economic concepts in animal health decision making, surveillance and intervention resources — and the substitution possibilities between the two — should be an integral part of popular approaches like CBA and cost-effectiveness analysis (CEA). Lessons learned from the conceptual and empirical work outlined above are now discussed in relation to the use of CBA and CEA for the economic evaluation of surveillance.

Cost-benefit analysis of surveillance and intervention

In short, CBA compares the total discounted benefits of a project with its total discounted costs (both in monetary units), and recommends that the project be implemented if the former exceeds the latter. It involves defining the useful life of the project, estimating costs and benefits in physical units, translating physical units into economic values, converting future values into present values by discounting, and calculating the net benefit (where net present value = total discounted costs – total discounted benefits). Using benefit-cost ratios as choice criteria can be misleading when multiple options are compared (Howe, et al., 2013; McInerney, 1991; Tisdell, 1995). In any assessment of this nature, it is therefore important to review all measures of project worth, namely the net present value, benefit-cost ratio, and internal rate of return and timing to estimate benefit and cost streams. Finally, the outcome of a CBA provides only an estimate of economic profitability for a technically feasible intervention; it does not provide any information on social acceptability or political management.

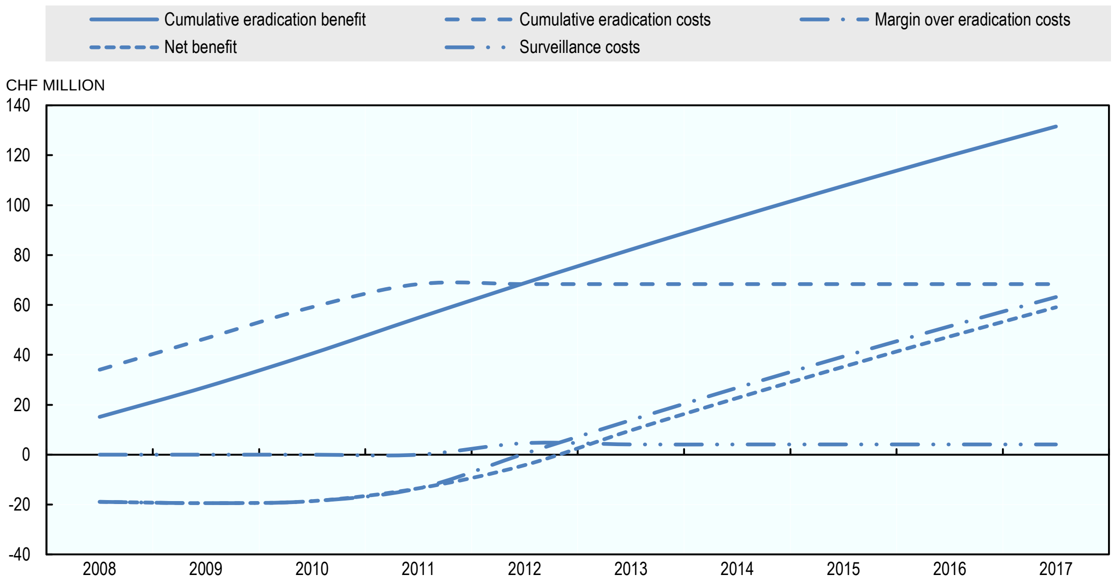
There are three key aspects to keep in mind when conducting a CBA of surveillance and intervention.

6. http://www.foodsafetynews.com/2011/06/germanys-e-coli-outbreak-a-global-lesson/.

- Loss avoidance (benefit) is only possible with a certain level of intervention. As explained above, surveillance is inextricably linked to intervention, so the assessment of benefits is only meaningful when interpreted as part of the overall disease mitigation process. This is corroborated by the fact that existing economic assessments of surveillance generally relate surveillance activities to the probability of a disease outbreak and its consequences, including response costs (e.g. Roman Carrasco, et al., 2010; Kompas, et al., 2006; Moran and Fofana, 2007). Therefore, the CBA must include data on intervention and surveillance, as well as the mitigation outcome.
- The counterfactual — i.e. the situation without the mitigation programme — can be highly dynamic depending on the disease in question. Epidemiological simulation models are therefore necessary to simulate proxies of loss avoidance over time.
- The timeline of the program to be evaluated must be chosen carefully, accounting for the planning, implementation and evaluation horizon. For example, if a program's endpoint is the elimination of disease from a population, the analysis will not 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 must also be considered (Häsler, et al., 2011).

Because the impact of surveillance on mitigation outcome cannot be measured directly or in isolation, one can only quantify the benefit arising from the combination of surveillance and intervention, and compare it with the expenditures on each. We recommended calculating a residual margin over intervention cost, which constitutes the maximum additional surveillance expenditures that could be made without lowering the net benefit from mitigation to zero. This margin can then be compared to the expenditures of various surveillance options. The best option, from an economic point of view, would be the one that maximises net benefit. An example of these relationships is depicted in Figure 5, which concerns the eradication of bovine diarrhoea virus in Switzerland (Häsler, et al., 2012c).

Figure 5. Illustration of a cost-benefit analysis of the Swiss national eradication programme for bovine virus diarrhoea virus*



* Explicitly taking into account surveillance and intervention.
Source: (Häsler, *et al.*, 2012c).

Cost-effectiveness analysis of surveillance

CEA, commonly used to assess human health interventions, has rarely been applied to animal health decision making problems (Babo, Martins and Rushton, 2013). CEA aims to assess the technical effect of a program in relation to its cost. In human health economics, the effect often refers to the avoidance of illness or death, but the outcome of any strategy can be measured in various technical terms that reflect a benefit (e.g. reduction of CO_2 emissions or detection of disease). This approach therefore lends itself to the analysis of animal health surveillance programs where decision makers do not often require explicit quantification of monetary benefits. They may, however, be interested in the costs of the surveillance options associated with certain performance indicators, which can act as proxies for a benefit. The type of effectiveness measure selected depends on the context and surveillance objective — which, in turn, is driven by the mitigation objective (Häsler, et al., 2011). 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. In a low- or middle-income country with endemic disease, the ability of a surveillance system to identify infected animals and target them for intervention will be key; in a high-income country that has controlled major diseases, the timeliness of surveillance and early detection may be of higher priority.

Whenever possible, the measure of effectiveness should reflect a final, rather than intermediate output, though the use of intermediate outputs is valid if they have a value in and of themselves (Drummond, et al., 2005). For instance, a reduction of farm-level zoonotic diseases that does not cause production losses is an intermediate output, while the avoidance of human illness is a final output. The choice of effectiveness criterion is critical in conducting CEA, and can have substantial impacts on the outcome of the analysis. Unlike in human health economics, where attempts have been made to harmonise CEA methodologies and encourage comparability of studies (Murray et al. 2000), there are as yet no specific guidelines available for its application in animal health. Measures of surveillance effectiveness, for example, include the time between disease introduction and detection, the probability of detecting an outbreak, the ability to document disease freedom for a certain hazard with a certain probability, and the number of cases detected or avoided. Obtaining measures of effectiveness is primarily an epidemiological issue. In order to determine the cost-effectiveness of alternative surveillance strategies, one must select and determine appropriate measures of effectiveness using epidemiological approaches.

CEA of surveillance can be categorised into two broad groups. In one group, the surveillance system is designed to achieve a defined objective presented as a binary outcome (objective achieved or not achieved), such as demonstrating with a certain confidence level that the prevalence of disease in the population is below a given threshold (e.g. 5%). If two or more alternative surveillance systems meet this criteria, the alternative with the lowest cost is the most cost-effective, and the analysis is, in practice, a least-cost analysis.

In the second group, the surveillance system is expected to fulfil an objective that results in a numeric outcome. For example, the objective may be to detect disease early, and the associated effectiveness measure may be defined as "the number of days from introduction to detection". In such a case, both the numerator and denominator vary, and estimates of the cost-effectiveness ratio (CER) will determine which option is more cost-effective.

If all the data necessary to conduct CEA are available (if effectiveness measures are defined, epidemiological methods are available to quantify the measure, and cost streams are identified), data collection can be organised and the CER can be calculated. The average CER is calculated for independent programs that are evaluated against a baseline, while the incremental CER is generally used to compare a new program to the best alternative available (Cohen and Reynolds, 2008). In other words, it compares mutually exclusive programs.

It should be noted, however, that in CEA of animal health surveillance, only technical outcomes are estimated without quantifying the economic benefit of the program. The effectiveness measure should be chosen to reflect the benefit resulting from the mitigation program, but only its explicit quantification in relation to the cost would give a comprehensive picture of its economic value.

Other practical considerations

The basic principles outlined above are valid for both known and emerging diseases. However, assessing the consequences of an unknown hazard poses a considerable challenge. Given the large impacts of emerging disease outbreaks in the past decade, many policy makers are faced with the question of how to handle the unknown. They have to respond to high expectations of consumers in modern, affluent societies that desire to be almost free from the risk of animal disease. While it is virtually impossible to be prepared for any type of hazard emerging at any time, risk analysis can help to prioritise efforts by making predictions about the nature of hazards, geographic location and populations where new diseases are likely to appear.

Based on such analysis, the consequences of likely hazards and the necessary surveillance and response measures can be assessed, for example, by decision-tree analysis. The availability of structured frameworks to support decision making will be important to direct resources towards hazards identified based on latest scientific evidence, thereby avoiding a “fishing in the dark” situation.

From science to policy making

Without data from surveillance programs, policy makers will not know if a threat is emerging, if a certain disease is present, or if an intervention is effective. In the absence of surveillance, the progress of a mitigation program can be reversed, infectious diseases might resurge, disease transmission and spread can increase, and outbreaks can become more intense (M’ikanatha, et al., 2007). With increasing pressure on government budgets arises an increasing need for frameworks that helps balance the costs and complexity of surveillance against the need for information and potential benefit. The framework presented here applies established economic criteria to demonstrate that mitigation (defined as loss reduction achieved by surveillance and intervention) must be explicitly conceptualised as a three variable process, and that relative contributions of surveillance and intervention resources to disease mitigation must be investigated to examine substitution possibilities between them. It shows that formulating animal health policy for economic efficiency needs to be supported by evidence from mathematical modelling and empirical analysis (which quantifies the relationships between loss reduction, surveillance and intervention) for different diseases. Importantly, incorporating economic analysis in the decision making process requires close collaboration between economists, epidemiologists, animal health scientists and policy makers at all stages.

While epidemiological criteria play a central role in veterinary decision making, economic analysis is rarely a key point of mitigation policy designs, and tends to be used either informally, implicitly or retrospectively to justify decisions that have already been made. The application of economic methodologies in animal health appeared to be limited (Ramsay, et al., 1999), but signs of progress have been reported (Howe and Christiansen, 2004). There is an increasing interest in animal health surveillance and an increasing demand for economic evaluations of surveillance. This has led to new initiatives that aim to develop tools to inform resource allocation to animal disease mitigation, such as RiskSur,[7] a framework seven-funded project that integrates epidemiological and economic criteria in a tool to support the design of cost-effective surveillance systems. A similar initiative, known as discontools,[8] applies standardised criteria (including impacts on animal health, human health, society and trade) to a wide range of diseases, in order to focus and prioritise research for disease mitigation. Furthermore, there are on-going initiatives to standardise metrics for disease impact assessment (a working group at the 2013 annual meeting of the Society of Veterinary Epidemiology and Preventive Medicine discussed ways to define such metrics), or to develop systematic approaches for complex patterns, such as the One Health and Ecohealth programs. A working group resulting from the Stone Mountain Meeting on One Health[9] is compiling business case studies to demonstrate the added value of One Health, while the recent call for Grand Challenges in Global Health explicitly mentioned One Health metrics.

These advances in methods and metrics will help develop improved approaches and produce more accurate estimates that, in turn, will produce better information for policy makers. This will enable scientists and policy makers alike to weigh and compare the relative costs and benefits of each strategy. Based on this information, they can then devise measures that allow for the allocation of limited funds to mitigation activities in ways that guarantee the best outcome for society as a whole, a key aspect to rational decision making (Rushton, 2009).

Because of the interconnectedness of economic and epidemiological analysis, and the need for interdisciplinary systems research in this area, the process should be supported from the start by dialogue between economists, epidemiologists, animal health scientists and policy makers. This is of particular importance for *ex ante* assessments, which inevitably rely on predictions subject to uncertainty. Although the call for interdisciplinary integration is hardly new, it is difficult to implement due to training, thinking and working in uni-disciplinary environments that are often isolated physically or administratively. Interdisciplinary work requires not only an understanding of the basic concepts and terminology of other disciplines, but a willingness to share exchange and collaborate, as well. Interdisciplinary research faces barriers due to disciplinary identity, performance evaluation, inadequate reward structures, lack of support structures and power struggles (Heberlein, 1988).

Policy makers have the institutional capacity to bridge such conflicts of interest by funding interdisciplinary research and proactively seeking dialogue with scientists. Scientists, in turn, should make an effort to understand and address the needs of policy makers. It is important to note that a team effort is required for a comprehensive analysis that produces practical outcomes. This is only possible if we understand the expectations, discuss outcomes, and effectively communicate what outcomes can be delivered. We need to talk, and conferences like “Livestock Disease Policies: Building Bridges between Animal Sciences and Economics” at the OECD provide important platforms for improved dialogue between policy makers and scientists.

---

7. Providing a new generation of methodologies and tools for cost-effective risk-based animal health surveillance systems for the benefit of livestock producers, decision makers and consumers, http://www.fp7-risksur.eu/.

8. http://www.discontools.eu/.

9. The Stone Mountain Meeting is an initiative implemented by the US Centers for Disease Control and Prevention upon request from the World Organisation for Animal Health, the World Health Organization, and the Food and Agriculture Organisation of the United Nations. The initiative aims to operationalize One Health by creating the necessary evidence that will facilitate implementation of the concept.

References

Babo Martins, S. and J. Rushton (submitted), "Cost-effectiveness analysis – adding value to animal health, welfare and production assessment", *Revue scientifique et technique,* World Animal Health Organisation.

Beattie, B.R., C.R. Taylor and M. Watts (2009), *The economics of production,* Krieger Publishing Company, Malabar.

Bennett, R. (1998), "Measuring public support for animal welfare legislation: A case study of cage egg production", *Animal Welfare*, Vol. 7, pp. 1-10.

Bennett, R. and J. IJpelaar (2005), "Updated Estimates of the Costs Associated with Thirty Four Endemic Livestock Diseases in Great Britain: A Note", *Journal of Agricultural Economics*, Vol. 56, pp. 135-144.

Burke, P. (2013), "Eradication program for Bovine Tuberculosis — United Kingdom", *Programs for the eradication, control and monitoring of certain animal diseases and zoonoses*, SANCO document number SANCO/10341/2013, http://ec.europa.eu/food/animal/diseases/eradication/program2013/tb_uk_en.pdf.

Capua, I. and S. Marangon (2000), "The avian influenza epidemic in Italy, 1999-2000: a review", *Avian Pathology*, Vol. 29, pp. 289-94.

Cohen, D.J. and M.R. Reynolds (2008), "Interpreting the results of cost-effectiveness studies", *Journal of the American College of Cardiology*, Vol. 52, pp. 2119-26.

Le Conte, Y., M. Ellis and W. Ritter (2010), "Varroa mites and honey bee health: can Varroa explain part of the colony losses?", *Apidologie,* Vol. 41, pp. 353-363.

Daszak, P., A.A. Cunningham and A.D. Hyatt (2000), "Emerging infectious diseases of wildlife--threats to biodiversity and human health", *Science*, Vol. 287, pp. 443-449.

Dobson, A.P. and E.R. Carper (1996), "Infectious Diseases and Human Population History effect of the growth of civilization", *BioScience*, Vol. 46, pp. 115-126.

Doll, J.P. and F. Orazem (1992), *Production Economics: Theory With Applications*, John Wiley and Sons, New York.

Drummond, M., et al. (2005), *Methods for the Economic Evaluation of Health Care programs,* Third Edition, Oxford University Press, Oxford.

Greger, M. (2007), "The human/animal interface: emergence and resurgence of zoonotic infectious diseases", *Critical Reviews in Microbiology*, Vol. 33, pp. 243-299.

Häsler, B., et al. (2012a), "A qualitative approach to measure the effectiveness of active avian influenza virus surveillance with respect to its cost: a case study from Switzerland", *Preventive Veterinary Medicine*, Vol. 105, pp. 209-222.

Häsler, B., et al. (2012b), "Economic evaluation of the surveillance and intervention program for bluetongue virus serotype 8 in Switzerland", *Preventive Veterinary Medicine*, Vol. 103, pp. 93-111.

Häsler, B., et al. (2012c), "An economic model to evaluate the mitigation program for bovine viral diarrhoea in Switzerland", *Preventive Veterinary Medicine*, Vol. 106, pp. 162-173.

Häsler, B., K.S. Howe and K.D.C. Stärk (2011), "Conceptualising the technical relationship of animal disease surveillance to intervention and mitigation as a basis for economic analysis", *BMC Health Services Research,* Vol. 11, pp. 225.

Heady, E.O. (1952), *Economics of agricultural production and resource use,* Prentice-Hall, Inc., New York.

Heberlein, T.A. (1988), "Improving interdiscplinary research: Integrating the social and natural sciences", *Society and Natural Resources*, Vol. 1, pp. 5-16.

Howe, K.S. and K.H. Christiansen (2004), "The state of animal health economics: a review", *Proceedings of the Annual Meeting of the Society for Veterinary Epidemiology and Preventive Medicine*, Martigny, pp. 153-165.

Howe, K.S., B. Häsler and K.D.C. Stärk (2013), "Economic principles for resource allocation decisions at national level to mitigate the effects of disease in farm animal populations", *Epidemiology and Infection*, Vol. 141, pp. 91-101.

Jones, K.E., et al. (2008), "Global trends in emerging infectious diseases", *Nature*, Vol. 451, pp. 990-993.

Karch, H., et al. (2012), "The enemy within us: lessons from the 2011 European Escherichia coli O104:H4 outbreak", *EMBO Molecular Medicine*, Vol. 4, pp. 841-848.

Kompas, T., T.N. Che and P.V. Ha (2006), "An optimal surveillance measure against foot-and-mouth disease in the United States", *International and Development Economics*, Crawford, http://hdl.handle.net/10440/1188.

M'ikanatha, N.M., et al. (2007), "Infectious disease surveillance: a cornerstone for prevention and control", in: *Infectious disease surveillance*, Blackwell Publishing, Oxford, pp. 3-17.

McInerney, J. (1996), "Old economics for new problems – Livestock disease: Presidential address", *Journal of Agricultural Economics*, Vol. 47, No. 3, pp. 295-314.

McInerney, J. (1991), "Cost-benefit analysis of livestock disease: a simplified look at its economic foundations", *Proceedings of the 6th International Symposium on Veterinary Epidemiology and Economics*, Ottawa, pp. 149-153.

Mclnerney, J.P., K.S. Howe and J.A. Schepers (1992), "A framework for the economic analysis of disease in farm livestock", *Preventive Veterinary Medicine*, Vol. 13, pp. 137-154.

McMichael, A.J. (2004), "Environmental and social influences on emerging infectious diseases: past, present and future", *Philosophical transactions of the Royal Society of London Series B, Biological sciences*, Vol. 359, pp. 1049-58.

Miller, G.Y. and L.J. Unnevehr 2001), "Characteristics of Consumers Demanding and Their Willingness to Pay for Certified Safer Pork", *Journal of Agribusiness*, Vol. 2, pp. 101-119.

Moran, D. and A. Fofana (2007), "An economic evaluation of the control of three notifiable fish diseases in the United Kingdom", *Preventive Veterinary Medicine*, Vol. 80, pp. 193-208.

Morse, S.S. (1995), "Factors in the emergence of infectious diseases", *Emerging Infectious Diseases*, Vol. 1, pp. 7-15.

Murray, C.J., *et al.* (2000), "Development of WHO guidelines on generalized cost-effectiveness analysis", *Health Economics*, Vol. 9, pp. 235-251.

Otte, M.J. and P. Chilonda (2000), *Animal Health Economics: an Introduction*, Livestock Information, Sector Analysis and Policy Branch, Animal Production and Health Division, FAO, Rome, Italy, ftp://ftp.fao.org/docrep/fao/010/ag275e/ag275e.pdf.

Palumbi, S.R. (2001), "Humans as the world's greatest evolutionary force", *Science*, Vol. 293, pp. 1786–1790.

Perry, B., J. McDermott and T. Randolph (2001), "Can epidemiology and economics make a meaningful contribution to national animal-disease control?", *Preventive Veterinary Medicine*, Vol. 48, pp. 231-260.

Potts, S.G., et al. (2010), "Global pollinator declines: trends, impacts and drivers", *Trends in Ecology & Evolution*, Vol. 25, pp. 345-53.

Ramsay, G.C., P. Philip and P. Riethmuller (1999), "The economic implications of animal diseases and disease control at the national level", *Revue scientifique et technique*, World Animal Health Organisation, Vol. 18, pp. 343-56.

Roman Carrasco, L., et al. (2010), "Economics of Robust Surveillance on Exotic Animal Diseases: the Case of Bluetongue", *Proceedings of the 2010 AAEA, CAES, & WAEA Joint Annual Meeting*, Agricultural & Applied Economics Association, Denver, Colorado.

Rushton, J. (2013), "An overview of analysis of costs and benefits of government control policy options", *Proceedings of the OECD Conference Livestock disease policies: Building bridges between animal sciences and economics*, OECD, Paris.

Rushton, J. (2009), *The economics of animal health and production*, CAB International, Wallingford.

Tisdell, C. (1995), "Assessing the approach to cost-benefit analysis of controlling livestock diseases of McInerney and others", *Research Papers and Reports in Animal Health Economics*, University of Economics, Brisbane.