LIVESTOCK DISEASE POLICIES:

BUILDING BRIDGES BETWEEN SCIENCE AND ECONOMICS
Preface

Contagious livestock diseases can cause significant harm to human and animal health, with major economic and social consequences for citizens, including farmers, industry, consumers and taxpayers. Efficiently managing these risks is a complex policy challenge that all governments face.

An efficient system to manage these risks requires collective action and an explicit understanding of the roles and actions needed from everyone. Good, timely, scientific advice and proper economic incentives are critical. Animal scientists and economists both need to contribute to the design of the system; other natural and social sciences, and effective communications, are also part of the equation.

It is for this reason that the OECD Trade and Agriculture Directorate, in collaboration with its Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems (CRP), organised the workshop “Livestock Disease Policies: Building Bridges between Animal Science and Economics”, on 3-4 June 2013. The World Organisation for Animal Health (OIE) contributed its expertise throughout the workshop and facilitated contact with national veterinary offices which, along with the FAO and the World Bank, also played active roles.

The workshop succeeded in creating a ground-breaking dialogue among veterinarians, epidemiologists, economists and social scientists. It concluded that policies can create either good or bad incentives, sometimes contributing to the overall costs of diseases, highlighting the need for comparative policy analysis to learn from experience. Participants also agreed that the complexities inherent in managing the risks of livestock diseases call for multidisciplinary collaboration.

This workshop was the beginning of what is expected to become an on-going dialogue across relevant disciplines. The OECD and OIE are committed to continuing to collaborate in the design of effective policies to manage livestock diseases, combining scientific excellence and sound economics.

Ken Ash
Director of Trade and Agriculture
Organisation for Economic Cooperation and Development (OECD)

Bernard Vallat
Director General
World Organisation for Animal Health (OIE)
Acknowledgements

Jesús Antón was the principal organiser of the workshop and these proceedings. He was assisted in the design of the workshop programme by the following experts: Alain Dehove (OIE), Jean-Paul Pradère (OIE), Jonathan Rushton (Royal Veterinary College, UK), Tim Carpenter (Massey University, NZ), Katsuaki Sugiura (University of Tokyo, Japan), and Philip Paarlberg (Purdue University, US). Michèle Patterson co-ordinated the publication of the proceedings, and Amar Toor edited all papers in addition to drafting several papers based on an audio recording of the workshop. Marina Giacalone-Belkadi was in charge of the logistics involved in the organisation of this workshop, and co-ordinated the work with the authors and the editor prior to the publication process.

The OECD expresses its appreciation to all participants and in particular to the authors of the papers included in these proceedings.

This workshop was organised under the auspices of the OECD Committee for Agriculture as part of the work on Agricultural Risk Management (http://www.oecd.org/tad/agricultural-policies/risk-management-agriculture.htm). It was co-sponsored by the Co-operative Research Programme of the OECD.
Table of Contents

Preface .................................................................................................................................................. 3
Livestock disease risk management: Highlights from a multidisciplinary policy dialogue ............. 7

1. Livestock disease management as a complex multidisciplinary problem
How epidemiology and animal health science can help identify and inform policy options
by Kurt Zuelke ........................................................................................................................................ 13
Economic analysis of animal health issues: A guide to critical thinking
by Lovell Jarvis and Pablo Valdes-Donoso .......................................................................................... 19
Challenges faced when integrating advice from epidemiologists and economists to inform policy makers
by Nigel Gibbens ....................................................................................................................................... 33

2. The strengths and limitations of cost-benefit analysis
An overview analysis of costs and benefits of government control policy options
by Jonathan Rushton ............................................................................................................................. 39
The economics of FMD outbreaks in the United States: Trade impacts, duration of outbreaks, and emergency vaccination
by Phil Paarlberg ...................................................................................................................................... 53
The epidemiology of FMD outbreaks in the United States
by Tim Carpenter ..................................................................................................................................... 65
Economic evaluation of FMD control strategies in the Netherlands
by Ron Bergevoet and Marcel van Asseldonk .................................................................................... 79
Surveillance and intervention expenditure: Substitution or complementarity between different types of policy
by Barbara Hälsler, Jonathan Rushton, Katherina D.C. Stärk and Keith S. Howe ............................. 89

3. The challenge of zoonosis
The occurrence, interventions and socio-economic consequences of BSE in Japan
by Katsuaki Sugiura and Ray Bradley .................................................................................................. 109
Managing livestock diseases as part of global health
by François Le Gall ................................................................................................................................. 119

4. Moral hazard and externalities
Livestock disease indemnity design: Considering asymmetric information
by Christopher Wolf ................................................................................................................................. 127
Biosecurity externalities and indemnities for infectious animal diseases
by David A. Hennessy ............................................................................................................................ 139
# 5. Experiences on cost-sharing and public-private partnerships

Cost sharing in compensation schemes for livestock epidemics  
*by Frank Allewelt* ................................................................. 151

European Union subsidies: A catalyst for epidemic disease market loss insurance?  
*by Miranda Meuwissen and Marcel A.P.M. van Asseldonk* ........................................ 157

Linking policy and market incentives for the control of animal disease outbreaks  
*by Alejandro Acosta* ......................................................................................... 165

# 6. Policy and communication

Social issues, risk perceptions and animal health policies  
*by Julie Barnett* ........................................................................................................ 169

Roundtable: Some insights from experiences on policy making ................................................................. 181

Annex A. List of contributors................................................................................................................... 189
LIVESTOCK DISEASE RISK MANAGEMENT: HIGHLIGHTS FROM A MULTIDISCIPLINARY POLICY DIALOGUE

Jesús Antón (OECD), Tim Carpenter (Massey University), Phil Paarlberg (Purdue University), Jonathan Rushton (Royal Veterinary College), Katsuaki Sugiura (University Of Tokyo) and Alain Dehove (OIE)

Contagious livestock diseases can cause major harm to human (zoonotic) and animal health, to economic enterprises (by their impact on income, markets and trade), and to third parties, consumers and taxpayers. The impact of diseases, and of prevention and control measures, go beyond national borders. For this reason, governments are increasingly acting to prevent and control livestock diseases, and international organisations like the OIE, WHO, FAO and WTO have developed standards, codes, guidelines, recommendations and programmes designed to enhance international co-operation and efficient disease management. Analysing the risk of these impacts requires a sophisticated combination of knowledge and techniques from animal health sciences and economics. Policy decisions need to bridge the gaps between these different disciplines, as well as manage and convey corresponding uncertainties. The OECD conference on livestock disease risk management created a dialogue to improve the knowledge and understanding about how economists working with animal health scientists can contribute to a comprehensive and efficient management of livestock disease risks. This conference also served to identify gaps in information, analysis and communication. This summary highlights some of the main ideas discussed according to the rapporteurs of the different sessions, but is by no means an exhaustive account of the conference.

Livestock disease risk management is a complex problem that requires a multidisciplinary collaborative approach

The conference brought out the complexity of livestock disease management, which is often described as a “wicked” social problem (Rittel and Webber, 1970). Policy responses can rarely be classified as either correct or false, and it makes little sense to talk about “optimal solutions.” There are significant uncertainties, and many parties and disciplines are well-equipped, interested and entitled to judge and analyse the solutions. Their judgments will likely differ according to their group or personal interests, value sets and methodological approaches. For this reason, the discussions pointed to the need for a collaborative strategy rather than authoritative or competitive approaches (Roberts, 2000), and which necessarily implies that all related disciplines must be engaged to find good possible solutions for society as a whole. “Multi”, or “inter”, disciplinary collaboration can help to avoid neglecting uncertainties and unknowns, and contribute to building bridges between animal and social sciences, and launching a broader discussion among all stakeholders.

The approaches of economists and veterinarians are complementary, but practitioners of each discipline have difficulty communicating with each other. Lovell Jarvis, argued that veterinarians generally tend to seek practical guidance for specific applications, while economists tend to look for broad insights. He recognised the inability of economics to determine a single optimal policy, but also its strength in providing intellectual guidance to understanding the trade-offs involved in complex decision areas.
Several examples were given to illustrate how animal scientists and laboratories can contribute in practice to identify and inform policy options. Kurt Zuelke, for instance, discussed the global response to novel influenza subtype H7N9 in China in 2013, where several laboratories contributed to health and economic policy by developing surveillance and diagnostic technologies. In this regard, a challenging question was left open: Who should develop, deliver and define priorities for health science in a globalised world?

Chief Veterinary Officers (CVOs) and other policy practitioners also discussed the challenges to integrating advice from epidemiologists and economists in order to inform policy makers. Although there is an upward trend to using more integrated advice to support decision making in animal health, Nigel Gibbens argued we are only in the middle of the transition towards a multidisciplinary integration. Gibbens cited examples from the United Kingdom, including the eradication of Koi herpes virus, foot-and-mouth disease vaccination and policy changes to control rabies risk, to illustrate how cost-benefit analysis can be used to gain or retain disease-free status. But he argued that cost-benefit analysis is only one of several key tools to decision making, rather than a solution in and of itself. The main challenge for policy making involves the low-likelihood of high-impact exotic disease outbreaks; that is, dealing with diseases subjected to large uncertainties with very little data. A balanced decision must recognise the impossibility of designing optimal policies under these conditions, especially when confidence levels are low. Policy makers must address the knowledge gaps and controversies over valuing non-monetary impacts, and need to co-ordinate many disciplines in order to provide coherent advice.

Other issues raised in the first session highlighted the complex nature of animal health policy decisions. The OIE-status – and its implications for trade and biosecurity — is a main driver of policy decisions. New approaches and methods will have to assess the impact of diseases and policy decisions not only on trade, but also on poverty, food safety, biodiversity and food security. It is difficult to find a balance between simple models — which may be more easily understood by policy makers — and sophisticated models that may be more scientifically sound. A good policy strategy combines different sets of policy instruments that must be acceptable for different layers of social and economic partners: individual livestock growers, the industry, social groups and different levels of government.

The strengths and limitations of cost-benefit analysis

According to Jonathan Rushton, there are several cost-benefit analyses of government control options in the literature, but comparing data, methods and results for different diseases in different countries remains a big challenge. Given that much of a disease’s impact relates to the societal reaction to either disease presence or risk of emergence, economists must look more carefully at how impact assessments are carried out. Economic assessment builds on information within the context of the livestock sector, disease circulation and the general socio-economic environment. When decisions pursue more than one objective, more thought must be given to the use of methods such as cost-effectiveness analysis. This would allow for much more refined estimates of costs of disease programmes, and to better predict the benefits that would support a more valuable policy dialogue.

Economists use different methods and approaches when looking at the impact of diseases: cost-benefit, input-output, partial budgeting, partial equilibrium and computable general equilibrium. Phil Paarlberg explained how these methods can be modified to help fit a disease situation, and what value this would add to the process of decision making. Partial equilibrium modelling is the most commonly used method. The most challenging aspect of economic impact studies is developing an interdisciplinary dialogue for integrated economic and epidemiologic analysis, rather than simply linking disparate models. Other challenges include incorporating OIE rules (and their level of implementation) to measure trade impacts,
and measuring consumers and supply chain responses — accounting for the response to policy incentives, in particular.

Tim Carpenter presented an example of an economic-epidemiologic modelling process to examine the possible impact of a hypothetical FMD epidemic in the United States. The work clearly demonstrated the importance of time to detection in limiting the impact of the disease. While sometimes complex, the models present different scenarios and sensitivity analysis to deal with uncertainties. In this way, models can help with the communication challenge among disciplines and policy makers.

Ron Bergevoet discussed an ex post analysis of the 2001 FMD epidemic in Europe. The Netherlands controlled the disease with a mix of ring vaccination and the removal of animals at greatest risk. Vaccinations were used to slow the spread of disease and to provide culling teams with enough time to protect these animals. The vaccine-and-cull strategy was largely driven by a desire to return to exporting livestock products as quickly as possible, yet was socially unpopular in the Netherlands. The government therefore requested an examination of different alternatives. The analysis showed that vaccination-to-live can be an attractive option, but shifts the cost burden of disease management from the government to the producer. This distributional effect deserves attention in the analysis because it can be a barrier to adopting certain policy measures.

The example of New Zealand was raised to describe the need for investment in animal health care that recognises the difficulties of providing veterinary coverage in rural areas. The OIE explained the importance of its Performance of Veterinary Services (PVS) process to identify gaps and weaknesses, and to address them through appropriate animal health investment policies to strengthen good governance of veterinary services and animal health systems.

The challenge of analysing potential impacts on human health and the trade-offs across different policies and diseases

The difficulties of applying standard cost-benefit analysis to zoonosis were illustrated by an example of BSE. Katsuaki Sugiura argued that the impact of BSE in Japan was largely due to societal perceptions and reactions to the presence of the disease, rather than by the losses it actually caused. It had minimal impact on farm-level production and, to date, limited impact on human health. However, the announcement of a human health link created a significant market shock and breakdown of trust in the government’s disease management system. Professor Sugiura emphasised the need to build in processes that allow for the reaction to such problems to be better managed.

Policy choices are also subject to economic trade-offs between broad animal health areas such as prevention and control. Barbara Haesler explained that investment in surveillance can be complementary to mitigation activities, such as prevention and control measures, and that they may also be substitutes, indicating that they compete for resources available for animal health. This would make it possible to map out the benefits of different combinations of surveillance and mitigation to obtain optimal (or at least better) allocation of resources between the two general activities.

Policy linkages also affect the allocation of resources across different diseases, and even between human and animal health. Francois Le Gall described the on-going changes in the global livestock sector that increasingly require greater global level investments, and a One Health focus for future investments on surveillance and control. This approach involves strengthening animal health systems alongside other systems for human and environmental health, which has proved to be crucial during recent episodes of avian influenza.
Some experts expressed the need to view economics as an art — rather than a science — in guiding resource allocation within such a complex setting. It would be only one factor contributing to the good governance of animal health systems and the animal sector in general. Some argued that animal health agencies need independence to promote public animal health institutions that are free from political interference and private lobbying, yet integrated within the sector, as well.

Policies can create good and bad incentives that contribute to overall costs

Knowledge gaps and uncertainties are not the only factors that make animal health policy a complex problem. Differentiated or asymmetric access to relevant information by farmers, government, consumers, insurers and other agents can also pose challenges. Christopher Wolf covered the issues of moral hazard and adverse selection in the context of livestock disease. Moral hazard occurs when a prevention, control or compensation programme encourages risky behaviour. Adverse selection occurs when there is an asymmetry of information that allows more risky farms or animals to benefit more from the schemes. Policies and subsequent design of policy tools (regulation and legislation, programmes, etc.) for issues such as biosecurity against livestock diseases and compensation must incorporate an understanding of moral hazard and adverse selection problems and limit their consequences. There can be tension between prevention and control measures; for example, increased compensation after a disease outbreak may increase disease reporting, while lowering biosecurity investment.

Individual disease control and prevention measures can also have externalities on other farms. David Hennessy described different aspects of these externalities, or interdependencies, among producers that are not reflected in market prices. For instance, the disease control efforts of one farm reduce the probability of infection of neighbouring farms. This can lead to a suboptimal “common pool” solution in which overall disease prevention and control efforts are reduced because everyone is “leaning” on their neighbours’ efforts. Similarly, if one farmer’s efforts only pay if their neighbours also make the effort, a coordination mechanism is needed to avoid the “weakest link” effect. Finally, financial heterogeneity among farms could suggest that programmes should provide greater compensation to “weaker” farms, because the exit of those farms during a disease event could weaken financially stronger farms if there are high fixed costs associated with the disease outbreaks.

Behavioural economics can be useful to understand individual behaviour in the context of asymmetric information and externalities. Policy design must focus on livestock farmers, who are typically the first to respond to diseases, and whose behaviour is crucial for prevention and control. The scope of public intervention requires careful evaluation to avoid incentives that reduce individual efforts.

Policy experiences highlight the importance of good governance and the need to compare and learn from other countries

Livestock farmers can enhance their engagement in the animal health system by participating in financing its costs. Frank Allleweldt covered cost sharing in compensation schemes across different countries. All such schemes are a blend of public and private money, yet each one works differently. Examples of policy incentives are reflected in provisions such as higher compensation rates for early reporting and penalties to increase biosecurity measures. However, individual risk assessment is rarely undertaken, and the only provisions to adjust contributions to individual risk profiles are individual bonuses (or “malus” applied to certain geographical areas). Costs sharing systems allow for financial contributions from all who contribute to the risk. They tend to face strong resistance when introduced, but have high
levels of acceptance where they already exist. However, there is little empirical evidence of how incentives work in practice.

Animal health insurance is also used to cover some disease risks. Miranda Meuwissen used the experience of the European Union to highlight its positive experience with mutual livestock insurance in the Netherlands. Compared to private insurance, mutual insurance can reduce problems of information asymmetry, lower costs, are more flexible in confronting new hazards, and broaden the scope of insurance.

Different kinds of public private partnerships can also contribute to stakeholder engagement in animal health systems. Herman Rojas explained that co-ordinated partnerships dealing with livestock disease in Chile has facilitated a quick and engaged industry response to maintain international trade flows, thereby mitigating total economic losses. Alejandro Acosta examined the incentive for private firms to contribute to the cost of disease control. The statistical analysis of a highly pathogenic avian influenza outbreak in Mexico shows that marketing margins fell during the outbreak, which suggests an incentive for marketing agents to share in the cost of controlling an outbreak.

International organisations could develop common frameworks to analyse public policy within the context of livestock diseases. A framework could begin with a simple structure of different diseases identified as zoonotic or non-zoonotic, and endemic to a nation or of foreign provenance. It would then analyse actual and potential policy instruments to control each disease outbreak, or to manage and prevent the disease. Additional levels of complexity could then be added; the types of externalities associated with each disease could be identified, linking specific concerns such as moral hazard and adverse selection to each potential policy instrument or provision. The framework would also identify who pays and the extent of cost sharing. A methodology and database to evaluate policy responses to outbreaks of different diseases in different countries could add transparency and improve the comparability of experiences and common understanding of policy intervention for livestock diseases.

Efficient communication can reduce the costs of animal diseases and create good incentives

All sessions raised the idea that scientific and economic analysis and models can help to identify and understand the issues, but cannot substitute for the need to communicate with different stakeholders. Communication has to clearly convey the complexity of the problem and the analysis that has been carried out, and should not focus solely on its complexity. Some speakers argued that messages should not hide uncomfortable truths, and avoid the temptation to respond to a political agenda or a private sector demand. Communication needs to take place on a broader scale to understand the capacity of people to manage diseases and the extra resources needed to improve responses to disease outbreaks in the future.

Julie Barnett discussed the relationship between communication, social risk perceptions and animal health policies. Referring to recent experiences in the United Kingdom concerning salmonella, BSE and GMs, she highlighted the importance of public risk perceptions, the social context and human reaction, to underscore the importance of strong communication. Public bodies are often reluctant to acknowledge uncertainty or “uncertain” knowledge. With risk communication, the role of the social scientist is to help develop methods, and to articulate reasonable explanations and values. The key elements of good risk communication are trustworthiness, and placing risk in terms of everyday practices and experiences to make it more understandable. When communicating risk, however, public bodies should avoid overconfidence in the effectiveness of information provision by acknowledging the uncertainties about outcomes. The Social Amplification of Risk Framework (SARF) was presented as a method to explain different views on risks from both experts and non-experts. A good policy design should develop intervention networks for influencing behaviour; it should be well targeted for different audiences — with different intervention points over time.
to avoid social amplification of risk — and engage individuals and social groups by recognising social practices and leading by example.

Yukiko Yamada described her experience with BSE in Japan in 2001 and argued that the lack of trust in public authorities arose from early miscommunication with statements such as “BSE will not occur in Japan”. Delayed decision-making and poor communication led to a loss of consumer confidence. A positive outcome, however, was the creation of a new Food Safety and Consumer Affairs Agency, which elevated the level of risk analysis (and especially risk communication), as shown by subsequent experiences in Japan with FMD and AI.

Policy makers need to pose the right questions to experts. They must increase their cooperation with different groups such as veterinary services, veterinary faculties, scientists, economists and other experts, listening to them and bringing them aboard early. Hans Wyss argued that communication is a key skill for decision makers, and that it will become more important in the future. Improving communication with stakeholders requires simplifying the message and developing an established communication strategy in times of peace (i.e. when we are not in the middle of a disease outbreak). Good communication requires decision makers to have credibility which is gained by consistently doing what they say.

Alberto Laddomada argued that policy makers need to have a full understanding about the costs of disease, prevention and control measures. This includes the costs associated with overreaction and the non-implementation of international standards. He emphasised that decision makers need to stick to the rules, and that the cost of non-implementation should always be considered in the analysis. In the case of the European Union, the establishment of a single market among the 28 EU countries is crucial for animal health policy, and points to the importance of alignment with international standards. A strong communication strategy can decrease disease losses by controlling emotions and preventing overreaction, while improving awareness and preparedness.

According to Gemma Harper, the analysis must also consider social and environmental impacts, in addition to the economics of disease. More work among multidisciplinary groups is needed, and collaboration should be facilitated by public agencies. Communication needs to overcome the use of technical language in order to keep the message simple. More work is needed in policy impact evaluation and comparison across country experiences in order to know what works, and interdisciplinary work is needed to demonstrate what will work in the future. Communication and trust could be facilitated at all stages with trustable and comparable data and policy analysis. Yet communication must also account for the heterogeneity of people involved in the animal sector and animal health systems.

References


Because the origins and impacts of animal diseases often reach beyond national borders, governments and international organisations are developing disease prevention and control programs. Scientific knowledge, understanding and technical expertise are critical to any animal disease prevention and control program. The scientific knowledge that underpins our understanding of disease pathogenesis and the transmission and design of diagnosis, surveillance and control programs is ever-evolving — as evidenced by the application of genome sequencing technologies and the development of more comprehensive molecular diagnostic tests. The increasing volume and scope of epidemiological information provide policy makers with more comprehensive data upon which to base their decisions. However, this increased speed and volume also exert greater pressures (and opportunities) for faster policy-making decisions to be made. In this paper, we provide an updated overview of the science and technologies that currently underpin disease surveillance, response and health policy. We also provide a scientist’s perspective of some of the economic and policy considerations required to inform and apply this science.
The origins and impacts of animal diseases often reach beyond national borders. As a result, state and national governments, along with international organisations like the World Organisation for Animal Health (OIE), the UN Food and Agriculture Organisation (FAO) and World Health Organisation (WHO), are developing disease prevention and control programs to mitigate and manage the potential economic and health-related impacts of livestock diseases. Scientific knowledge and understanding of the diseases themselves are critical to any animal disease prevention and control program. Equally important is the technical expertise and ability to deploy the most appropriate diagnostic tests, and to enact the required control and treatment strategies.

The Australian Animal Health Laboratory (AAHL) is a global leader in research on major diseases affecting livestock. The laboratory is a frontline defence, helping to protect Australia from the threat of exotic and emerging animal and human diseases. In 2004, the OIE designated the AAHL as an international collaborating centre for new and emerging diseases. In addition, the AAHL has been designated as an international reference laboratory by both the OIE and FAO. The AAHL provides services to Australia and the Asia Pacific region to assist with rapid diagnosis of animal and aquatic disease, national and international surveillance, and emergency response support.

The scientific knowledge that underpins our understanding of disease pathogenesis and the transmission and design of diagnosis, surveillance and control programs is ever-evolving. Nowhere is this new science more evident than in the application of genome sequencing technologies and the development of molecular diagnostic tests that offer more complete information (e.g., complete genomic sequence of a new virus). With these tests, information is delivered within just hours, rather than days or weeks.

The increasing volume and scope of epidemiological information provide policy makers with more comprehensive data upon which to base their decisions. However, this increased speed and volume also exert greater pressures (and opportunities) for faster policy-making decisions to be made. This review will provide an updated overview of the science and technologies that currently underpin disease surveillance, response and health policy. It will also provide a scientist’s perspective of some of the economic and policy considerations required to inform and apply this science.

2009 H1N1 influenza case study

The case study presented below is related to the 2009 global H1N1 Influenza pandemic. It nicely illustrates the links between science, economics and health policy in action.

In April 2009, a novel pandemic H1N1 influenza A virus (H1N1pdm09) emerged among humans in North America. This antigenically distinct H1N1 virus spread quickly; on 11 June 2009, the WHO declared that the outbreak had reached pandemic phase six. Although the sequences of the virus’s eight gene segments were similar to corresponding genes of swine influenza A viruses from North America and Eurasia, no closely related ancestral influenza A viruses with this gene combination had ever been identified. For the human population, the genome of the H1N1pdm09 virus contained novel forms of the matrix (M) and neuraminidase (N1) genes that rendered it antigenically distinct from strains that had previously circulated (Garten, 2009). Therefore, global human and swine populations were immunologically susceptible to the virus, and diagnostic tests available at the time could not differentiate it from other influenza strains.

Within the first few weeks of the 2009 pandemic, a team of scientists from the US Department of Agriculture’s National Animal Disease Center (NADC) developed a differential diagnostic test for the virus in swine. Led by Drs. Amy Vincent, Kelly Lager and Kay Faaberg, the team conducted a series of high containment pathogenesis, transmission and
vaccine experiments with the H1N1 virus in swine (Vincent, 2009; Vincent, 2010). In response to this outbreak, a number of key countries immediately closed their borders to US pork exports, citing concerns that the H1N1 virus could affect the safety of pork products. The pathogenesis studies performed at NADC were the first to demonstrate that the tissue distribution of the 2009 pandemic virus was limited to tissues of the respiratory tract, and that the virus was quickly cleared from infected pigs. These results confirmed that the H1N1 virus did not pose a food safety risk (Vincent, 2010) and that US pork products were safe.

This rapid research response provided data that was invaluable to US and international pork producers, allowing for science-based decisions on the safety of US pork and pork products during the early stages of the pandemic. The US government and the US pork industry cited this research while engaging trading partners in a science-based conversation to maintain and re-open market access to over 27 countries that had banned or threatened to ban US pork and pork products. This alone cost the industry over USD 5 million per day.

Science employed to detect, respond and survey for infectious diseases

The fundamental science and technology that underpin any animal disease prevention and control program typically target three broad objectives.

- Identifying the causative agent (pathogen) and determining how it causes disease.
- Developing and deploying valid diagnostic tests to detect disease and determine its geographic locations.
- Developing and deploying treatment and control measures.

Identifying the causative agent is often based on clinical signs observed in the field combined with a battery of diagnostic tests to confirm the presence or absence of a specific pathogen in clinical samples (i.e. tissue samples, nasal swabs and blood samples). An important differentiating feature of any disease with potentially profound policy implications is whether or not the suspected pathogen has zoonotic potential. If it does, it could cause clinical disease in humans as well as animals. By their nature, diseases with zoonotic potential often require a combined and coordinated response from both veterinary and human public health communities. Validated diagnostic tests are essential to monitoring disease transmission and spread, and can ultimately provide surveillance data, as well. These data, in turn, can furnish evidence of any previous exposure, or confirm “freedom from disease” after a control program has been implemented. Treatment and control measures (e.g. therapeutics and vaccines) are employed to treat clinical disease, slow or prevent transmission, and protect potential target species from contracting disease in the future.

A typical diagnostic test is aimed either at identifying and confirming the presence of a specific pathogen in a clinical sample, or determining whether or not an individual animal was previously exposed and mounted an immune response to a pathogen (either in the presence or absence of clinical disease symptoms). The traditional “gold standard” diagnostic test is to isolate and culture the actual causative pathogen directly from a clinical sample. For example, in the case of a bacterial disease such as salmonellosis, the diagnosis could be confirmed by culturing and characterising the specific salmonella bacterium present in clinical samples. In the case of a viral disease such as influenza, the diagnostic procedure would entail isolating the virus from a clinical sample (e.g. nasal swab) and then growing and purifying it in a laboratory egg or cell culture. The identity of the purified virus would then be confirmed by observing its morphological characteristics under an electron microscope, followed by a series of specific confirmatory tests.

Virus isolation typically takes four to six days to perform, and though it has been somewhat superseded by more rapid molecular tests, it remains important. In fact, virus
isolation is still the method of choice for obtaining virus for subsequent detailed genome sequence analysis, characterising newly emerging viruses, and establishing viral lines as potential vaccine candidates. By its nature, virus isolation requires a laboratory constructed and maintained at biosafety levels appropriate for the pathogen in question. The laboratory must be equipped to perform cell culture and virus isolation, and staffed with highly skilled people trained in cell culture and microbiological diagnostic techniques.

Serological and immunological tests represent another broad diagnostic testing paradigm. These tests use cellular or molecular components of an animal’s immune response to detect recent or previous exposure to a pathogen, or to directly detect and identify a specific molecular aspect of the pathogen itself in a tissue or blood sample. When an animal is exposed to a pathogen, its immune system typically mounts an antibody response to ultimately neutralise and eliminate the pathogen from its body. Post-exposure presence of the resulting antibodies constitutes epidemiological evidence that the animal was exposed to the pathogen at some previous time, though it may not show any clinical signs of disease at the time of testing.

This immune response typically takes between seven and 14 days to develop, and can vary in its efficacy depending upon a number factors — including the specific characteristics of the pathogen, and the age and immune status of its host. Since the antibodies produced in response to an exposure are often highly specific to that particular pathogen, they can be purified from blood obtained from an exposed animal and be used as a reagent in an immunological test to detect that pathogen. The targeted specificity of a particular antibody (or molecular subcomponent of an antibody) against a specific pathogen forms the basis upon which immunological and serological diagnostic tests are designed and validated.

A drawback of immunological tests is the requirement to purify, characterize and validate specialised reagents (i.e. antibodies, antisera and control sera). However, once validated, serological tests are extremely sensitive and specific, rapid and scalable (they can be automated for high-throughput processing), and relatively cost-effective to deploy. Immunological tests are typically used to augment virus or bacterial isolation as a primary diagnostic test, and are ideally suited for performing post-exposure surveillance, epidemiologic surveys, or for confirming freedom from disease following an outbreak. Current research is aimed at developing immunological tests in a field-deployable format (e.g. dipsticks) for “pen-side testing” or “point of care” deployment.

On-going advancements in molecular biology techniques, biotechnology and lab instrumentation have revolutionized the development and application of molecular based diagnostic tests in animal and human health. The fundamental characteristic of these molecular tests is that they detect (and quantify) a very well-defined segment of DNA or RNA sequence that is uniquely diagnostic for the pathogen in question. They are therefore used to directly detect a pathogen in a clinical or field sample. These tests are often referred to as PCR tests, based on the polymerase chain reaction (PCR) chemistry they use to amplify and quantify their DNA or RNA target sequences. A PCR test is highly sensitive and can potentially detect a single organism in a sample. It is also relatively fast, yielding results within a few hours from the time of sample submission.

Given this high degree of sensitivity, PCR tests can be prone to false positives (i.e. yielding a positive result when the pathogen is not present), so their results must be confirmed and validated. Although a PCR test is typically used to detect the presence of a pathogen in acute clinical cases, it does not differentiate between RNA or DNA obtained from a living or dead pathogen, and thus may confirm the presence of the pathogen in an inactive infection. As more genomes are sequenced, the variety of potential diagnostic RNA and DNA targets is nearly endless. Given their wide range of potential utility, high degrees of sensitivity and specificity, wide availability of routine reagents, and relatively low cost, PCR tests are
quickly becoming the principal workhorse in diagnostic labs around the world. As with immunological tests, research is now underway to develop field-deployable instrumentation and reagent kits that would enable portable PCR tests to be performed remotely anywhere in the world.

Recent advances in genome sequencing technologies and instrumentation now enable full length sequencing of a human or animal genome in about a week’s time. It is now possible to sequence a complete viral or bacterial genome in a day or two, and at a low cost. In fact, full-length sequencing has become a routine procedure in many research and diagnostic laboratories. Currently, a PCR-based diagnostic test requires a detailed knowledge of a specific portion of a pathogen’s DNA or RNA sequence.

In the early days of the 2009 H1N1 influenza pandemic, the only way to reliably identify the newly emergent H1N1 virus (H1N1pdm09) was to obtain its full genome sequence and compare it against the genomes of other related influenza viruses that were also circulating at the time. Obtaining the full H1N1pdm09 genome sequence was also crucial to designing the subsequent PCR tests against this new strain. Full genome sequencing requires specialised equipment and considerable technical expertise to perform, but will become more cost-effective over the coming years. In addition to sequencing individual microbial genomes for diagnostic purposes, this technology is now also enabling epidemiological research that characterizes the ecology of entire bacterial and viral populations in their native environments. This ability to clearly define and track the ecology of bacterial and viral populations in their native environments over time should make it easier for health professionals to identify and predict the emergence of potential new pathogens earlier in the emergence process. Within the next five to ten years, it will likely be possible to use these sequencing-based techniques to predict and track emerging diseases (or the flow and evolution of potentially dangerous, disease-causing genes) around the world.

Transforming science into health and economic policy

The scientific knowledge that underpins our understanding of disease — and enables new technologies to detect and control it — is evolving and, increasingly, being used to inform policy and economic decision-making. A laboratory such as the AAHL possesses highly specialised infrastructure that enables its staff to investigate and respond to known and unknown diseases caused by some of the most dangerous pathogens known to humans (e.g. nipah virus and highly pathogenic avian influenza). As a result, AAHL provides vital national and international animal health research and diagnostic capabilities. It would cost approximately USD 1.5 billion to replace AAHL or the handful of comparable facilities like it around the world. One could ask how much national or global investment is sufficient to assure that the capabilities that laboratories like AAHL provide are available when required. Since the range of diagnostic and control technologies is vast and ever-expanding, cost-benefit analyses as well as disease and health risk assessments will become even more important to ensuring effective investment of (potentially limited) healthcare resources. Considering that over 70% of newly emerging human diseases find their origins in animals, health, economic and disease management policies will have to become more integrative — a “one health approach”. As scientific knowledge evolves and the potential economic or health impacts of disease become greater, effective channels of communication between policy makers and the public — and across different disciplines — are becoming more vital than ever before.
References


Both economists and veterinarians analyse the threat and reality of animal disease with the intent of preventing, controlling or eradicating that disease. Both are aware that such efforts have costs as well as benefits, and each seeks to balance those considerations when deciding on a course of action. Yet despite the benefits of working together, economists and veterinarians often struggle to feel comfortable in dialogue with each other. As a result, some of the mutual gains that could be achieved through collaboration are lost. This paper will discuss some of the contributions that economists can bring to this effort, and how these contributions can be used in partnership with veterinarians. We identify two reviews on cost-benefit analysis of allocating animal health resources, as well as two useful summaries of methodologies utilised by economists in animal health studies. We also discuss the factors that influence the choice of methodology, and the ways in which they can be applied. We emphasise that analysis is generally as much an art as it is a science, and discuss the implications of this important fact.
Both economists and veterinarians analyse the threat and reality of animal disease with the intent of preventing, controlling or eradicating that disease. Both are aware that such efforts have costs as well as benefits, and each seeks to balance those considerations when deciding on a course of action. This paper will discuss some of the contributions that economists can bring to this effort, and how these contributions can be used in partnership with veterinarians.

Economists and veterinarians have come to recognise the value of each other’s specific knowledge and perspective. Economists analysing disease are aware of many basic medical details from veterinary science, including epidemiological considerations, while veterinarians are aware of basic economic principles, including the use of cost-benefit analysis and the importance of behavioural responses to private incentives when crafting public policy.

Nonetheless, results are generally better when the two disciplines work in collaboration. Economics and veterinary medicine are highly specialised fields with disciplinary paradigms and specific knowledge, and practitioners have relative strengths and weaknesses in understanding their clientele (e.g. animals, their owners and the broader public) and in communicating with them. Yet despite the benefits of working together, economists and veterinarians often struggle to feel comfortable in dialogue with each other. As a result, some of the mutual gains that could be achieved through collaboration are lost.

The organisers of this conference presented us with a question: “How can the economic analysis of costs and benefits help in allocating animal health resources?” Numerous papers have been written on this topic and many are quite good. We therefore did not feel that a similar summary would add much value. Instead, we identify two reviews that stand out for their clarity of presentation, as well as two useful summaries of methodologies utilised by economists in animal health studies. These methodologies are now fairly standard. We also discuss the factors that influence the choice of methodology, and the ways in which they can be applied. We emphasise that analysis is generally as much an art as it is a science, and discuss the implications of this important fact.

We also attempt to describe and analyse the different perspectives of economic and veterinary practitioners to suggest that some of the problems of communication and understanding are inherent to disciplinary paradigms and professional practices. We hope our depiction will lead to useful dialogue. In fact, the authors of this paper have each experienced good communication between economists and veterinarians, having worked in each discipline. If the differences we present erroneously characterise the perspectives of practitioners in either or both disciplines, please forgive and correct us. This paper is intended to provoke discussion.

Economics

Economics is the science of choice. In general, it recognises that we cannot “have our cake and eat it too.” We must choose between alternatives in an attempt to maximise our welfare, or utility. Every choice has a rational and nonrational component, but economists focus primarily on the rational component. Economics is therefore the study of how best to make choices. It determines the net benefit of any action and allows for a systematic comparison of all such actions. Analysis can proceed by comparing the effects of different actions separately, and identifying the one that provides the best, or so-called “optimal,” result.

Economists generally use monetary units, or prices, to value the gains and losses associated with a given action. The use of monetary units is based on the rather heroic assumption that prices observed in markets reflect the (relative) values of the different resources exchanged there. This assumption allows economists to combine or “add up” gains
and losses regardless of the form that they assume (e.g., labour expenditures, pharmaceutical costs, or saving the life of an animal). Prices provide weights that allow the net effect to be calculated.

The assumption that prices reflect value depends on restrictive conditions regarding how a market works. In fact, not all markets “work well.” If markets do not work well, the prices realised and observed in those markets will likely not be the “correct” prices to use in economic analysis. For example, economists note that many actions create “externalities” that can be positive or negative, and that these externalities must be considered when determining which actions are most desirable.

In the case of vaccinations, economists recognise that protection of one animal provides benefits for other non-vaccinated animals if the vaccinated animal is less likely to become infected and transmit a contagious disease to others. Epidemiologists call this phenomenon mass immunity, and it assumes a reduction in the rate of contact rate between sick and healthy animals. Since vaccination can reduce the probability that other animals will also be infected, the benefit of vaccination exceeds the cost to the owner of the vaccinated animal. It is therefore economically reasonable for a government to subsidise vaccination, though the appropriate subsidy must be calculated carefully, and remains dependent primarily on the degree to which one vaccination is likely to influence the probability of infection in other animals. Thus, to repeat, economists place money values on different goods, but the values used are sometimes not directly taken from prices observed in the marketplace.

Economists generally conduct their analysis at the level of “society”, meaning they must consider how any action affects individuals throughout society. Of course, economists acknowledge that they cannot observe the welfare of different individuals and thus cannot make strictly economic welfare comparisons among people. Economists cannot prove that society is better off if person X gains USD 5 and person Y gains USD 10, or if USD 1 is taken from X and given to Y. Nonetheless, economists often implicitly assume that the marginal effect of receiving or gaining USD 1 is the same for everyone. Thus, when calculating the net benefits of any action, economists generally sum across the gains and losses of different individuals to determine if society benefits or suffers depending on whether the net gain is positive or negative.

However, economists are aware that the distribution of gains and losses is an important aspect of their analysis, and that it is of particular interest to policy makers. Some economic studies take the distribution of gains and losses as a major element of their work, either by identifying who gains and who loses, or by imposing some assumptions about the weights on gains and losses of different individuals. This point is important because economists usually treat each person in society as equally important, unless they have identified a group to be of particular importance (e.g. if a study focuses on how to improve the lives of people in poverty, subject to some cost constraints that can be imposed on others).

Economists note that most individuals do not like risk. Risk has important consequences. For example, if faced with an on-going equal likelihood of receiving an income of USD 100 or USD 200, so that the expected value is USD 150 (E[V] = 0.5 * USD 100 + 0.5 * USD 200), many consumers would prefer to pay some amount (δ) to smooth the income variation. An expected income of USD 145 every year might be preferred to an income that varied unpredictably between USD 100 and USD 200, but with equal probability. Accordingly, maximising economic benefits is not always preferred. Faced with alternative policy choices to control a disease, individuals or society might prefer the choice that leads to a somewhat lower expected benefit, but with less likelihood of a terrible outcome.

To conduct their analyses, economists often construct elaborate models intended to capture the effects of all variables involved in the consideration of a particular problem or choice. However, economists sometimes narrow the scope of their analysis to focus on a
smaller part because it is easier and may allow a satisfactory answer more quickly, or at significantly lower cost.

Economists often speak of “partial equilibrium” analysis and “general equilibrium” analysis. The former assumes that a useful answer or solution can be obtained by focusing on a subset of the total economy; other aspects of the economy may be affected, but such interactions are considered to be so small as not to be essential for inclusion. General equilibrium analysis, by contrast, includes a larger set of interactions. This is done if it is believed that interactions and their effects are both large and widespread, so that a suitable answer requires broader consideration.

With partial equilibrium, for instance, an economist might analyse the effect of an increase in the price of vaccines on the willingness of farmers to vaccinate their cattle. In that restricted study, the economist may decide not to disregard the chance that a reduction in the rate of vaccination would lead to an increased rate of infection, which would then lead to a decrease in the supply of beef and, perhaps over the longer run, a higher price of beef. Higher prices may, in turn, lead to higher demand for the vaccine.

In partial equilibrium analysis, the economist does not pay attention to how a higher rate of disease affects meat processors or consumers. The economist will surely be able to imagine that these other factors may be associated with the decision to vaccinate, but if he or she is interested simply in producers’ decision to vaccinate or not, he or she may decide to ignore other related issues on the grounds that they will not affect farmers’ initial vaccination decisions. In contrast, if an economist wants to study whether it is wise to eradicate Foot and Mouth Disease in a country with a large cattle herd, an appropriate answer likely could not be obtained without a broad model. Such a model would include farmers, food processors, consumers, and important constituencies linked to international trade and the macroeconomy.

Although economists attempt to be selectively “comprehensive” in their analyses and often develop highly-detailed studies, many economic studies are largely “theoretical” — useful not so much for identifying precise instructions for policy actions as they are for providing insights about how to think about a particular problem. Indeed, many empirical economic studies seek only to obtain a general characterisation of a solution to a problem because it is too expensive to obtain the detailed information and model needed for a specific solution. Economists also tend to believe that real world problems are likely to differ in important ways from any problem that has already been conceptualised and analysed. Accordingly, economists believe it is more important for policy makers to understand the complex elements likely to be involved in a particular type of problem and be able to devise an appropriate policy when a need arises (e.g. designing and implementing a disease control policy in a rapidly evolving context).

Paul Samuelson, one of the great economists of the 20th century, said that economics could be described as a set of parables. The dictionary defines a parable as a simple story told to represent a basic moral truth or religious principle. In a more general sense, a parable is a short story that illustrates a principle or lesson — one that uses a concrete narrative to make an abstract argument.

Characterising economic discoveries as parables says a lot about how economists think about their profession, and provides insights about their likely contributions. As noted, a parable is illustrative, but does not provide specific instructions. It provides a way of thinking about problems — an intellectual guide to understanding complex issues, or a tool for gaining insights into a complex world. It does not necessarily provide concrete instructions on what to do in a specific context.

Policy makers have to develop specific policies that can be implemented effectively. Such policies could include increasing the money supply, expanding the number of school days in a
year, or determining whether to vaccinate or cull animals during a disease outbreak. Nonetheless, many economics articles are of a more general nature, seeking to establish the insights needed to develop an adequate policy response when a specific problem arises.

A brief review of reviews of the economics of animal health

A number of excellent books and articles explain the paradigm, basic theory, and general methodologies used by economists to identify and analyse economic problems. Some of these publications have been written specifically for veterinarians and others interested in animal health, including an article by Otte and Chilonda (2000) and a book edited by Rushton (2009). The latter includes chapters by several authors that provide a useful overview and illustrative applications to specific problems.

Rich, Miller and Winter-Nelson (2005) provide a useful overview of economic methodologies, including quantitative techniques that can be used in conjunction with epidemiological information to analyse animal disease problems. The approaches discussed include cost-benefit analysis, linear and mathematical programming models, partial equilibrium models, multi-market models, input-output and social accounting models, and computable general equilibrium models.

Some of these economic approaches are intended to be parsimonious in their demand for data and calculations, while others aim to be more comprehensive by incorporating more economic actors in the analysis. Some assume that only first-order effects need to be considered, while others seek to understand additional effects via a wide array of linkages across sectors. Some models attempt simply to say whether one choice is beneficial or not; others seek the “optimum” choice. Although different techniques are available, each attempts to determine the desirability of a specific solution to an identified animal health issue. In that sense, all approaches balance benefits against costs, with the choice of approach determined primarily by the modeller’s assessment of what analysis is needed to get a useful answer, available data, knowledge of the disease and associated disease processes, and the modeller’s facility with different techniques.

Rich, Winter-Nelson and Miller (2005) extend the discussion to examine how economic models can be linked to epidemiological models to better analyse animal health issues. Finally, Rich and Perry (2011) explore the use of value chain analysis through its application to disease control. In this framework, value chain analysis is used to conceptualise the multiple interactions likely to exist. Value chain analysis, in and of itself, is not highly useful in developing specific results. However, value chain analysis leads the analyst toward a much more complete understanding of the broader context within which animal health issues evolve, and helps identify which interactions warrant more detailed examination. This type of analysis is necessary for the development of any broader general equilibrium model.

Applications of economic tools

We have chosen several specific studies to illustrate how economists have used economics to analyse specific animal health issues. Lack of time and space requires that we only briefly characterise each study.


Ekboir hypothesised that California’s dairy sector was vulnerable to extensive loss if an FMD outbreak were to occur. The sector was composed mainly of large dairies (more than 500 cows each) that were dependent on important external services, including veterinarians, milk pickup, feed delivery and manure removal crews that visited multiple dairies on a daily
or weekly basis. Considering the three-day latency period after an outbreak begins and before clinical signs appear, it seemed likely that these services would cause any outbreak to become widely diffused before the outbreak had been discovered. Moreover, the disease would continue to spread in the absence of a strict quarantine, both because many dairies are located in close proximity to one another, and because many within heavily-trafficked automobile corridors.

Working without a detailed epidemiological framework, Ekboir used a Markov Chain analysis to simulate the rate of disease diffusion under different policy actions, and to estimate and compare the expected damages associated with each. Ekboir assumed that the most policy relevant parameters available to policy makers were the delay in identifying the presence of the disease, the rate at which diseased and exposed herds were culled, and the effectiveness of quarantine.

The principal economic loss to the US economy from an FMD outbreak in the California dairy sector was shown to result from an expected immediate and nearly complete cessation of international trade in beef. This is because primary importing countries — principally Japan and South Korea — reject all beef from countries with open FMD outbreaks, even if the outbreak is far from the site of the cattle whose beef might be exported. The expected US loss would therefore be great, even if the outbreak in the dairy sector was eradicated relatively quickly, and despite the fact that California exports very little beef. The loss arising from a decline in US milk exports was much smaller, though the losses associated with culling animals and lost production on dairy farms were significant.

Ekboir’s study was undertaken relatively rapidly, and the model and its parameters were somewhat crude. Nonetheless, the study had two particularly surprising and important results. First, it showed that the expected spread of an FMD outbreak was considerably more rapid and extensive than had been previously recognised. Any outbreak would therefore be extremely serious, requiring the culling of a large fraction of the dairy herd and resulting in a sharp reduction of California milk output for a prolonged period. There would also be huge losses to the beef cattle sector, including ranchers and processors.

Second, the study found that measures taken to control the outbreak would face serious obstacles in California. Many dairies are located in zones that have become largely urbanised in recent decades. Auto traffic is heavy in these regions, as individuals commute to work and firms ship cargo in all directions. It therefore seemed difficult to impose an effective quarantine on movement within the region, as the economic losses in the broad economy associated with halting traffic would greatly exceed any savings that would result from more quickly controlling the FMD outbreak.

Further, it would be extremely difficult to dispose of the hundreds of thousands of carcasses that the model suggested could result from attempts to stamp out the disease. The carcasses could not be burned because the area suffers from severe air pollution, and permits for burning simply would not be provided by the local air quality control boards. In addition, firewood supplies were not considered adequate to permit the incineration of animals as fast as they were culled. Similarly, the carcasses could not be buried because of likely groundwater contamination. Therefore, although US policy called for stamping out in case of an FMD outbreak, this policy was limited by other factors in the region.

Ekboir did not propose specific remedies, though alternatives were mentioned and suggested for further analysis. However, the study did awaken California state authorities (specifically, the Secretary of Agriculture and the Head of the State’s Animal Health Branch within the Department of Food and Agriculture) to the significant threat of an FMD outbreak, prompting more attention to FMD within the UC Davis School of Veterinary Medicine. Leaders of dairy producer associations began holding conversations immediately, organising meetings throughout California to discuss the implications of a possible FMD outbreak. These
meetings were also intended to discuss proposed measures that the industry thought useful, including courses for farm workers to bring attention to possible signs of an outbreak. Dairies were urged to improve biosecurity, specific measures were proposed, and the state began contingency planning for how best to deal with a possible outbreak.

In short, the Ekboir study was important primarily because it identified FMD as an important disease threat, conceptualised and modelled the problem to highlight the major policy decisions that would be faced if an outbreak occurred, and garnered attention from animal health authorities and producers. Ekboir’s study showed the need to consider the various issues that may be faced by efforts to deal with an animal health issue, and to prepare policy makers for various possible scenarios.

As a result of Ekboir’s analysis, numerous subsequent studies were conducted to analyse FMD sanitary policy, anti-terrorism policy and the best policies for FMD control in case of an outbreak. These included the feasibility and economic attractiveness of using ring vaccination to control an outbreak. Although these studies might have been developed even if the Ekboir study had not been undertaken, it appears that Ekboir’s work significantly heightened attention to this topic.

One reason for its impact is the fact that Ekboir sought partial funding for his analysis from the School of Veterinary Medicine at the University of California, Davis, and carried out the analysis with significant input from university faculty, state veterinary authorities and dairy producers. Participation from veterinary and producer communities improved the quality of the study and brought its results very quickly into the hands of those most interested in animal health policy.


The Hagerman et al. paper reexamined the attractiveness of vaccination as a control strategy, looking both at a possible FMD outbreak in the California dairy sector and the Texas beef cattle sector. The study noted that USDA policy “favours emergency vaccination use only if standard culling practices may not be enough to control spread of the disease.” In other words, the study sought to determine whether emergency vaccination might be useful.

Designed by a team of veterinarians and economists, the Hagerman et al. study used simulation modelling with both epidemiological and economic details to analyse and compare a standard culling approach with the use of standard culling plus several emergency ring vaccination strategies. Under standard culling, herds that are infected with FMD or that are deemed to be dangerous as a result of exposure to FMD are culled. Remaining herds are monitored and movement restrictions are imposed. The alternative approach includes standard culling and also vaccination of herds that are deemed most at risk — and the vaccinated animals are later slaughtered. Vaccination is undertaken as an additional precautionary effort to stop spread of the disease. It should be noted that epidemiological information is used in these models to provide parameters for the economic analysis, but the epidemiological and economic analyses are not directly linked.

The study examined effects on both animal loss and economic welfare. One of the major issues highlighted is the skewed distribution of the benefits and losses among producers and consumers. Indeed, the paper notes that if a particular strategy leads to social gains of 100, farmer losses of 20 and consumer gains of 80, it may be difficult to implement because farmers may seek to avoid components that are associated with economic loss. It is important to mention that veterinary studies probably place more emphasis on animal and producer effects, while economists probably place more emphasis on the broader economy. This may be an important source of on-going tension between veterinarians and economists.
The paper also focuses on the likelihood that an outbreak could become truly massive, and whether a ring vaccination strategy might reduce the probability of such an outbreak — even if it comes at a greater expected cost than simple culling. In fact, results from the paper’s simulations yield an average result in which culling is the most cost-effective strategy for controlling an FMD outbreak. However, under numerous scenarios, if adjusted for risk, the benefits of using vaccination are deemed greater than those arising from simple culling. The study concludes that ring vaccination may be an attractive instrument for reducing the risk of an expanded outbreak, though again, this is a general result.


An important issue in animal health is the potential spread of infectious disease among wild and domesticated animals, in which wildlife acts as a disease reservoir and a vector of disease transmission. That is, even if disease is eradicated in domesticated animals, it remains present in wildlife, where it remains unless all wildlife is eradicated — which is usually very costly. As a result, continued contacts between wildlife and domesticated animals are likely to re-introduce disease. Bicknell, Wilen and Howitt (1999) advanced analysis in this area using a bioeconomic model to analyse the control of bovine tuberculosis spread by Australian bush-tailed possums to dairy herds. Farm-level control efforts included both farm testing of cows and also hunting possums to reduce the wildlife contacts.

Horan and Wolf (2005) then analysed the management of infectious bovine tuberculosis within a four-county area in the US state of Michigan, where the disease is endemic among white-tailed deer. Though the deer infection creates risks for cattle within the region, the white-tailed deer are valuable as hunting trophies. Horan and Wolf assert that deer hunting “is arguably the highest-valued use of land in the infected area.”

Moreover, it appears that the disease is self-sustaining only where deer density is high. Feeding programs in this area have increased deer density, thereby allowing the disease to become endemic. It appears that the disease will not be self-sustaining outside areas where deer density is lower. However, Horan and Wolf note that the threat of deer-spread infections among cattle has resulted in increased testing, culling and business interruption for cattle producers, and that may encourage trade restrictions on state animals in addition to mandated testing requirements.

The policy question is whether the deer should be eradicated, or whether their numbers should be managed to control disease. Horan and Wolf utilised a dynamic optimal control model to analyse the problem. The model produced results that were surprising and thought provoking. This model assumed that the cattle sector was exogenous to the deer sector, with infected deer imposing a fixed cost on the cattle sector. Because infected deer cannot be identified before they are killed, they cannot be selectively eradicated. Thus, the two instruments available to policy makers are the amount to feed deer and the rate of deer harvest. Each instrument can reduce deer density, thereby reducing or gradually eliminating the disease, albeit at the cost of lost deer productivity.

As it turns out, the model identifies a dynamic policy that is both complex and unexpected. The optimal policy is to at first feed deer more to increase the stock, even though this increases disease prevalence. The value of the larger harvest temporarily outweighs the rise in disease, though the stock soon approaches a boundary at which additional feeding will not affect stock numbers. At this point, the model predicts a gradual, continuing increase in prevalence and a reduction in stock. If a planner — in this case, the hunting authority — perceives this constraint and the expected end result, the planner should immediately introduce a high culling rate, sharply reducing the stock and moving to a second dynamic path.
with lower stock and zero feeding. Along this second path, the smaller stock now increases slowly, but disease prevalence declines because of the lower density. This path would eventually lead to eradication of the disease with an intermediate stock, after which feeding could be reintroduced (assuming no reinfection from outside the area).

However, the model surprisingly indicates that it is economic to periodically provide small amounts of supplemental feed to increase the stock — which rises without a significant increase in disease prevalence — before quickly increasing deer harvest that returns the stock to the second dynamic path. The model shows it is optimal to follow the same path repeatedly, never eradicating the disease unless constrained by some outside sanction (e.g. from the US government). Thus, the economically optimal policy for Michigan is to allow the disease to remain endemic at low levels, with periodic investments to enhance the deer stock followed by larger harvests.

In a subsequent paper, Horan et al. (2008) developed and analysed a dual-host pathogen model involving cattle and deer. Whereas the first paper solved for an optimal solution for a single-host pathogen model involving deer, with effects on the cattle sector treated exogenously, the second paper allows for simultaneous interaction between deer and cattle sectors. The bioeconomic model is used to explore economically optimal management, with the goal of maximising discounted net benefits of deer hunting and cattle production.

The model recognises that the disease potentially spreads from deer to cattle and vice versa. More cattle create opportunities for within- and cross-species infectious contacts, while reducing the host density threshold for deer. As in the previous paper, the relationship between density and disease prevalence is important within the deer sector, but there is no relationship between density and disease prevalence within the cattle sector, since farmers test cattle in each period and cull any animals that test positive. Veterinary data show that there are few false positives or false negatives in such testing.

In this model, management has an additional tool: biosecurity (e.g. fences), which reduces livestock sector damages and transmission back to deer, thereby easing pressure to reduce disease prevalence. As a result, there is a greater incentive to feed deer. Depending on the model’s parameters, biosecurity may not achieve a complete separation, because as disease prevalence decreases in the cattle herd, there are fewer damages and lower incentives for additional biosecurity. Thus, the two sectors are almost, but not entirely managed separately.

Given the low value of cattle production and the high value of deer production in this relatively isolated region of Michigan, and considering the small likelihood of disease transmission outside the region, the optimal result involves the culling of infected cattle stock and the use of biosecurity to reduce cross-species transmission. As with the lower stock dynamic path found in the first paper, deer continue fed and are periodically harvested. This solution contrasts markedly with conventional policy, which recommends the eradication of wildlife populations to protect livestock.

The authors do experiment with alternative assumptions. For example, if cattle were more profitable, biosecurity more costly, and deer less valuable, the optimal policy might shift to deer eradication as a means to eliminate bovine tuberculosis, with reintroduction of deer after the disease had been eliminated. Interestingly, under the alternative assumption that cattle prices increase by 32% or more, the optimal policy is to increase biosecurity investments to totally separate cattle and deer management. However, if biosecurity is too costly, the optimal policy is to allow reductions in cattle stock when the risk of infection from deer is high, and vice versa. This produces offsetting oscillations in the number of cattle and deer over time, but bovine tuberculosis remains in the deer herd, while infections in cattle are controlled by culling and quarantine.
The paper is notable for several reasons. First, it emphasises that the ability to use different controls is crucial to determining the optimum disease strategy. Pathogen eradication is not necessarily recommended, but depends on the availability of mitigation as an alternative strategy, which is shown to be optimum in certain cases. Moreover, if pathogen eradication is not recommended, animal management strategy allows for alternating levels of deer feeding and harvests, and even for alternating levels of cattle stocks. Clearly, the paper is not intended as a specific guide to policy, but instead seeks to demonstrate how changes in the general context can lead to different preferred approaches to disease control.


This study analysed the degree to which the international beef market is separated due to FMD, and whether eradication of FMD was likely to lead to a significant increase in access to additional markets and/or higher export prices. As such, the analysis did not focus on control of animal disease per se, but on the degree to which FMD, through trade restrictions, imposed a significant economic burden on exporting countries.

As part of the analysis, the study explored the degree to which the development of sanitary policies that restricted trade in bone-in beef — but not deboned beef — had also reduced the price sanction due to FMD. Science has shown that FMD is carried in bones, but not in muscle. Thus, while beef cuts containing bone (bone-in) poses a risk of FMD transmission, beef cuts that have been deboned are not a significant risk to the importing country. Accordingly, the study sought to determine whether the secular trend toward the export of deboned beef, rather than the traditional trade in whole carcasses, had increased the price of beef exported from countries manifesting endemic FMD relative to the price of beef from FMD-free exporters.

The study first analysed the degree to which the prevalence of FMD in exporting countries and the sanitary policy in importing countries affect trade between pairs of countries. Exporting countries were classified as FMD-endemic, FMD-free with vaccination, and FMD-free. Importing countries were classified as having zero tolerance for the presence of FMD in the exporter, allowing for minimum risk, i.e. accepting de-boned beef and/or beef from cattle that had been previously vaccinated, and having no restrictions on FMD. The results showed a clear interaction between exporting country FMD status and importing country FMD sanitary policy. For example, exporting countries with FMD-endemic status did not export to importing countries with zero tolerance, but did export to importing countries allowing for minimum risk — a set of countries that has been growing over time.

The analysis then examined whether the prices received by beef exporters in different importing countries were affected by the FMD status of the exporting country (assuming imports were allowed). Somewhat surprisingly, countries with an FMD-compromised status (either FMD-endemic or FMD-vaccinating) received prices for their beef that were significantly lower than those received in the same import markets for beef from FMD-free countries. Thus, there appears to be an FMD-related sanction to beef prices in markets even if access to the market is achieved, though it is not clear whether this is a result of long-run quality differences in beef among exporting countries that may be related to the historical presence of FMD or to some other factor.

Combining these results, the analysis indicated that an exporter’s FMD-compromised status has varied effects on its ability to export, depending on its traditional relationship to importers and to their specific sanitary policies. Countries that eliminated FMD (e.g. Uruguay) did see increased access to foreign markets and increased export prices, but the estimated export price increases were smaller than anticipated. This smaller increase suggests
that the economic incentive to eradicate FMD to achieve higher export prices may be smaller than expected.


We briefly mention these two studies to demonstrate how much economists and veterinarians have left to do, and how essential it is to communicate with policy makers and the general public. Following outbreaks of highly pathogenic avian influenza (H5N1) in Southeast Asia, efforts were launched to control the disease through culling, vaccination, market closure and various types of biosecurity — both to isolate poultry from infection and to protect humans from contracting the disease. Fear of an international pandemic created enormous pressure from developed countries to undertake drastic measures in the developing countries in Asia and Africa where the disease outbreaks were occurring. In hindsight, though, these efforts appear to have been much less effective than anticipated. The control measures focused in large part on culling small (backyard) flocks and shutting down wet markets in East and Southeast Asia, and parts of Africa. These efforts had harsh impacts on incomes of the poor, resulting in increased evasion and political resistance. Moreover, flocks were extensive in number, producers were opposed to the measures taken, and government institutions agencies had limited administrative control. As a result, the measures taken were not successful in eradicating the disease. In some cases, the disease appeared to remain endemic in the wild bird reservoir and elsewhere in domestic ducks, which were carriers of the virus despite showing no clinical symptoms.

We do not believe that a clear consensus emerged from this effort. The Pro-Poor study concluded that, as a class, smallholders had lower individual risk than large producers, in addition to lower prevention potential. Yet because the number of smallholder flows was so large, it may be that they jointly combined to create greater risk of infection and contagion among humans. However, analysis also concluded that it was politically impossible for some governments to ban smallholder production. The disease is believed to infect millions of birds, wild and domesticated, not all with manifested clinical symptoms. It seemed that large scale vaccination was highly likely to be incomplete and thus unlikely to end infection. However, it might serve to hide infection if small outbreaks were less likely to be reported, or even lead to positive selection pressure on vaccine-resistant influenza strains. That is, vaccination that fails to eradicate the virus that eliminates some, but not all of the disease may result in the survival of increasingly vaccine-resistant strains. Moreover, the short lifespan of poultry required frequent vaccination campaigns. Thus, no clear result emerged from the multiple economic-veterinarian studies undertaken. The complexity of the disease threat and its broad spread left the animal health sector without a clear strategy for controlling highly pathogenic avian influenza.

Scoones and Forster emphasised the political dimensions of the international response. They, among other scholars, document the “multiple, competing policy formulae and diverse, sometimes conflicting, intervention responses” to the H5N1 outbreak. Although economists and veterinarians may analyse issues, and though some may hope to play important roles in the implementation of control strategies, the HPAI experience clearly demonstrated that animal health experts could not dictate solutions that had broad political implications. As a result, economic-epidemiological models are needed, but are likely to be insufficient for determining courses of action. Scoones and Forster emphasised the need for communication with policy makers so as to better understand the political-, health- and income-related implications of disease and the crucial need to craft clear messages to the public.
Disciplinary perspectives

Communication among economists and veterinarians is essential to conducting better analysis of animal health policy. Below, we provide some thoughts on issues that influence such communication. We aim to identify the causes of “stress and tension” between veterinarians and economists who are (or should be) working together collaboratively, and will hopefully determine ways to make this collaboration more fruitful.

Economists and veterinarians have similar goals — e.g. controlling or eliminating animal disease to benefit animals, people and the economy. The two disciplines have worked together more closely in recent decades to analyse animal health issues. Considerable progress has been made, including growing knowledge of, and appreciation for, the importance of collaboration among members of each discipline. Furthermore, there are many veterinarians with considerable knowledge of economics, and many economists with knowledge of veterinary medicine and epidemiology.

Economists have applied a variety of theoretical and methodological tools to analyse specific animal health problems. As previously noted, these tools are often not intended for direct application as policy, but are designed to give an overview of a problem that requires significantly more information concerning the specifics of a disease, institutions, politics, and likely human response to different policies. These models focus on the big picture, rather than on details of how lessons may be applied.

This approach contrasts with veterinarian studies that incorporate well-known economic techniques in their analyses. These studies apply prices to anticipated effects to determine “benefits and costs”, but often pay little attention to endogenous price responses and other market adjustments that occur, or to producer and consumer behavioural responses to changing incentives. These less inclusive economic models are not necessarily wrong, but they run the risk of yielding the wrong result, which could then be proposed as a policy guide for veterinary practitioners. For example, veterinarians might anticipate that quantification of tangible costs such as vaccines, other treatments and mortality losses will yield adequate clarity regarding which actions should be preferred, while the economist would suggest a broader view. Veterinarians might also conclude that a given approach is dictated by medical requirements, and would therefore prefer a cost effectiveness analysis instead of a cost-benefit analysis that might produce a different result. Economists criticisms may be correct, but they may be seen as a disciplinary turf protection (and might be in some cases), increasing rather than reducing tension between practitioners in the two disciplines.

Disciplinary perspectives are also important. When thinking about disease, the economist’s first thought is about society as a whole, while the veterinarian’s is about animals, their owners and other people that may be directly affected by animal disease. Although both have “broad” perspectives, veterinarians are more focused on a specific clientele, while economists insist on the importance of a general perspective. Veterinarians with a specialisation in epidemiology also tend to think from the overall to the specific. For example, they think first about animals and the factors that influence their health (e.g. pathogen agents, interactions with other populations and environmental status). Subsequently, the epidemiologist may look at owners of these animals and factors that may affect health status. After that, they may turn their attention to other people who may be directly affected by animal disease. Thus, the hypotheses, study unit and study focus of the two disciplines are often different.

The economist may become uncomfortable with the effort to provide “recipes” for behaviour, under the pretence that it is better to communicate broad principles and allow individuals to exercise judgment based on these principles. The veterinarian, by comparison,
is uncomfortable with the vagueness of the economist’s prescriptions, and is concerned instead with more specific guidance to those acting on the ground level.

Veterinarians are more strictly concerned with diseases and how these diseases can affect productive systems, ecosystems, and human well-being, but they focus less on how human behaviour is likely to alter the causes and effects of animal disease. Economists are often supremely confident in the quality of their analyses, and in their ability to ask the right questions and combine obtained information in comprehensive analyses to formulate valuable overviews of how to proceed. Economists may be uncomfortable with veterinarians’ efforts to provide “recipes” for behaviour, based on the belief that it is better to communicate broader insights that would allow others to exercise judgment based on the principles established.

Economists often structure their analyses to learn how best to think about a problem. Their studies may lead to precise answers, but their analysis is usually intended to provide insights into the nature of a problem, and to identify the best policy instruments to use. Veterinarians in contrast appear prepared for action ex ante, and seek answers to support the action they believe they need to undertake. To take an exaggerated analogy, economists are more akin to philosophers thinking generally about a problem in need of a solution, while veterinarians are more like engineers seeking a blueprint to build a bridge.

The problems encountered in the pro-poor study of avian influenza control and eradication underscored some of these issues. Policy makers were eager to see the disease stopped. Veterinarians saw the situation as a mandate to act and as an opportunity to obtain significantly more resources for their professional institutions. They thought they had the appropriate tools and knew how to use them to stop the spread of HPAI. Action required somewhat draconian measures in the short run, but similar measures had been deployed with significant success in previous cases. Economists looked at the problem and wondered how to understand it, but had no immediate insight regarding what to do.

As it turned out, policy makers found that neither economists nor veterinarians could offer a solution. The policies implemented by veterinarians resulted in many culled and/or vaccinated animals, but did not eradicate the disease, fuelling a tremendous popular backlash. Economists did not have many viable ideas to improve this policy, so policy continued in an ad hoc manner until, gradually, the highly infectious course of the disease seemed to dissipate.

What does the future hold? The epidemiology of many animal diseases is fairly well known, and the likely effects of the disease as well and the optimum policy are either well established or currently being improved through small innovations on a long-term strategy. FMD is one such example: more differentiated sanitary policies, more careful meat processing, higher quality vaccines, greater producer understanding and education, and more effective governmental institutions. Interactions between economists, veterinarians and policymakers are strong and improving. Models, policies and communications are leading to improved results.

For other diseases with potentially large human impacts such as HPAI, we do not yet have a clear policy. The situations are highly complex and not adequately understood, while epidemiological models are incomplete and unclear. The economic effects are potentially large, but many important model parameters are still unknown, and no comprehensive model has been formulated. Moreover, considering the potentially huge costs of dealing with an outbreak or pandemic, we do not know whether a politically acceptable policy can be developed. We do not know the extent to which any policy will work, and thus do not know whether proposed strategies will be successful. We suspect that if such a situation develops, many different policies will be proposed and implemented in different areas of the world. Analyses of these policies’ effects would continue until the disease either runs its course or until one or more policies appears to offer a socio-economic-political attraction. Within this
difficult situation, a multidisciplinary approach seems essential, but it will face multiple difficulties simply because of the enormous pressure that is likely to exist for action.

References


Nigel Gibbens*
DEFRA, United Kingdom

This paper offers a perspective on integrating advice from epidemiologists and economists to inform policy on disease control. The fields of epidemiology, economics and social research have become increasingly integrated over the years, though this process is still in transition. Recent examples of this transition are presented below, including the UK experience with infected koi carp, foot-and-mouth disease and rabies control. There is clearly great value in integrating these three fields, though significant challenges remain. Important information must be conveyed in a clear and concise way to policy makers, and risk must be communicated more clearly, without relying too heavily upon central estimates. Ultimately, policy makers must consider a wide range of evidence and factors when making disease control decisions, and must weigh them accordingly.

* This paper has been edited by Amar Toor based on a transcript of the audio recording of the Workshop.
In this paper, we provide a perspective on integrating advice to inform policy on disease control. The proposition put forward is that we are in a state of transition. We are progressively getting better at integrating epidemiology, economics and social research into a multidisciplinary approach to inform policy formulation, though several challenges remain. Below, we cite examples of this transition and describe the challenges in conveying information to policy makers.

We conclude there is a real value in bringing together the disciplines of epidemiology, economics and social science, because they consider different areas of relevant evidence and can enrich the analysis that informs policy decisions. There are often, however, high levels of uncertainty in these areas, and one must therefore take care to avoid false precision. Integrating these disciplines to produce an analysis is not a decision, in itself; analysis can only inform the policy maker’s consideration of available options.

Transition in the use of integrated advice to support disease control decisions

There was a time when economic analysis barely played a role in disease control policy making (Figure 1). Instead, policy makers relied heavily on expert veterinary advice, while assuming, rather than quantifying, expected benefits. That began to change, for example with global rinderpest control policies, which were formulated based on cost-benefit analysis and resulted in tremendous success.

More recently, diseases such as brucellosis, rabies and bovine tuberculosis have posed major public health threats. Some of these diseases have since been eradicated, while others continue to pose risks. In each case, policy makers were faced with important questions of whether they could implement a policy that would control the disease, and whether they could afford to deliver it. Costs were weighed against benefits, and in these cases, the outcomes were clearly worth the expenditures.

Enzootic bovine leucosis has been eradicated in the United Kingdom and most of the European Union, though this case was rather unique in nature; it posed no public health risk and impacts only on adult cattle production. Today, in fact, there is an on-going debate in the OIE over whether enzootic bovine leucosis should even remain reportable. Yet as with the diseases mentioned above, the fundamental cost-benefit questions remained the same: Does a proposed policy pass cost-benefit tests, including whether it will result in disease-free status, thus ensuring long term benefits at reduced costs?
Infected koi carp and the separate application of economics

Recently, UK policy makers were faced with the question of whether to eradicate a herpes virus that had infected koi carp. As with any decision, there were winners and losers. Anglers, of course, did not want the carp to be diseased, because their enjoyment of their sport depended in part on the health of free-living carp. But if disease control measures had been implemented, they would have had a severe impact on the thriving ornamental fish industry, including on imports of koi carp. Once the data was analysed, it was clear that the costs of pursuing disease control were very large (GBP 220 million over two years, according to estimates), while the benefits for stakeholders were comparatively small (estimated at less than GBP 50 million). As a result, policy makers decided against eradication, choosing instead to declare an “infected status” for the United Kingdom and maintaining control measures short of eradication.

The associated costs and benefits of this decision fell on different parties, underscoring the difficult decisions that policy makers often have to make. No single decision was going to please everyone, and there were serious social issues to consider, as well. Ultimately, though, the analysis helped support the decision, and allowed various stakeholders to understand how it came about.

Integrated epidemiology and economics: FMD vaccination analysis

In the case of foot-and-mouth disease (FMD), UK policy makers were planning for the decision of whether or not to implement a vaccination program in the event of an outbreak of the disease. Here, economic (cost-benefit) analysis was integrated with epidemiology and veterinary science. Broadly, policymakers considered the FMD outbreaks most likely to arise, the scenarios that might play out under a vaccination program, and where the associated costs and benefits would fall. Key drivers were identified, as were scenarios under which vaccination would have a net benefit. Economics and epidemiology were used to project costs of different control strategies, and to evaluate the potential trade-off between costs of vaccination and the estimated reduction in the number of culled animals (Figure 2).

When this analysis is done in an integrated way — with epidemiologists, veterinarians, and economists iterating the process to produce useful outcomes — one finds that the costs fall differentially, with overall benefits flowing indirectly to government through maintenance of a competitive livestock industry that contributes to national finances. One also finds that the chances of an overall benefit depend on the size of the outbreak. There are small outbreaks where costs of vaccination exceed benefits, but in a larger outbreak, the benefits are greater. However, this remains a very complex analysis, and it does not provide an answer as to whether or not a government should vaccinate. This becomes especially evident when one considers the levels of uncertainty involved with predicting how big an outbreak will be. In short, this is an aid to decision making, albeit one with significant uncertainty.
Impact of social factors

The final example concerns the United Kingdom’s decision on controlling the risk of rabies. The United Kingdom has been free of rabies for a long time, and has maintained that freedom through severe import controls. The public was made aware of the risks that rabies posed, and a very strict quarantine regime was put into place. Policy makers spent the past decade debating this disease and the enormous risks it posed. The European Union, meanwhile, had been successfully controlling rabies in parallel, reducing risks to very low levels through vaccination. This dramatically lowered risks for the United Kingdom (incursions were estimated at one every 220 years), while costs for control programs remained high. Analysis showed that the benefits of removing import control measures dramatically outweighed the estimated extra costs of a potential incursion (Figure 3).

Figure 3. Rabies: Costs and benefits of the United Kingdom adopting the EU regime

- **Scenario 1:** Single infected animal
- **Scenario 2:** Spread in domestic animals
- **Scenario 3:** Spread to wildlife

### Probability of scenario

- 90%: **Scenario 1**
- 9%: **Scenario 2**
- 1%: **Scenario 3**

### Weighed average extra cost

- Mean cost of outbreak: GBP 2.2 M
- Increase in risk under new policy: 1/220
- Expected extra cost/year: GBP 0.01 m/yr
- Extra benefit: GBP 7.2 m/yr
Given this discrepancy between costs and benefits, one would assume that the United Kingdom would immediately adopt the EU regime. But this decision was complicated by several important social factors — namely, whether a change in policy would be politically and socially deliverable. This is where understanding of the social context comes into play. The decision on rabies control was as much about the social acceptability of a change in policy as it was about cost-benefit and practical deliverability. Changes were ultimately put into place, though only after significant consultation and dialogue on how to best deliver the message to politicians and the public. If these changes had been implemented prematurely, they would have likely been overturned.

Challenges for policy makers

Policy makers face several challenges when integrating various disciplines into the decision making process. When analysing low-likelihood, high-impact events, the confidence levels associated with given estimates can be very large — especially for diseases that have not occurred in decades. These estimates are then used in economic analysis, which itself has levels of intrinsic uncertainty. As a result, projected outcomes have very wide confidence intervals, though that does not mean that they are useless. Even with wide confidence intervals, such systematic analysis allows policy makers to understand the factors that must be considered when making decisions. Nevertheless, expressing risk and uncertainty around central estimates remains an area for future improvement.

However, danger arises when economists take the central estimate, run analyses, and come out with a single figure. Much progress has been made in building levels of uncertainty into integrated analyses, though it is important for disease and economic models to provide ranges and likelihoods for their outcomes, in order for policy makers to arrive at informed decisions. This is especially critical in situations where “zero risk” status is impossible or prohibitively costly.

Conclusions

In conclusion, decisions on disease control should integrate an entire range of disciplines — especially epidemiology, economics and social research. As a result, building communication and understanding among these disciplines (and with society, at large) is increasingly important. Multi-disciplinary evidence can be very useful in informing decision making, by providing an empirical underpinning and highlighting the bounds within which decisions can be made. Ultimately, however, models, scenarios and estimates can only inform a decision — they cannot tell policy makers what they should do. Policy makers must consider a wide range of evidence and factors when making disease control decisions, and must therefore weigh them accordingly (Figure 4).
Figure 4. Policy makers make use of evidence from a variety of sources

- Risk assessment
- Industry and other groups
- Economic
- Legal
- Political
- Social acceptability
- Veterinary
- Modelling
- Scientific
- Epidemiological analyses
- Risk appetite
Governments have played an important role in decision-making on animal health over the years. Early initiatives were based on principles of epidemiology — and many had success — though economists have also played a role, examining how animal diseases and health problems impact on individuals and societies. Given the relatively recent introduction of formalised processes of epidemiology and economics to assess animal disease and health, it is unsurprising that animal health economists have yet to formalise their approaches to policy making. Economic analysis of animal health is complex and disease-dependent. This complexity only increases at a policy level and requires a systems approach with interdisciplinary working. The paper aims to highlight areas where there have been advances, and to identify areas of best practices. It will also look at areas where economics may be best used to provide clarity for, and add value to, the assessment of animal health policy in the future.
Over the years, governments have played an increasingly large role in decision-making on animal health. Investigations into livestock diseases began as early as 1776, when Louis XIV established a Commission on Epidemics to assess a severe epidemic (probably rinderpest) in cattle (Harrison, 2004). It was not until nearly 100 years later (1865) that Great Britain established a veterinary service in response to growing problems with the control of rinderpest, contagious bovine pleuropneumonia and foot-and-mouth disease (Fisher, 1998). These examples mark the beginning of national-level initiatives to manage disease in animals for the benefit of society. At an international level, the World Animal Health Organisation (OIE) was created in response to global problems of managing rinderpest in 1925.

Historically, the presence of disease in animals has generated societal responses. Initially, these have spurred investigations leading to improved policies for surveillance, control and prevention of these diseases. Early initiatives were based on principles of epidemiology, and many had success; rinderpest and CBPP were controlled, and in some cases eradicated, in Europe in the late 1800s, while FMD and classical swine fever were eradicated in the United States in the early 1900s. Epidemiological principles were not formalised as a discipline until the 1960s and 1970s, and only recently have they become an accepted part of veterinary curricula. Economists have also played a role in this epidemiological movement by examining how animal disease and health impact societies; the first studies on disease control were published in the early 1970s (Ellis, 1972; Powell and Harris, 1974; Hugh-Jones, et al., 1975). These studies served as *ex post* assessments of successful disease campaigns in developed country settings — which, in turn, were based on significant investments in general agricultural research and institutional developments during the post-World War II period.

Given the recent introduction of formalised processes of epidemiology and economics to assess animal disease and health, it is unsurprising that animal health economists have yet to formalise their approaches to policy making. This paper aims to highlight areas where there have been advances, and to identify areas of best practices. It will also look at areas where economics may be best used to provide clarity for, and add value to, the assessment of animal health policy in the future.

*Are livestock important?*

Societal responses to animal disease stem, in part, from the importance of livestock to society. Our varied use of animals demonstrates that animals are a fundamental aspect of societies around the world. Animals feed people, provide pleasure and company, act as a store of wealth, and, in many places, provide power to till land and to transport goods and people. In their ground-breaking work on the economics of animal welfare, Norwood and Lusk (2011) go even further in stating that human evolution has unfolded alongside the evolution of animals, and that in general, “human lives are enhanced by the use of animals.” This importance is underscored by the sheer number of animals that humans have domesticated. A very rapid estimate using FAOSTAT data indicates that the nearly 7 billion people in the world have 2.65 billion livestock units. A majority of these domesticated animals are cattle, sheep, goats, pigs and poultry — livestock that are kept for food production, transport and draught power and as a form of investment (Figure 1).

For every person in the world therefore there are approximately 0.38 livestock units, or an estimated 190 kilos of live animals. This means that for every person in the world, there are three chickens, a third of a sheep or goat, a fifth of a cow, a seventh of a pig and a tenth of a cat or dog. There has not been enough time to determine whether these proportions are changing, though it is likely that poultry and pigs are becoming more important based on

1. Livestock Unit = 500 kg liveweight.
increasing populations — particularly of poultry — and increased consumption of meat from these species.

It is therefore clear that animals are important and that livestock, in particular, are critical to food systems. Animals are involved in everything we do; they compete for resources such as land and water, and they pose risks because the diseases they contract can be transferred to humans. Thus, policies to manage animals and the diseases they suffer from remain critical.

Figure 1. Global livestock units by species

Note: Camel = 1.2; Cattle and Buffalo = 1; Equines = 0.7; Pigs and other camelids = 0.3; Sheep and Goats = 0.2; Turkeys and Dogs = 0.05; Chickens, Ducks, other Poultry, Cats = 0.01.

Source: FAOSTAT, 2011 data author analysis.

Economic analysis of animal disease mitigation

Maintaining animal health has led to policies that reflect the importance of livestock in society. Such policies and responses are dynamic, changing as society evolves and advances. As things change, available resources, demand and supply will change as well, which necessitates changes in policies. Susan Jones (2003) explains these changes in her book, Valuing Animals. For the United States, she identifies three phases:

- Until the late 1800s and early 1900s, early veterinary science was dominated by horses.
- From the early 1900s to the 1970s, there was a strong focus on food animals.
- More recently, veterinary science has seen an increased awareness of and investment in pet animals.

The ways in which animals are used can vary according to the phase of development for a given society. Many developing countries, for example, still rely on cattle, buffalo, camels and equines for transportation and draught power. This affects the way animals are valued, as well as the products they produce. Countries and regions that use cattle for draught power have lower offtake rates and hence lower meat production, reducing the availability of meat on urban markets (Barrett, 1992). At the extremes, some argue that the importance of draught animals has become entwined with cultural rules, pointing to the as religious taboo of eating beef in India or the meat abstinence observed during Lent in Europe (Crotty, 1980).

The general development of a society and its use of animals influence governmental responses to livestock disease, animal health and welfare. These responses reflect the importance of animals in each society. Key differences are as follows.
In countries with a high animal health status and sophisticated livestock agri-food systems, surveillance is critical to limiting public liability and safeguarding private investments (Häsler, 2011).

Disease eradication and animal health status are critical for exports in countries with emerging export livestock industries.

Feeding people is critical in countries with food deficits and large, intensive systems.

It is clear that societies are rapidly changing, and that demand for livestock products is increasing. Historically, this has created health problems. The current rate of change has raised new challenges in terms of emerging and re-emerging diseases. Addressing these diseases with adequate investments in health education, research and institutional development remains a major challenge. This is a societal resource allocation and socio-economic challenge.

What do we know about disease impact?

Given the challenges involved with allocating resources for disease management, it is no surprise that economists are working to assess the magnitude of these challenges, while developing stronger tools, methods and data collection procedures. Assessing disease impact remains one of the most important aspects to this economic analysis. Figure 2 presents some examples that are frequently used in presentations.

**Figure 2. Estimated global impacts of the major panzootics since the early 1990s**

![Estimated global impacts of the major panzootics since the early 1990s](image)

*Source: Bio-Era. Courtesy of Dr. Will Hueston, Center for Animal Health and Food Safety, UM.*

Figure 2 is based on animal disease crises that the world has experienced in the last 20 years. It does not provide information on insidious animal diseases. These estimates are not based on empirical datasets, and in many cases have not been published in peer-reviewed
papers. The World Bank and TAFS forum (2011) have attempted to fill this void with a study that looks at the losses of animals (measured as livestock units) by disease. Their work is based on disease incidence data collected by OIE combined with FAOSTAT data on livestock populations (Figure 3).

**Figure 3. Estimated global losses of livestock units by major diseases**

The World Bank/Tufts study (2011) focuses only on animal losses measured as livestock units and therefore follows a logic similar to that underpinning WHO work on human diseases. A livestock unit (LSU) is a standard weight of animal biomass, with one livestock unit usually being an animal of 500 kilos liveweight. WHO work tends to prioritise diseases based on their impact on humans, and measures this impact in daily life-adjusted years (DALYs). This approach ignores other impacts relating to responses to disease presence, including investments in disease surveillance, control and prevention, as well as market-based responses and shocks. Neither of the two highlighted works disaggregate animal disease impact into losses due to production and reactions from societies, businesses and individuals to the presence and/or risk of disease. The only study that has systematically done this was carried out for a list of endemic diseases in Great Britain (Bennett, 2003). This study was later updated to include welfare measures (Bennett and Ijplaa, 2005). Bennett describes and explains the methods he used in the recent special edition of *Eurochoices* (Bennett, 2012), while Perry and Randolph (1999) present a framework for looking at parasites in animal production.

**The problem and some solutions**

Estimating the overall impact of a disease event is useful in raising the profile of animal health governance and highlighting the need for investments in animal health organisations and institutional environments. Yet it provides little useful information on where scarce disease management resources may be best placed, or how public policy can address important issues of externalities and market failure. See Wolf (2013) for a comprehensive explanation of these issues. If estimates highlight the impact of major crises and look at only a limited spectrum of overall disease impact, significant public funding may be used in reaction to short-term crises such as major outbreaks or diseases. This underscores the need for a more
rational use of economics in animal health policy making, which should include better frameworks to assess impact and evaluate change. The results from such work must also be presented in ways that are socially acceptable and politically palatable.

Fortunately, there is no need to start from the beginning. Professor John McInerney examined this problem with Keith Howe and other colleagues over many years. Much of his thinking was summarised in a paper he presented to the Agricultural Economics Society (McInerney, 1996). Through a theoretical application of production economics to animal disease, McInerney identified an area where impacts of disease relate to disease losses and control expenditure. These impacts are connected: higher spending on control leads to lower disease losses. If this relationship can be established, then optimal and sub-optimal points of expenditure can be identified. Figure 4 indicates some of the main points underpinning such a relationship.

![Figure 4. Disease loss – expenditure frontier](image)

In a less theoretical framework, Rushton, et al. (1999) disaggregate animal disease impacts (Figure 5). They identify direct and indirect impacts — the former relating to McInerney’s disease losses and the latter being control expenditures related to human reaction to disease presence and risk. They separate the direct impact into visible losses that have immediate impacts (e.g. animal deaths) and invisible losses that usually go unnoticed and often relate to fertility management issues. Among indirect impacts, a distinction can be made between the control measures (additional costs) and foregone revenue. Revenue foregone relates to opportunities that are lost due to the presence or risk of disease. For example limited or no market access, and the selection of technologies, such as breeds by farmers and people along the food system. Knight-Jones and Rushton (2013) present a practical application of this method for FMD at a global level.

When developing a framework, one must recognise that not all costs are equal. Some relate directly to an animal disease management process and could be defined as variable costs. Others cannot be so easily assigned, and relate to the development of infrastructure, training, and organisational capacity in general. These can be defined as fixed costs. Professor Clem Tisdell examined this issue more carefully during his work on FMD in Thailand, and
proposed that countries that do not invest in fixed cost elements of their animal health systems would find it difficult to incorporate and succeed with individual disease management campaigns. Tisdell (2009) developed a theoretical framework around his arguments (Figure 6).

**Figure 5. Elements required for disease impact assessment**

- **Disease impact**
  - Direct
    - Visible losses
      - Dead animals
      - Thin animals
      - Animals poorly developed
      - Low returns
      - Poor quality products
  - Invisible losses
    - Fertility problems
    - Change in herd structure
    - Delay in sale of animals and products
    - Public health costs
    - High prices for livestock and livestock products
  - Indirect
    - Additional costs
      - Medicines
      - Vaccines
      - Insecticide
      - Time
      - Treatment of products
    - Revenue forgone
      - Access to better markets denied
      - Suboptimal use of technology

*Source:* (adapted from Rushton et al., 1999).

**Figure 6. Cost-benefit model for livestock disease control with fixed costs**

- **Variable costs**
- **Fixed costs**
- **Benefits**

*Source:* (adapted from Tisdell, 2009).
Once these weaknesses are identified, policy changes (e.g. legislation and/or direct interventions) need to be assessed using a classic cost-benefit analysis framework. This framework examines marginal changes in costs and benefits over time and assesses the economic profitability of a given change.

Costs and benefits of animal health policies

When assessing the costs and benefits of animal health policies, one must identify additional costs and new benefit streams. Mitchell, et al. (2012), present a very understandable and clear approach to this problem. This approach can be used as a framework for incorporating more complex methods of examining market impacts and possible price changes.

As mentioned above, fixed costs for animal health include investments in coordination, research, information and key infrastructure — areas that have traditionally been under governmental control. Yet in some countries, private sector skills and investment are making government involvement less important, particularly in contexts where power is concentrated in agri-food systems. In such situations, private organisations are large enough to invest in infrastructure for animal health, and in some cases may be powerful enough to coordinate and manage disease control processes. This is increasingly the case in sectors such as the poultry industry, where some companies act as quasi state-like organisations. From a public policy perspective, it is important that animal health investments create synergies with on-going private investments.

The variable costs described above are specific to a disease campaign, and will vary with the level of a campaign’s activity. They include the use of vaccines, anti-parasitic drugs, medicines and diagnostics, with state support ideally being dependent on whether the benefits derived from medicines can be captured by the individual (public vs private goods as explained in Wolf, 2013, and Hennessey, 2013). Questions concerning the state’s role usually hinge upon whether a market failure has arisen.

If economics is used as described above, cost estimates for animal health interventions should guide policy on allocating public investments, and can be used for financial and social cost-benefit analyses of proposed policy changes.

Benefit streams for future investments are predictive, not definitive. For animal health decisions, they are based on epidemiological and market models. Market models are dependent on epidemiological models, and each contain levels of uncertainty. Explanations of models used to look at market impacts and the beneficiaries of proposed changes can be found in Upton (2009), Rich, et al. (2005) and Paarlberg (2013).

Evaluating a change

Rushton (2009) gives an overview of the different methods available to assess change and differentiates these methods from individual or farm level assessment tools and from tools for wider societal issues. Upton (2009) provides an overview of the methods available to assess impacts on prices and markets. Rich, et al. (2005) also provide a summary of the main economic methods and models used in assessing livestock diseases, downplaying the central role that cost-benefit analysis has played in previous works. (Animal health has traditionally used cost-benefit analysis as the method for assessing change.) Gittinger (1980) provides an excellent explanation of cost-benefit analysis and gives a clear explanation of how to incorporate cost-benefit analyses into livestock population models. The discipline of human health has much more experience and willingness to use cost-effectiveness analysis (Drummond, et al., 2005). Neither area of research has seen a need to develop ranges of outcomes, although Carpenter (2013) explains how this can be represented.
Presenting levels of uncertainty and strategy options should be a critical aspect of decision making. However, this can create difficulties in relaying information back to a policy maker, and many often resort to simple measures of project worth such as benefit-cost ratios or net present values for single strategies. Reducing the complexity down to simple ratios for single interventions can ease communication, but such analysis cannot be described as economics because it does not search for the best resource allocation across society.

**Which discount rate?**

A discount rate measures the rate at which one is willing to trade present for future consumption. It remains one of the most critical inputs in cost-benefit analysis. For public projects, two different measures (Lopez, 2008) can be used: Social Opportunity Cost of capital (SOC) and Social Time Preference (STP).

SOC indicates the need to measure investments in purely economic terms of the returns of capital across the economy, whereas STP implies the need to look at longer and less quantifiable aspects of investments. Animal health decision making creates an interesting dilemma between a productive industry and the well-being of society. The choice of discount rate is dependent on the type of diseases. Diseases with a public health impact, such as the zoonoses, should use a lower discount rate (STP), whereas diseases controlled in ways that are beneficial to commercially run companies while improving economic efficiencies should use a higher rate (SOC).

**Economic logic for an intervention: Is it enough?**

An investment is deemed worthwhile if avoidable losses generated from a disease management process are greater than costs of a change in disease status. This is normally measured using the metrics from a cost-benefit analysis, which simply measure economic profitability. These metrics give no indication of financial feasibility, and only a limited assessment of social acceptability and political palatability.

**Are the tools appropriate?**

Decision making using cost-benefit and cost-effectiveness analysis would appear to have limitations. The mixing of fixed and variable costs in the analysis may not allow for an examination of where activities are adding value to the overall animal health system. A complete ground zero cost-benefit analysis does not help in this regard. Lessons could be learned from other areas, such as farm management or business. A suggestion for further exploration would be to separate the fixed costs of the system — including infrastructure, salaries and maintenance — and identify all the activities that are part of the system. Each discrete activity would be associated with the specific resources it uses and its variability with activity levels. These would be akin to the variable costs identified in a gross margin analysis. The benefit streams could be estimated in terms of the disease reduction achieved where a disease is endemic. If a disease, health or welfare problem has been eradicated, benefit streams could be estimated in terms of the re-entry costs of that problem along with an estimation of the likelihood of re-entry. The suggestions from Paarlberg (2013) and the work presented by Carpenter (2013) would contribute to such work, as they use complex modelling approaches to examine the impact of disease.

These suggestions are based on the theoretical frameworks proposed by McInerney (1996) and Tisdell (2009), which underscore the need to examine the variable application of resources to animal health problems. These frameworks could also be used to develop relationships between resource use and outcome, or to examine the switch between animal health activities under a constrained budget. The examination of resource allocations across animal health activities could be placed in a linear programming process with very narrow
objectives of either cost minimisation or maximisation (if benefit streams are available) within desired constraints. For countries within the European Union, some of these constraints would be legal requirements; this approach would be useful in examining the change in outcome with the relaxation of legal constraints.

Suggestions for the future

Impact assessment frameworks are needed to identify bottlenecks in animal health and welfare management. In addition it is important that such impact assessments collect and document the public and private expenditure (see Gilbert and Rushton, 2013) on animal health and disease management in order to generate cost profiles. Many governments currently focus their work on public expenditure which is a partial and limited picture of expenditure across a society. In order to achieve a more complete picture the impact assessment frameworks need to direct national and international data collection efforts.

There must be clear information on the capacity of the private sector to manage fixed costs, and this is particularly relevant in situations where livestock sectors are becoming integrated with a small number of large companies. Economics needs to be incorporated in epidemiological models, as well as in the monitoring and evaluation of animal health projects and programs. The state’s role must be better defined with regard to coordination, legislation and investment in research and information provision. One must also understand that cost-benefit analysis only provides an estimate of economic profitability. Overall, good policy dialogue needs to build on data from different areas of the economy, as well as analysis that incorporates biological, technical and economic disciplines. Figure 7 presents a summary of this approach.

Figure 7. Elements required to build a sound economic assessment of animal health and welfare problems

Policy dialogue
Sustainability, justification, cost-benefit analysis

Costs and cost-effectiveness
Disease impact

Disease prevention and control strategies

Disease
The livestock sector, companion animals and wildlife

Wildlife
Production systems and population
Value chain analyses
Livelihoods
Markets
Conclusion

Livestock health is important to societies across the world. Economic analysis of animal health is complex and disease-dependent. This complexity only increases at a policy level and requires a systems approach with interdisciplinary working. Such analysis must account for the roles that animals play in society and the prices of resources they compete for. This implies that a realistic assessment of costs and benefits from animal health policy making will be complex. The communication of results should focus on what decisions need to be made and why, using economic principles to focus on resource allocation. Wider societal issues such as social acceptability and political palatability should also be considered and included. Once programs are established, they must be regularly reviewed with the same rigour in order to avoid institutionalisation.

References


Gilbert, W.; Rushton, J. (accepted) Estimating farm level investment in animal health and welfare in England. Veterinary Record


Knight Jones, T. and Rushton, J. (accepted), “The economic impacts of foot and mouth disease – What are they, how big are they and where do they occur?”, *Preventive Veterinary Medicine*.


THE ECONOMICS OF FMD OUTBREAKS IN THE UNITED STATES:
TRADE IMPACTS, DURATION OF OUTBREAKS, AND EMERGENCY VACCINATION

Philip L. Paarlberg*
Purdue University, United States

Methods for analysing a hypothetical Foot and Mouth Disease (FMD) outbreak in the United States have improved greatly over cost-benefit methods. The estimated magnitudes vary greatly depending on assumptions about the epidemiological input, export loss and recovery, and consumer response. Greater consensus on those assumptions would narrow the range of estimates. Current research uses improved measures of economic welfare and has enhanced understanding of trade-offs in economic welfare that could affect compensation rules. Analyses have shown economic welfare gains from early detection but not from vaccination. Further research is needed to improve consideration of movement restrictions and animal welfare concerns.

* The author wishes to thank Amy Hagerman, Ann Hillberg Seitzinger, and Dustin Pendell for reading an earlier draft and providing useful comments. Remaining errors are the responsibility of the author.
Performing an economic analysis of an FMD event in the United States is not dissimilar to forecasting major weather events, except that there has been no occurrence since 1929. Consequently, there is no observed experience to use as a benchmark. It is scenario development that drives numerical results, and the estimated economic impacts range widely depending on scenario assumptions. A risk assessment for the future National Bio- and Agro-Defense Facility (NBAF) undertaken at the behest of the Department of Homeland Security (DHS, 2012) reports lost economic welfare of between USD 16 billion and USD 140 billion from FMD escaping containment at the laboratory. In fact, the upper end of that range was criticised for being too low (National Research Council, 2012).

In this paper, we consider the literature from the perspective of an economist doing an analysis of a hypothetical FMD outbreak in the United States. What economic frameworks are available? What decisions are needed to construct an FMD outbreak scenario? What decisions have economists made in earlier analyses? What lessons were learned in their work?

Analytical framework

There are four analytical frameworks that have been used and one potential framework that, to date has not been used to analyse a hypothetical FMD event in the United States. Models simulate the interaction of large numbers of commodity producers and consumers to determine market prices for commodities. These models are used either for comparative static analyses that compare the outcomes for a single time period (usually one year), or for comparative dynamic analyses that report differences across multiple time periods. Pritchett, Thilmany, and Johnson (2005) provide a comprehensive discussion of frameworks used for economic analysis. Economic models are useful in describing changes in prices, quantities and economic welfare for an outbreak given an industry structure. They do not incorporate structural change such as any rationalization of an industry (firm exit, downsizing) arising from a disease event.

Cost-benefit analysis is a well-known static technique commonly applied in project evaluation. This technique is best used on a limited scale, since it is frequently applied assuming no changes in market prices or costs. Including changes in market prices and costs in the analysis requires a market model that allows for more complete analysis. Bates, Carpenter, and Thurmond (2003) apply this technique to evaluating supplemental vaccination and slaughter for an FMD event in California. They conclude by recognising the limitations of their cost-benefit analysis when they note that market level factors such as trade disruption could alter their observations on the effectiveness of supplemental control measures.

Another method is input-output analysis, or I/O. Ekboir (1999) uses an I/O model to determine the impacts of an FMD outbreak in the California dairy industry. Lee, et al. (2012) use a multi-state I/O model to examine a terrorist attack scenario. Pendell, et al. (2007) include an I/O component for Kansas to complement their market model. The DHS (2012) analysis also includes I/O modelling. This modelling technique has been extensively used in regional planning and regional development. Its advantage is in showing the direct and indirect linkages among economic activities within a region, as well as the flow of expenditures and revenue through a region’s economy. Disadvantages include the absence of price effects and a tendency to confuse changes in expenditures and revenues with changes in measures of economic welfare. For example, expenditure can be higher because a consumer is buying more of a commodity, or because he or she is paying a higher price. Expanding the quantity consumed is a gain in economic welfare for the consumer, while paying a higher price would constitute a loss. Producer revenue can be greater but if costs are rising faster, the producer is not better off.

Another approach is known as partial budgeting (Elbakidze, 2009). This approach involves calculating lost export revenue, the value of animals depopulated and public sector
costs incurred from a disease event. The advantages of this method are its simplicity and the fact that the data required may be more easily obtained compared to other techniques. There are some disadvantages, including the exclusion of both changes in prices and the response of producers and consumers to price changes. Theoretically, correct changes in economic welfare are not measured.

Partial equilibrium models — sometimes called equilibrium displacement models — have been a mainstay of agricultural economic analysis since the middle 1970s. Most analyses of potential FMD outbreaks in the United States use this framework. Some analyses include international trade while others do not. The earliest example can be found in the analysis published in a bulletin by McCauley, et al. (1979). The most recent example can be found in an article by Hagerman, et al. (2012). These models come in different forms. The model appearing in McCauley, et al. is an econometric simulation model. Paarlberg, et al. (2008) apply a system of dynamic differential equations to a baseline in order to analyse an FMD outbreak. Pendell, et al. (2007) rely on a more traditional formulation using explicit demand and supply functions in their analysis of an FMD outbreak in Kansas, while the model in Hagerman, et al. (2012) comes from the tradition of mathematical programming.

The popularity of this framework reflects its flexibility. It can capture upstream and downstream activities from feeds, to animals, to meats. Models can be annual or quarterly, static or dynamic. The results focus on adjustments in prices, and how quantities respond to price movements. As Pendell, et al. (2007) show, national and regional partial equilibrium modelling can be blended. Economic welfare measures such as producer surplus and consumer surplus can be determined.

The major disadvantage of partial equilibrium frameworks is that at some point, they truncate linkages to other sectors and do not determine national income or expenditure endogenously. As shown in the 2001 FMD outbreak in Britain, impacts on non-agricultural sectors can be large. In this case, British authorities decided to restrict access to the countryside in an effort to limit spread. As a result, the tourist industry in Britain was severely hurt, with an estimated loss of between GBP 2.7 billion and GBP 3.2 billion — roughly equal to the GBP 3.1 billion estimated for impacts on agriculture, the food industry, and the public sector (Thompson, et al., 2002). While rural tourism plays a significantly different role in the United Kingdom than it does in the United States, the British experience has affected thinking about how a hypothetical FMD outbreak might impact the United States. Analysis for the Department of Homeland Security did incorporate adverse effects on tourism (DHS, 2012). Since that analysis focused on an FMD outbreak in the Central Plains, the estimated spill over effects were not large, though they could be larger in other outbreak locations.

The pattern of impacts estimated for the British 2001 outbreak also raised discussions of quarantine and surveillance zone implementation. Agricultural interests traditionally operated as if such zones would amount to “lock-downs” with full isolation. Given potential spill over effects, many have reconsidered options that would restrict agriculturally-related movement while allowing non-agricultural economic activity with the outside world to continue.

Computable general equilibrium (CGE) models are designed to capture inter-sector linkages. Using such models allows for the quantification of spill over effects to other sectors, including input markets like the labour market. In the case of the Taiwanese FMD outbreak, Lin (1998) found small positive economic welfare impacts on canned and frozen food industries. To date, an FMD event in the United States has not been analysed using a CGE framework. Major obstacles to such analysis include the overly aggregated treatment of livestock in CGE models, as well as a tendency for such models to be annual and static.
Epidemiological input

Epidemiological input is a critical component of any FMD outbreak scenario. That is, how long does the outbreak last, what species are depopulated and what is the size of this depopulation? At present, the interface between epidemiology and economics is problematic. In the Apollo 13 explosion, the coordinates of the guidance computers in the command module and the lunar landing craft were incompatible. Transferring the coordinates from the command module to the lunar lander meant recalculating them by hand. A similar situation arises when epidemiological inputs are used in economic analysis.

Epidemiological models do not usually generate the information needed by an economic model because they are used for different things. Therefore, economists must convert the information generated by epidemiological modelling into a form that makes sense for economic modelling. Typical outputs from epidemiological models include outbreak duration and daily culling results by herd, number and species. Depending on the model input, there may be information on depopulation by production type, such as cow and calf operations or feedlots. For economic analysis, it is important to know the numbers of animals depopulated by species, whether they are breeding or market animals, and, in the case of market animals, their weight and age, since these factors drive price trajectory over time. The price — and therefore economic welfare — effects of depopulating breeding animals differ greatly from those that arise from depopulating market-ready animals.

Epidemiological models could generate the kind of output used in an economic analysis, but at an enormous cost. Imagine a daily-running epidemiological model that keeps track of the disease state and weight of each animal in its database. The model would also have to incorporate weight gain by each animal over time. Epidemiological models tend to be daily while most economic data are reported quarterly, at best, with some data reported monthly.

Although there has been consideration given to merging epidemiological and economic modelling, keeping such models separate seems best, considering the present state of affairs. A forced marriage would likely doom both. Improved communication and data would be beneficial. Epidemiological modellers would benefit from a stronger understanding of the results that economic modelling demands, while economists would gain from an improved knowledge of what epidemiological results mean. Improved data about livestock populations and sales would allow the economist to improve the quality of epidemiological input into economic models.

Published analyses of hypothetical FMD outbreaks in the United States contain a wide range of assumed duration, magnitudes and export reductions. This makes comparisons difficult. In analysis by Paarlberg, et al. (2008), the outbreak is assumed to start in a small-scale swine operation through waste feeding. At an average of 56 days, the outbreak is short-lived, with less than 100,000 head depopulated. On the other extreme, Zhao, Wahl and Marsh (2006) assume a one-year outbreak, with 9% to 77% of the US beef cattle herd depopulated. Depopulation in the DHS (2012) risk assessment varies from 100 beef cattle for the lowest fifth percentile for a medium tornado, to over 27 million head across multiple species at the highest percentiles for fomite or aerosol releases. Most other analyses using epidemiological models have outbreak durations of one quarter or less, with livestock depopulation ranging from a few head to 1 or 2 million.

These analyses assume each outbreak is equally likely. That is, the chance of a short outbreak depopulating a few head is just as likely as an outbreak lasting over one year and depopulating millions. One question to ask is whether attaching probabilities to outbreak duration and magnitude would help reduce the range of magnitudes. Epidemiological model results tend to generate mean and median results with short outbreaks and small depopulation...
relative to the national US herd. Could recasting the economic results in an expected welfare context that incorporates event probability narrow the range of estimated value?

**Exports**

Another critical decision when performing an analysis of FMD involves the extent and duration in US export loss and recovery. Paarlberg et al. (2008) report relatively small losses in returns to capital and management of between USD 2.8 billion and USD 4.1 billion over 16 quarters, partly because they assume full export recovery upon regaining FMD-free status. Hayes, et al. (2011) assume complete losses of US beef, pork and livestock exports for ten years, which results in a total loss of USD 128.23 billion. With annual US beef and pork exports at over USD 10 billion, different assumptions about trade make it difficult to compare final estimates.

If the US had experienced an FMD event, or if the observed trade effects for other nations were more consistent, assumptions about export loss and recovery might be more similar. Johnson, et al. (2012) examine the time to market recovery for several diseases, including FMD. They report considerable differences. Export recovery for the United Kingdom was slow after its 2001 outbreak and lasted well after that nation regained its FMD-free status under OIE rules. Pork exports by Taiwan never recovered because the FMD event was used as a means to restructure the pork industry (Huang, 2002). The experiences of Brazil, Argentina and the Netherlands in 2001 were very different from those of Britain and Taiwan, with shorter trade disruptions and faster export recovery (Johnson, et al., 2012).

**US consumer response**

Assumptions about the reaction of US consumers to an FMD event are also a critical driver of any estimated impacts. Paarlberg, Lee and Hillberg Seitzinger (2002) consider alternative demand reductions by US consumers. Increasing the assumed decline in US consumer demand from 10% to 20% increases the annual loss in US producer revenue from USD 14 billion to USD 21 billion. If there is no adverse US consumer reaction, the estimated annual loss in producer revenue falls to just under USD 7 billion. The risk assessment done for DHS assumes demand reduction during the outbreak of between 5% and 10%, (depending on the severity of the event) and a post-event recovery occurring after two quarters. Zhao, Wahl and Marsh (2006) assume a 5% demand reduction for three years. Most other analyses assume no US demand reduction.

**Results and lessons learned**

With such diverse scenarios, it is difficult to arrive at a range of estimates for economic impacts of hypothetical FMD outbreaks in the United States. Nevertheless, briefly recounting research results can yield important lessons about economic analysis of FMD.

Economic studies of hypothetical FMD outbreaks in the United States trace back to the economic analysis published in the McCauley, et al. bulletin from 1979. That analysis blended a multi-year disease event with an annual econometric simulation model to evaluate the cost of FMD control, mitigation and prevention. The work was a blueprint for how to blend epidemiological and economic modelling. It concluded that import bans were the least costly means of dealing with FMD for the United States.

From the perspective of a trade economist, one problem with the McCauley et al. (1979) analysis is that it does not properly account for the economic welfare effects of the ban on imports from nations with FMD. The FMD events in their analysis occur occasionally — and with many years in between — so the benefits of preventing FMD using import bans are intermittent. But import bans result in consistently higher prices to consumers year after year,
imposing a continuous consumer welfare loss not recognised in the analysis. In order to support their conclusion that import bans are the least costly instrument, they should have included the forgone consumer welfare and any benefits associated with lower prices during an outbreak, when exports fall.

Paarlberg and Lee (1998) investigate whether it’s possible to design a trade barrier that incorporates the gains from trade while recognising the risk of FMD associated with imports. A standard result of traditional trade theory is that a trading nation that can affect international prices can improve its terms-of-trade using a welfare-maximising tariff set as the reciprocal of the excess supply elasticity. Paarlberg and Lee (1998) find that when imports represent a disease risk the magnitude of the trade intervention is enhanced. New terms are added to the traditional formula to capture the impact of lost output and the probability of an FMD outbreak triggered by imports. In effect, the added duty generates revenue that is used to compensate for economic welfare losses arising from an outbreak.

To implement a risk-based trade intervention, the economic welfare impacts from an FMD event must be known. There are several analyses that try to determine these elusive impacts. Using a disease spread model for dairy production in central California, Ekboir (1999) generates a cost impact of USD 8.5 billion to USD 13.5 billion, of which USD 6 billion represents lost US exports. Lee, et al. (2012) extends Ekboir’s analysis in a scenario they characterize as a hypothetical bioterrorist attack. They use Ekboir’s outbreak in the California dairy industry, but calculate the loss in economic activity for all states to obtain a range of USD 23 billion to USD 34 billion. Paarlberg, Lee and Hillberg Seitzinger (2002) attempt to estimate the economic impacts if a UK-magnitude FMD event occurred in the US. Their estimate is that with a 10% consumer demand reduction, US product, livestock and crop producers would lose USD 14 billion in revenue per year. Hayes, et al. (2011) update the Paarlberg, et al. (2002) analysis by adding a dynamic aspect and recognising changes in the role of exports for US meats, especially pork. Their analysis generates revenue losses for just the pork and beef industries at USD 12.8 billion per year over a ten-year period.

One problem with early analyses is that revenue changes are not equal to changes in economic welfare for producers. Revenue changes do not reflect changes in producer cost structure along the supply chain that are occurring at the same time. This difference is nicely illustrated in the analysis by Hayes, et al. (2011). For the pork industry, the loss in revenue is USD 5.7 billion per year, while returns over variable costs are USD 1.8 billion per year lower. The same is true for consumer expenditure; it is not a measure of changes in the economic welfare of consumers. Paarlberg, Lee and Hillberg Seitzinger (2003) investigate how to measure changes in economic welfare for producers and for consumers in a disease situation using FMD. They argue that changes in economic welfare should be measured using changes in producer and consumer surplus — a traditional approach.

Those measures should also be decomposed. Changes in producer welfare should be differentiated according to whether or not producers have animals that can be marketed. This is important for producer compensation. Under US law, producers with animals depopulated by the US government as part of a stamping-out program are entitled to compensation. The US Department of Agriculture does not have the authority to compensate producers receiving a lower price for animals because of demand reductions. Producers were not compensated when export demand collapsed after the discovery of a cow with Bovine Spongiform Encephalopathy. Consumers also need to be differentiated between those who continue to consume beef and pork — and so enjoy an economic welfare gain from the lower price — and those who forgo consumption and experience a welfare loss. The impact on non-agricultural industries also plays a role in compensation. In the UK outbreak, livestock producers received full compensation for animals, so the cost was borne by the public. Equally large losses were incurred by the tourism sector, but those losses were not compensated (Poe, 2002).
Economic analyses have investigated issues associated with introduction, prevention, control, mitigation and surveillance of FMD. A dominant theme in such analyses is the trade-off in economic consequences, especially among various slaughter protocols, detection lags and vaccination programs. Such trade-offs are linked to the rules or guidelines outlined in Chapter 8.5 of the Terrestrial Animal Health Code of the OIE, and how trading nations implement their responses. Article 8.5.8 specifies actions needed to recover FMD-free status in the event of an outbreak. For a country that is initially FMD-free and does not vaccinate, FMD-free status recovery time depends on the control actions taken during an outbreak. If a stamping-out policy and serological surveillance without emergency vaccination are put into place, FMD-free status is regained three months after the last case. If emergency vaccination is undertaken in conjunction with a stamping-out policy and serological surveillance, FMD-free status is regained three months after the last vaccinated animal is slaughtered. When vaccinated animals are not slaughtered, the time period for recovery of FMD-free status moves to six months, and is contingent upon the results of a serological survey. If a stamping-out policy is not practised, then the time period for recovery extends to 12 months and disease-free status must be re-established as done when disease free status is initially recognised. The estimated economic results depend on the magnitude of depopulation, the outbreak duration, time to regain FMD-free status and export recovery time. The manner in which these factors are embedded in the analyses drives differences in results.

Schoenbaum and Disney (2003) consider alternative slaughter and vaccination strategies. Their net welfare change — producer surplus, consumer surplus and government cost — ranges from USD 300 000 — USD 2.86 billion. Ring slaughter is more costly than other slaughter strategies. Ring vaccination costs more than pure stamping-out unless the outbreak spreads quickly and the vaccinated animals are slaughtered for meat.

Bates, Carpenter and Thurmond (2003) compare the direct costs of indemnification, recovery and vaccination with benefits from pre-emptive slaughter and ring vaccination in California. They find that the cost-benefit ratio favours ring vaccination over supplemental slaughter because of the high indemnification cost for dairy cattle. If slaughter of vaccinated animals occurs in order to regain export status, they speculate that the cost-saving found for supplemental vaccination would be negated.

Similar results are found for other nations. Garner and Lack (1995) examine stamping-out, dangerous contact slaughter and ring vaccination for a hypothetical outbreak in Australia. They find benefits associated with stamping-out and pre-emptive slaughter. Ring vaccination could reduce the size and length of outbreaks, but remains economically inferior to stamping-out, given the assumptions in their analysis. Berentsen, et al. (1992) examines vaccination strategies for the Netherlands and find that in the most likely situation annual vaccination is not practised. But if pessimistic situations are assumed, annual vaccination of the cattle population results in lower annual costs. Rich and Winter-Nelson (2007) compare the discounted short- and long-run national revenues from stamping-out and vaccination for Southern Cone nations of South America. In their base case long-run results, stamping-out is preferred to vaccination when all nations have a uniform response. A mixed strategy, whereby a country vaccinates while other nations adopt stamping-out policies, dominates a uniform stamping-out response. This is the strategy that Paraguay adopted. However, the difference is small, because the net revenue from the mixed strategy is USD 21 369 million, while the net revenue for pure stamping-out is USD 21 367 million. The short-run rankings from Rich and Winter-Nelson (2007) are different, with uniform preventative vaccination dominating and the uniform stamping-out response having the least benefit. They note that the different ranking reflects the dynamics of cattle production, the high costs of culling and export revenue losses in the outbreak year.

The economic consequences of three alternative destruction strategies are estimated by Paarlberg, et al. (2008). These results differ from Schoenbaum and Disney because of
different epidemiological inputs. The epidemiological model used by Paarlberg, et al. (2008) assumes an outbreak caused by waste feeding on a small scale swine farm. Those model results show that compared to ring destruction, slaughter only of animals having direct contact with other animals and animals where contact occurs indirectly through feed tracks, etc., result in outbreaks of longer duration. The livestock depopulation is small relative to the national herd, and the number of head destroyed does not significantly differ among destruction options. Thus, ring slaughter results in shorter export disruption and a smaller loss of economic welfare.

Zhao, Wahl and Marsh (2006) compare alternative tracing and surveillance strategies by varying the depopulation rate for beef cattle. The outbreak is introduced during the 20th year, and the model is solved through year 2050. In this context, depopulation rate can be interpreted as the percentage of latent infectious herds depopulated. As a result, high depopulation rates result in a smaller share of the beef herd depopulated and smaller losses in economic welfare. A depopulation rate of 90% results in a 9% loss of animals and an economic loss of USD 18.54 billion. When the depopulation rate falls to 30%, 77% of the beef herd is lost and the economic welfare cost is USD 266 billion.

They also examine vaccination. In their results, the base scenario without vaccination is associated with the smallest loss in total economic welfare. Zhao, Wahl and Marsh examine the importance of biological lags in replacing breeding stock by modifying their model to immediately replace any breeding stock losses. Ignoring the biological dynamics causes a USD 14 billion underestimation in the economic welfare loss, altering the pattern of gains and losses for producers and consumers.

Pendell, et al. (2007) focuses their analysis on the economic consequences of regional location and production type of the index case. The index case appears in southwest Kansas and three alternative production types are analysed. The index cases analysed occur in a cow/calf operation, a single feedlot and five feedlots. Mean duration ranges from 29 days for the cow/calf introduction to 89 days when the event starts in multiple feedlots. Depopulation varies from 121 000 head with the cow/calf start to over 1.7 million head when the outbreak appears in multiple feedlots. The direct changes in producer surplus reflect the differences in duration and depopulation. Added features of this analysis include the regional effects on Kansas. The strongest effects occur in the direct location of the index case — southwest Kansas — with declines in economic activity of between USD 24 million and USD 686 million. For the rest of Kansas, the losses vary from USD 12 million to USD 260 million.

There are dimensions of movement restrictions that have not been analysed for a US outbreak. When movement restrictions are considered, it is in the context of how depopulation of infected herds and outbreak duration affect livestock and livestock product sectors. This does not take into account the effect movement restrictions might have on other sectors. The regions to which such restrictions apply are usually smaller than the regional disaggregation of regional input-output analysis, and application of this technique for small regions remains difficult, as the regional multipliers may not be appropriate. Applied general equilibrium modelling captures multi-sector linkages, but normally at a national level. To date, CGE modelling has not been applied to a US FMD outbreak scenario. The linkages between movement restrictions and welfare slaughter have not been examined.

In the 2001 UK outbreak, healthy animals that could not be moved because of movement restrictions were culled (Thompson, et al., 2002). Would the public tolerate widespread slaughter of healthy animals because of movement restrictions for a disease that does not infect humans, is not necessarily fatal to animals, and for which vaccines exist? Production practices adopted for the convenience of producers — tail docking, gestation crates, use of antibiotic drugs — are coming under increased criticism. Could welfare slaughter generate the same response from the public?
Elbakidze, et al. (2009) use a partial budget approach to compare early detection, enhanced vaccine availability and enhanced surveillance with index cases appearing in various production types in Texas. They argue that for the strategies analysed, the costs — government costs and lost animal value — are lowest for early detection. As with other analyses, they find that vaccination strategies are not effective at reducing outbreak costs, partly due to their assumption that vaccinated animals are worth half the value of non-vaccinated animals.

Hagerman, et al. (2012) are concerned with the role of emergency vaccination and diagnostic delays in a California outbreak. They assume a short, single-event outbreak having durations ranging from just over one month to nearly three months. Depopulation varies from under 10,000 head to just over 173,000. The duration of the assumed export ban is independent of the outbreak duration and the vaccination strategy. Estimated mean annual agricultural economic welfare losses range from USD 2.7 billion to USD 21.9 billion. The additional costs from destroying vaccinated livestock and implementing the vaccination program more than outweigh the gains from reduced outbreak duration. Benefits also arise from lower economic welfare losses under a seven-day diagnostic delay compared to a 14-day delay. Longer detection delays would translate into greater economic losses, and could therefore alter the conclusion regarding vaccination.

A paper by Carpenter, et al. (2011) varies the detection delay for a simulated California outbreak using a model that includes market-level and trade effects. They find very large added economic losses as the detection delay lengthens. As the detection delay increases from seven days to 22 days, the median national economic welfare loss increases from USD 2.3 billion to USD 69.0 billion.

**Conclusion**

There are some broad conclusions to draw from this literature. One set refers to the methods of economic analysis. The ability to analyse the economic impacts of hypothetical FMD outbreaks in the United States has improved greatly over the past decade. Application of partial equilibrium models and analysis instead of cost-benefit methods enhances understanding of the economic impacts of FMD. Still, there remains a need to enhance understanding of spill over effects to other sectors. Input-output methods can help identify spill over effects, but more robust computable general equilibrium analysis would improve the measurement of the effects. At present, the treatment of livestock dynamics in such models poses a difficulty. Depopulation results from epidemiological modelling require additional computation before they are ready to be used as input in an economic analysis. Improved communication between epidemiologists and economists, and data allowing separation of animals by weight would be beneficial. For hypothetical FMD outbreaks in the United States, assumptions about the changes in export and domestic demand drive the magnitude of impacts. Differences in assumptions result in a wide range of differences in estimated economic impacts. A greater consensus on likely demand shifts could be helpful.

Another set of conclusions refers to the results obtained to this point. An FMD outbreak alters the distribution of economic welfare as market prices change, resulting in winners and losers. Understanding the trade-offs in changes in economic welfare among producers, consumers and taxpayers is important to control, mitigation, surveillance and compensation decisions. Current indemnification is focused on producers with depopulated animals. Lower prices as export markets are lost and/or any domestic demand reduction result in losses to producers who do not have infected animals and gains to consumers. In terms of response, early detection appears to reduce economic impacts from an FMD outbreak. So far, vaccination has not been shown to lower the economic losses from an FMD event, because any gains from disease control have not been sufficient to offset the export effects. But most
US analyses assume vaccinated animals are not marketed, warranting further consideration of vaccination of animals that are marketed domestically or used in lower-value meat products. The consequences associated with movement restrictions and enhanced movement restrictions have yet to be determined.

References


Ekboir, J.M. (1999), Potential Impact of Foot-and-Mouth Disease in California: The Role and Contribution of Animal Health Surveillance and Monitoring Services, Agricultural Issues Center, Division of Agriculture and Natural Resources, University of California, Davis, California.


Foot-and-mouth disease (FMD) is one of the most contagious diseases of cloven-hoofed animals, including cattle, deer, goats, pigs and sheep. It can spread rapidly through livestock or wildlife populations, and could be widespread in a population before clinical signs in infected animals have been detected, or before the disease has been diagnosed in a non-infected country. Although FMD-endemic countries can use epidemiologic data to more accurately predict the spatial and temporal distributions of the disease, the same is not true for FMD-free countries such as the United States. Using the US experience as a case study, we demonstrate how FMD-free countries can estimate the potential spread and impact of the disease, and discuss models used to predict the impact of vaccination-based strategies and early diagnosis.
Background of foot-and-mouth disease (FMD)

Foot-and-mouth disease (FMD), caused by the FMD virus (FMDV), is one of the most contagious diseases of cloven-hoofed animals, including cattle, deer, goats, pigs and sheep. It is endemic throughout much of Africa, Asia, the Middle East and South America. Currently, only 37% (66) of the 178 OIE member countries are FMD-free where vaccination is not practised (http://www.oie.int/?id=246, accessed 8 July 2013). Among the FMD-free regions is North America, which has not had a reported case of FMD in 60 years.

FMDV can spread rapidly through livestock or wildlife populations, and could be widespread in a population before clinical signs in infected animals have been detected, or before the disease has been diagnosed in a previously FMD-free (non-infected) country. If FMD were introduced in a previously FMD-free country, emergency control or eradication strategies would be put into place at the time of diagnosis. These strategies can include vaccination, slaughter of susceptible animals that are believed to be at a high risk of being exposed to FMDV, and movement restrictions. Once the disease is diagnosed in a country previously recognised as FMD-free, that country will likely lose access to export markets, which may not be regained for several months or years.

Disease spread and control in previously FMD-free countries

Although FMD-endemic countries can use epidemiologic data to more accurately predict the spatial and temporal distributions of the disease, the same is not true for countries that have been FMD-free for an extended period of time. This is well illustrated by the experience of the United Kingdom, which was free of FMD for more than 30 years prior to the devastating outbreak in 2001. Although FMD outbreaks occurred relatively frequently in the early 1960s, their magnitude was minor until 1967 (Table 1). In the 1967 outbreak, more than 2000 premises were infected with FMDV, resulting in the slaughter of approximately 443,000 animals from more than 2,000 premises over a period of approximately ten months.

Table 1. Impact of FMD in previously FMD-free countries

<table>
<thead>
<tr>
<th>Country and year</th>
<th>Infected premises</th>
<th>Animals slaughtered</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States 1924</td>
<td>948</td>
<td>131,000</td>
</tr>
<tr>
<td>United States 1929</td>
<td>5</td>
<td>3,600</td>
</tr>
<tr>
<td>United Kingdom 1967-8</td>
<td>2,339</td>
<td>443,000</td>
</tr>
<tr>
<td>Taiwan 1997</td>
<td>6,147</td>
<td>4 million</td>
</tr>
<tr>
<td>United Kingdom 2001</td>
<td>2,030</td>
<td>6.3 million</td>
</tr>
<tr>
<td>United Kingdom 2007</td>
<td>8</td>
<td>2,160</td>
</tr>
<tr>
<td>Japan 2010</td>
<td>1,250</td>
<td>289,000</td>
</tr>
<tr>
<td>Korea 2010/11</td>
<td>&gt;3,000</td>
<td>&gt;330,000</td>
</tr>
</tbody>
</table>

FMDV was reintroduced in the United Kingdom in 2001. Although the duration and number of infected premises in the 2001 outbreak were similar to those reported in the 1967 outbreak, the number of animals slaughtered due to FMD exceeded 6.5 million, many of which were slaughtered for welfare reasons (Haydon et al., 2004). FMD was once again diagnosed in the United Kingdom in 2007; however, the impact of this outbreak was substantially different from the 2001 outbreak, due to relatively early diagnoses and more rapid initiation of controls (including an animal movement ban). As a result, animals on only eight premises were infected and 2,160 animals were slaughtered in order to eradicate the disease (Anderson, 2008). These very disparate outcomes represent the variability that may occur in previously FMD-free countries. Alternative methods are therefore needed to make...
informed decisions when planning for the potential spread and control of FMD in FMD-free countries.

Vaccination of susceptible animals is one alternative method to control or eradicate FMD. Currently, one vaccination option is to slaughter vaccinated “at risk” animals during their normal productive life, which would reduce the duration of any export bans resulting from an FMD incursion. This strategy, however, can have dramatic results, as illustrated by the recent example in Japan in 2010, when more than 40% (125 000) of the nearly 300 000 slaughtered animals were killed because they were vaccinated (Nishiura and Omari, 2010).

The speed of response to an FMD epidemic is critical, not only for the country of origin but for its trading partners, as well. The European Union imposed a worldwide ban on all livestock, meat and animal product exports from the United Kingdom on 21 February. This came two days before the first case of FMD was confirmed, but two days after it was first detected in an abattoir — and potentially three weeks after the index case was infected in a pig farm. Approximately ten days after the index case and ten days before confirmation, approximately 4 000 sheep were sold at market, including FMD-infected sheep (Cumbria FMD Inquiry Report, 2002). These transactions involved 120 dealers and resulted in long-distance movements from northern to southern England (Gibbens et al., 2001).

The importance of rapid movement controls within an infected country underscores the importance of markets in disseminating FMD over long distances and short periods of time. It was reported that the majority of marketed infected-animals went through one market, which during the ten-day period prior to the movement ban at least 24 500 sheep were potentially exposed to FMDV. Subsequently, authorities began tracing more than 100 000 sheep movements by 5 March 2001, approximately two weeks after confirmation of the outbreak (Gibbens et al., 2001). As a result, it is believed that at least nine of the 12 major geographic areas with cases were infected due to the movement of infected animals prior to the implementation of national movement controls. Furthermore, eight of these areas were believed to be infected prior to the first case being diagnosed (Gibbens, et al., 2001).

FMD in the United States

North America is currently an FMD-free continent. There has not been a reported case of FMD in North America since 1953, and none in the United States since 1929. The most recent FMD outbreaks in the United States (1924 and 1929) occurred in California. As with the two recent FMD outbreaks in the United Kingdom, the extent of California’s outbreaks was highly variable (California Department of Food and Agriculture and United States Department of Agriculture, 2010). In the 1924 outbreak, 131 000 animals were slaughtered, including more than 22 000 wild deer in 948 herds (Table 1). The 1929 outbreak, by contrast, was limited to fewer than 4 000 animals slaughtered from five herds. It was also much smaller due in part to earlier detection (three days versus 63 days before diagnosis) and more rapid response (ten days versus 90 days before emergency declaration).

Livestock production in the United States has changed dramatically since the 1920s. Although there are fewer livestock premises today, they are more intensively managed and have herd sizes several times larger than those of the 20th century. The frequency and distance of animal movements have similarly increased, amplifying the impact FMD could have if it entered the United States. Predicting the potential spread and impact of alternative controls in the United States is confounded by the fact that the country has not experienced a case of FMD for approximately 85 years. The US livestock industry is dramatically changing as well, which would greatly affect the disease’s transmission dynamics.
Probability of an introduction of FMD into the United States

Before estimating the potential impact of FMD if introduced into an FMD-free country, one must first ascertain the likelihood of the disease entering the country and becoming established in wildlife or livestock populations. FMDV may enter a country through infected animals, animal products, or fomites (e.g. humans or materials arriving in an FMD-free country after having been contaminated in an FMDV-infected country). The introduction of FMDV through an infected live animal could occur either through legal importation of an animal or illegal movements, such as smuggling or unauthorised border crossing. While the probability of smuggling an FMDV-susceptible animal (e.g. cattle, sheep, goat or pig) into the US is small, given the large size of the animal and the fact that the United States does not share a boundary with an FMD-infected country, the most likely route of introduction would be legal importation. The probability of such an introduction was recently reported by Miller et al. (2012). They estimated the annual probability of FMDV introduction into the United States via legal importation of livestock from the eight countries exporting live FMDV-susceptible animals was 0.415% — on average, once every 241 years. Not surprisingly, the major risks came from the two countries that annually export the most live animals to the United States: Canada (9 million cattle and pigs) and Mexico (1 million cattle). As low as this probability is, it may even be an overestimate, because the majority of livestock coming from Canada and Mexico will go directly to slaughter, thereby avoiding direct contact with susceptible livestock populations in the United States.

Planning for the control and eradication of FMD if introduced into the United States

Although the United States has not had a reported case of FMD since 1929, it remains important to plan ahead to minimise the consequences of a reappearance. Although FMD can be eradicated through culling FMD-infected herds, alternative control strategies — including vaccination — may be of value. Under this strategy, the USDA would have to decide how many, and which livestock types, to vaccinate (e.g. dairy, beef or sheep). They would also have to determine the location and extent of a vaccination program. For example, while vaccination in a dairy intensive region such as the central valley of California may be economically viable, the same may not be true for a rural area in the southeast US. The extent of a vaccination program may be restricted to within a given distance from an infected premises — e.g. within a radius of one, three, five, or ten kilometres.

Epidemic modelling to simulate spread and control of FMD

Given the lack of recent exotic disease experience, we must find alternatives to analysing epidemiological data, including epidemic simulation modelling. Epidemic modelling has been used for more than 100 years to better understand the epidemiology of a disease, including its potential spread and the value of alternative controls. The technique has become increasingly popular over the past 15 years, especially when it comes to planning for potential FMD incursions. Epidemic modelling can be performed either prior to, during, or after the outbreak has occurred. It was used during the 2001 FMD outbreak in the United Kingdom, but not without controversy (Kitching et al., 2006). This was partly because some of the models used had not been verified or validated at the time, and the demographic and epidemic data they were based on were not always accurate. By contrast, epidemic models applied either before or after an outbreak may be populated with data that have been subjected to greater scrutiny, typically leading to more accurate inputs and results.
FMD modelling in the United States

Several epidemic simulation models have been used to predict the spread and control of FMD if it were to enter the United States. The four most commonly reported are the AusSpread model (Garner and Lack, 1995; Garner and Beckett, 2005; Becket and Garner, 2007), the Davis Animal Disease Simulation (DADS) model (Bates et al., 2003a,b; Carpenter et al., 2007; Carpenter et al., 2011), Interspread Plus (Stevenson et al., 2013) and the North American Animal Disease Simulation Model (NAADSM) (Schoenbaum and Disney, 2003; Harvey et al., 2007). These models have been used to simulate different types of introduction (e.g. accidental or intentional) across different locations in the United States, and to evaluate the impact if the index case were located in a variety of herd types or other venues (e.g. a sales yard, livestock fair, or wildlife population). They have also been used to evaluate alternative control measures including national or state-wide movement bans, culling of potentially exposed herds, and vaccination of susceptible livestock herds. Alternative approaches have been developed to better interpret and present the results generated from various spread and control scenarios, in order to help decision and policy makers better understand the information presented to them.

The potential benefit of epidemic models can be illustrated by examples. The DADS model (Bates et al., 2003b) was used to simulate an FMD epidemic occurring in a three-county area in California. They reported that if FMDV were introduced into a randomly selected herd type, approximately 50 livestock premises would be infected on average (Figure 1). They also reported that the extent of the epidemic was highly dependent on the type of herd that contained the initial (index) case; epidemics would be smaller if the index case were located in either a beef or backyard herd, but larger than average if the index case were located in a dairy or swine herd. Epidemics would be especially large if the index case occurred in a sales yard, where the expected median is approximately five to ten times larger than in non-sales yard index cases.

**Figure 1. Simulated number of infected herds**

*Note:* Assuming FMDV were introduced into a variety of livestock premises types in a three-county area in California.


In a recent study, Carpenter et al. (2011) simulated a series of outbreak scenarios to examine the importance of diagnostic delay and vaccination if FMD were introduced into a
large (>2 000 cow) dairy herd in California (Figure 2). As expected, they found that the benefit from an effective surveillance system — one capable of detecting the index case seven days after the first infection — would substantially reduce the simulated impact of FMD. Under a seven-day detection delay, the maximum number of livestock culled was estimated to be approximately 50 000 animals; with a 14-day detection delay, that estimate increases to 150 000 animals. Similarly, the median number of slaughtered animals was expected to be less than 10 000 with a seven-day diagnostic delay, compared with between 60 000 and 70 000 after a 14-day delay. Although vaccination (to die) appeared to provide no benefit with respect to the number of animals culled, a seven-day diagnostic delay could bring benefits — especially under a 20-kilometer radius ring vaccination strategy.

Figure 2. Simulated cumulative probabilities of number of livestock culled (slaughtered)*

* If FMD were introduced into a large dairy in California, assuming alternative vaccination alternatives.

The benefits of early diagnosis and vaccination were also examined with simulations of an FMD outbreak in Texas (Ward et al., 2009) and the AusSpread-High Plains model (Elbakidze et al., 2009). Similar benefits from early detection were reported if FMD were diagnosed in seven rather than 14 days (Figure 3). A five-kilometre ring vaccination strategy was also found to be beneficial, regardless of whether the index herd was diagnosed seven or 14 days after the initial infection. These results highlight the importance of knowing the location and herd type where the index case occurs before assessing the importance of alternative control strategies, such as vaccination.

The impact of index case diagnostic delay was investigated over a wide range of days — spanning from one to 28 — reflecting a very active surveillance program, e.g. detection delay of seven days or less, to a potentially more realistic scenario, e.g. detection delay of 21 days or more, if the index herd were comprised primarily of either beef, sheep or goat. As reported in Figure 4, if the diagnostic delay in identifying the index case is limited to 14 days or less, the expected outbreak would be relatively minor; however, as the delay increases, the outbreak would more closely replicate what occurred in the United Kingdom in 2001, and may even be worse.
As shown above, the potential spread of FMD in the United States depends upon the herd type in which it is introduced, the time needed to detect the infection, and the control strategy used to stem the spread of the disease. The United States is also concerned about the possibility that FMD may be intentionally introduced by actors looking to do major economic damage to the US economy. Figure 5 presents the expected magnitude resulting from multiple simultaneous introductions of FMD. In this example, an accidental introduction of FMDV into a single herd (baseline) is compared with three other scenarios, under which three, five or ten herds are infected simultaneously. Based on the results, it is clear that if there were multiple, simultaneous infections, the ensuing number of infections could more than double or increase by as much as five times compared to the single index case scenario.

Vaccination has been previously used to control FMD outbreaks in three [four are listed below] countries: Argentina (Perez et al., 2004) and the Netherlands in 2001 (Pluimers et al., 2002) and Japan (Nishuira and Omari, 2010) and South Korea (Yoon et al., 2013) in 2010. Due to the large number of strains and serotype, no single vaccine can protect animals from
FMDV. Vaccination of susceptible livestock is highly controversial, because once an animal is vaccinated against FMD, it may or may not be permitted to live the remainder of its productive life. In addition, import bans from countries that used vaccination are extended for months longer than those that did not. The benefits of vaccination — reductions in the number of infected animals and premises, and shortened epidemic duration — have been simulated frequently (Plumiers et al., 2002; Bates et al., 2003b; Garner and Beckett, 2005; Ward et al., 2009).

Hagerman et al. (2012) conducted two analyses to evaluate emergency vaccination in the face of an FMD outbreak — one originating in California and the other in Texas. They reported that in the California simulations, vaccination at ten and 20 kilometres from an infected premises, vs. no vaccination, reduced the median duration by only one to two days, if the diagnostic delay were 14 days and not at all if it were seven days. The median number of culled animals declined was relatively unchanged, if vaccination were used and the delay were seven days; however, substantially more culling was associated with the vaccination alternatives, if the diagnostic delay were increased to 14 days. In the Texas simulations, they found that if a five-kilometre vaccination ring were used, the median number of culled animals would increase by between approximately 40% and 90%, depending on whether the disease was diagnosed after seven or 14 days, respectively. The median epidemic duration would also increase by two or four days, if the diagnostic delay were seven or 14 days, respectively.

Ward et al. (2009) reported that vaccination did not significantly affect the epidemic duration, with only minor impacts (e.g. 0.03 day reduction). The study concluded that early detection had the largest effect on reducing both epidemic duration and the number of herds depopulated. Vaccination supply, on the other hand, did not show a significant advantage in terms of reducing either epidemic duration or the number of herds depopulated.

In addition to epidemics originating from livestock located on permanent premises, there is the possibility that an index case of FMD may occur in a venue where animals are present for a short time prior to being moved to a more permanent location (e.g. a sales yard or livestock show or fair). A simulation study was conducted to predict the extent of an outbreak if it occurred in a state fair (Carpenter et al., 2007). Results from surveys of California livestock owners and individuals that were exhibiting livestock at the 2005 California State Fair were used to simulate the potential for an infected animal (or animals) to enter the fair.
without clinical signs and subsequently infect additional animals being exhibited at the same time. Animals were present at the fair for a five-day period, during which they were able to contact one another and transmit FMDV either through fomites, airborne transmission, or direct and indirect contacts. Once the exhibition ended, the majority of animals were returned to their premises of origin, which often housed additional livestock susceptible to FMD. In fact, some of these premises were large commercial livestock operations.

Two stochastic epidemic models were used to simulate the spread of FMD. The first was a non-spatial model that simulated the spread of the virus within the fairgrounds, which housed 195 cattle for five days. The second, the DADS model, was a spatial model that simulated the spread of the virus outside of the fair — throughout California and potentially into other states. Results for the first model generated the number of animals expected to be infected by between one and five other animals assumed to be subclinically infected when they entered the fair. If they were simulated to be infected at the state fair, they were further simulated to return to their premises of origin upon departing the fair (if they were not going to slaughter). Simulation results obtained from the state fair model predicted an average of 14 to 88 latently or subclinically FMD-infected animals at the end of the five-day exhibition, depending on the number of infected animals (between one and ten) on day one of the exhibition.

These results were then used to seed the DADS model, which simulated the movement of FMD-infected livestock leaving the fair and returning to livestock premises throughout California. They reported that if FMD-infected animals were allowed to leave the fair undetected, there would be an epidemic lasting between 111 and 155 days, and infecting between 33 and 244 premises, depending on whether there were one or ten index cases, respectively. In addition, the expected probability of at least one FMD-infected animal leaving the state ranged from 28% to 96% as the number of index cases increased from one to ten, respectively.

Wildlife as a reservoir for FMDV is of concern because of the potential for uncontrolled spread to neighbouring and even distant livestock premises over time. In addition, the impact on the wildlife population itself could be severe, as demonstrated in the 1924 FMD outbreak in California, which resulted in the destruction of 22,000 white-tailed deer (California Department of Food and Agriculture). Ward et al. (2007) simulated the spread of FMDV in an 85,000 domestic cattle population if the virus were introduced into either a 134,000 feral pig population or 395,000 wild deer population located in a 24,000 square kilometre area in southern Texas. One hundred days after the introduction, the impact in cattle would be more than double than if FMDV were introduced into the feral pig vs. feral deer population. They also found that a substantial portion of the simulation runs did not result in further spread from the wildlife population. These findings highlight the uncertainty surrounding the epidemiology of FMD in wildlife and underscore the importance for improving our understanding of wildlife population demographics and movements. Such understanding is critical to making more accurate predictions about the spread and control of FMD in wildlife populations.

Pineda-Krch (2010) simulated the spread and control of FMD if it were introduced from wild pigs into livestock in California. They found that the impact was highly dependent on the type and location of the index herd. In addition, the duration of a state-wide movement ban imposed after FMD was detected in the index herd played a major role in determining the outcome of the epidemic. For example, outbreaks stemming from a dairy index herd were of longer duration, and resulted in more infected premises and animals than those arising from a beef index herd. Although the expected epidemic impact varied significantly according to the location of the index herd, these variations were not as pronounced under dairy index herd simulations.
Efficient presentation of simulation results to a decision maker

Once desired simulations have been completed, results may be presented to decision or policy makers in a variety of ways. Due to the high number of scenarios, results are often reported in figures showing distributions, as opposed to limited findings on extremes and central tendencies — e.g. mean, median or mode. However, the number of scenarios that may be presented in a single figure is often limited to 12 or less. Alternatively, a decision or policy maker may request that findings be stored in something known as a scenario library. The rationale is that if FMD were introduced, the decision maker could go to this library and quickly identify the impact of a selected control strategy or strategies. The problem is that given the number of locations, controls and index case scenarios, the potential size of this library is unmanageable and could quickly become obsolete, requiring results to be regularly updated if they are to be of any value.

An alternative to this process is to take the simulation results that would have been used to generate this scenario library and treat them as if they were experimental results produced by the combination of various controls or inputs. Using this logic, an algorithm could be created that would quantify the associations between the inputs and outputs, e.g. vaccination and epidemic duration. Given these relationships, the decision maker could then quickly determine the expected result of a certain control strategy under a given set of underlying conditions. For the sake of multiple simultaneous comparisons, it is recommended that the relationship between results and inputs be displayed graphically, rather than mathematically. This allows for a clearer understanding of the implications that a selected course of action may hold — both in and of itself, and relative to alternative actions.

To illustrate this approach, an algorithm was created from a regression analysis of 10,000 simulated FMD epidemics in California and the results are presented graphically in Figure 6. In this example, the relationship between two controls (ring vaccination and surveillance) and an outcome (epidemic duration) is presented graphically. The figure illustrates the expected epidemic duration if the vaccination ring ranged from zero (i.e. no vaccination) to 20 kilometres, and if FMD could be detected in between nine and 16 days.

Results shown in the figure may be best interpreted by using an example. If vaccination is used on susceptible premises located within five kilometres of an infected premises, and if a surveillance program is expected to detect the index case 14 days after exposure, the expected epidemic duration can be found at the intersection of a horizontal line drawn from the five kilometre vaccination value and a vertical line drawn from the 14-day delay value. In this case, these two lines intersect at an epidemic duration of approximately 56 days. If no vaccination is performed, the epidemic would last approximately 62 days.

In addition to identifying the expected epidemic duration arising from different combinations of inputs (vaccination ring radius and initial detection delay), one could also use these relationships to identify the range of input combinations that could produce a given output. For example, assume a decision maker is interested in limiting the duration of the epidemic to 60 days, which corresponds to the line separating the second and third colours, starting at the bottom right hand corner of the figure. From the figure, it can be seen that a 60-day epidemic is expected if, for instance, vaccination were not used (vaccination ring radius = 0) and if the initial case is detected slightly less than 15 days after introduction of FMDV. Alternatively, a 60-day epidemic would be expected to occur if ring vaccination with a radius of almost five kilometres were used and if the initial case diagnostic delay were 16 days. Additional input combinations ranging between these values can be identified along the 60-day epidemic line (e.g. vaccination with a radius of 2.5 kilometres and a detection delay of 15.5 days). Similarly, a decision maker may be interested in the expected epidemic duration if the disease could be identified 14 days after it was introduced. As demonstrated previously, if the delay and vaccination occur at five kilometres, the expected epidemic...
duration would be 60 days; however, if no vaccination is used, the expected duration would be approximately 58 days. On the other hand, the expected epidemic duration could be reduced to approximately 49 days if the vaccination ring were increased to 20 kilometres from infected premises.

Once the algorithm is specified, this approach could be expanded by including the costs of alternative control actions. With that information, one could construct a budget constraint line reflecting the price ratio and quantities of inputs used. With this budget constraint, a decision maker could identify the least expensive way to produce a given output, or calculate the expected epidemic duration under certain circumstances. In addition, one could determine the most efficient input combinations and their associated outputs — known as an expansion path — as a way of simultaneously evaluating the most efficient allocation of input combinations.

Figure 6. A response surface representing the association between levels of two inputs* and the expected outbreak duration

* Initial detection delay and vaccination ring radius.

References


California Department of Food and Agriculture, Animal Health Branch (AHB) and Veterinary Services; Animal and Plant Health Inspection Services (VS: APHIS), United States Department of Food and Agriculture (2010), personal communication.


As agricultural trade continues to increase both volume and diversity, livestock sectors have become increasingly dependent on exports. The increasing importance of trade poses challenges to controlling contagious animal diseases. When a country is confronted with a transboundary disease like foot-and-mouth disease, the infection must be eradicated as soon as possible. A number of countries do this through large scale preventive culling, though vaccination-to-live strategies pose a compelling alternative. Compared to preventive culling, a vaccination-to-live strategy poses several differences, including the size and duration of the outbreak, total economic losses, loss distribution among different stakeholders, and consequences for financing mechanisms. But because vaccination-to-live strategies are relatively new in the European Union, markets may be slow to accept products originating from FMD-vaccinated animals. The objective of this paper is to evaluate different economic aspects of a vaccination-to-live strategy deployed to eradicate FMD in a country previously free of vaccination. 

* Acknowledgement is given to Jantien Backer, Thomas Hagenaars, Herman van Roermund, Aldo Deckers, Gonnie Nodelijk WUR-CVI, Coen van Wagenberg, Nico Bondt, WUR LEI, and to the financial support of the Dutch Ministry of Economic Affairs, which enabled much of the underlying research.
The world has become a global marketplace in which agricultural trade continues to increase both in volume and diversity (Figure 1). This trend is also observed for livestock sectors, which have become increasingly dependent on exports. As Table 1 demonstrates, exports are important not only for countries with traditional export-oriented livestock industries, such as the Netherlands and Denmark, but also for a country like Germany, which sees substantial imports as well as exports. The increasing importance of trade poses challenges to controlling contagious animal diseases. The introduction of diseases like foot-and-mouth disease (FMD) presents a constant threat for countries, and can affect their trade opportunities. Despite OIE and EU regulations to protect countries from the threat of contagious animal diseases, there is always a risk of introduction. The consequences of an FMD outbreak can be devastating for the livestock sector in an affected country and for its economy in general (Box 1 shows the cost of the last outbreak in the Netherlands).

**Figure 1. Export of agricultural products**

<table>
<thead>
<tr>
<th>Year</th>
<th>WORLD</th>
<th>EU (25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Value</td>
<td>Value</td>
</tr>
<tr>
<td>1990</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>2000</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>2010</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

*Source: WTO, international trade statistics (2012), USD current prices.*

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Value (EUR million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>1767</td>
</tr>
<tr>
<td>Denmark</td>
<td>3333</td>
</tr>
<tr>
<td>Germany</td>
<td>2458</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Trade</th>
<th>Total Value (EUR million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-EU</td>
<td>1543</td>
</tr>
<tr>
<td>Extra-EU</td>
<td>224</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trade Type</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-EU</td>
<td>61%</td>
<td></td>
</tr>
<tr>
<td>Extra-EU</td>
<td>39%</td>
<td></td>
</tr>
</tbody>
</table>

*Source: De Winter et al., LEI 2010.*

When a country is confronted with a transboundary disease like FMD, the infection must be eradicated as soon as possible. Both OIE and the European Union offer guidelines on eradication, but additional measures are often needed to contain the outbreak — especially in densely populated livestock areas. In a number of countries, these additional measures include large scale preventive culling of animals around infected premises. Large scale culling is believed to have had a devastating impact on society, animal welfare and the environment, and is associated with high economic losses.
Previous epidemics caused societal outcry and disturbance (Cohen et al., 2007). In several countries, this response bolstered arguments for adopting alternative strategies to control future epidemics. This, in turn, fuelled calls to reconsider non-vaccination policies, and to discuss alternative prevention and control strategies that would be supported by society at large. There were also calls for strategies that would minimise financial and environmental impacts.

One alternative under consideration involved the implementation of a vaccination-to-live strategy. The implementation of a vaccination-to-live differs from culling, as well other strategies in which vaccination is used as a way to postpone culling until a later moment. Decision making in the control contagious animal diseases is a complex process, characterised by a mixture of epidemiological, economic and social-ethical value judgements. Different stakeholders will have different ideas about which strategy should prevail. Their views may represent the interests of the farming community, the processing industry, the animals, the consumer, or the general citizen. This may create a situation of conflicting interests, as economic motives may prevail in the views of some, while animal or human welfare motives may be more prominent in the views of others (Mourits et al., 2010).

Compared to preventive culling, a vaccination-to-live strategy poses several differences, including the size and duration of the outbreak, total economic losses, loss distribution among different stakeholders, and consequences for financing mechanisms. Since vaccination-to-live strategies are relatively new in the European Union, markets may be slow to accept products originating from FMD-vaccinated animals. The objective of this paper is to evaluate different economic aspects of a vaccination-to-live strategy deployed to eradicate FMD in a country previously free of vaccination.

**Box 1. Costs of the 2001 FMD outbreak in the Netherlands**

Twenty-six infected herds were detected. All susceptible animals on approximately 1,800 farms were vaccinated. All farms were subsequently depopulated. In total, approximately 260,000 animals were culled.

- Total for Dutch society: EUR 900 million or 0.3% GNP
- Direct costs (e.g. enforcement costs, compensation of culled animals, screening): EUR 90 million
- Indirect and export market losses: EUR 320 million
- Other parts of the livestock chain: EUR 215 million
- Tourism and recreation sector: EUR 275 million

*Source* (CPB 2001 cited by Huirne et al., 2002)

**Economic aspects of an outbreak of FMD**

During an outbreak of a contagious disease like FMD, farmers, livestock sectors and governments are confronted with direct and indirect losses. When evaluating the costs of an epidemic, different components can be distinguished.

*Direct costs related to the control of the epidemic*

These include infrastructure costs to control the epidemic, the costs associated with culling and destroying of infected and contact animals, the costs associated with destruction of feed and eggs on detected farms, and compensation and vaccination costs. In EU member states, these costs are co-financed by the European Union (Council Decision 90/424/EEC).

Consequential losses can occur during an outbreak, as well. These include the following.
Costs related to movement restrictions affecting the primary sector

Farms culled during the epidemic are confronted with income losses; during the time, stocks are not fully repopulated and culled farms are not in production. Farms are also confronted with new start-up costs. Farms in a surveillance or movement restriction zone face indirect losses during the standstill period, mainly due to the fact that they are not able to freely move animals or livestock products. An epidemic affects the entire livestock sector, restricting national and international market access to animals of susceptible species and their products. Even after the outbreak has passed, it takes time to lift restrictions and return to pre-epidemic market conditions.

Ripple effects

The effects from outbreaks are felt upstream and downstream along the livestock value chain, from breeding, feed production, input supply, slaughter and processing, to final sale and consumption.

Spill-over effects

During outbreaks, tourism and other services in a member state may be confronted with reduced incomes. Because typical agricultural production is becoming more important for the rural economy, these spill-over effects are likely to comprise a large part of total epidemic costs.

A major drawback of consequential losses is the fact that they are difficult to determine, and can usually be estimated only after the outbreak has ended, once the situation has returned to “business as usual.”

Recent research from the Netherlands as illustration

A number of recent studies in the Netherlands have examined vaccination-to-live strategies (Backer et al., 2012a, Backer et al., 2012b, Backer 2009). Results from these studies indicate that the epidemiologic and economic outcomes of an FMD outbreak depend on both the control strategy chosen, as well as the farm density in the region where an outbreak occurs.

In these studies four alternative control strategies were evaluated.

- the EU minimum strategy (EU-min); this strategy consists of culling of infected farms, tracking and tracing of risky contacts and establishment of inspection zones (3 km) and surveillance zones (10 km) (COUNCIL DIRECTIVE 2003/85/EC).
- a culling strategy (Cul1), which calls for the culling of all FMD-susceptible and infected animals within a radius of one kilometre around infected farms (in addition to the EU-min strategy).

The remaining two preventive vaccination strategies are identical to the Cull strategy, differing only with respect to the size of the vaccination radius.

- Vac2 (radius of two kilometres); and
- Vac5 (radius of five kilometres)

The Cull strategy would be implemented during the first week of the outbreak, before the deployment of a vaccination strategy. (A maximum one-week delay was anticipated, taking into account the necessary preparation of a vaccination strategy.)
The effect of each identified strategies was determined for a typical Dutch, densely populated livestock region with more than four farms per kilometre. The economic analysis was based on the results of a stochastic epidemiological FMD simulation model. It was developed to investigate the consequences of the aforementioned alternative control strategies, and is described in detail by Backer et al., (2012a and 2012b). A partial budget model was developed to evaluate the economic consequences of different control strategies (Dijkhuizen and Morris, 1997). Economic parameters were estimated based on previous outbreaks and were discounted to reflect current prices. Cost parameters were based on Meuwissen et al. (1999), Mangen et al. (2002), Huirne et al. (2002) and Meuwissen et al. (2003), among others. Products of vaccinated animals had to be processed separately from the products of non-vaccinated animals (logistic slaughtering), resulting in reduced market access — especially for non-EU countries. Logistic slaughtering and reduced market access pose substantial costs to the industry (Meuwissen et al., 2009). Due to volume and reduced market access, products derived from vaccinated animals will lose value.

Results of the simulation studies

Because Backer et al. (2009, 2012a and 2012b) comprehensively described epidemiological consequences in terms of probability distributions, only the descriptive statistics are presented, including the mean value as well as the fifth and 95th percentiles. The duration of an outbreak and the number of farms infected, culled, and vaccinated differ substantially across control strategies (Table 2). The epidemiological simulation outcomes showed that in a Densely Populated Livestock Area (Densely Populated Livestock Area in which the farm density is larger than two farms per km²), the EU-min strategy will too often result in a lengthy outbreak, and is therefore not likely to be a preferred option for involved stakeholders. As a result, it is excluded from further evaluation. In terms of economic consequences, the Vac2 strategy entails the lowest average loss in a Densely Populated Livestock Area (Table 3). However, under favourable circumstances with limited spread, Cull is the preferred strategy (see the fifth percentile); under adverse circumstances, the Vac5 strategy is preferred (see the 95th percentile).

Table 2. Descriptive statistics of simulated epidemiological outcomes for different control strategies of epidemics that started in a Dutch Densely Populated Livestock Area region

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Duration in days</th>
<th>Number of detected farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>5%</td>
</tr>
<tr>
<td>EU-min</td>
<td>254</td>
<td>166</td>
</tr>
<tr>
<td>Cul1</td>
<td>61</td>
<td>25</td>
</tr>
<tr>
<td>Vac2</td>
<td>70</td>
<td>33</td>
</tr>
<tr>
<td>Vac5</td>
<td>47</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Number of pre-emptively culled farms</th>
<th>Number of vaccinated farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>5%</td>
</tr>
<tr>
<td>EU-min</td>
<td>463</td>
<td>355</td>
</tr>
<tr>
<td>Cul1</td>
<td>1 015</td>
<td>336</td>
</tr>
<tr>
<td>Vac2</td>
<td>199</td>
<td>92</td>
</tr>
<tr>
<td>Vac5</td>
<td>188</td>
<td>84</td>
</tr>
</tbody>
</table>

1Hobby farms excluded.
Table 3. Descriptive statistics of simulated economic losses for different control strategies of epidemics that started in a Dutch Densely Populated Livestock Area region*

<table>
<thead>
<tr>
<th>Area strategy</th>
<th>Total losses EUR million</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Cul1</td>
<td>193</td>
</tr>
<tr>
<td>Vac 2</td>
<td>163</td>
</tr>
<tr>
<td>Vac 5</td>
<td>170</td>
</tr>
</tbody>
</table>

* Export losses excluded.

Export losses

An epidemic restricts national and international market access for animals of susceptible species and their products. An FMD will result in trade restrictions that are largely related to the epidemic *per se* and do not depend on the specific characteristics of the chosen control strategy. Once exports resume, it can take considerable time to regain access to profitable markets.

Export market losses were excluded from the calculations. Market access for live animals, meat, meat products, milk and milk products from infected countries is restricted for another three months without vaccination and for another six months with vaccination-to-live (OIE Terrestrial Code Article 8.5.8). The total effects of export losses are determined according to the size and duration of the outbreak, the control strategy applied, and especially the country or area affected.

Distribution of costs and financing the consequences

In addition to differences in total costs, there is a shift in cost components across different strategies, underscoring a variability that has implications for involved stakeholders (Figure 2). EU community measures call for the co-financing of veterinary emergency measures. Council Decision 90/424/EEC allows for co-financing 60% of the costs of compulsory and pre-emptive slaughter for FMD, and any related operational expenditure (Bergevoet et al., 2011). In addition, the remaining costs for specific components are shared between the government and livestock farmers through a compulsory public statutory compensation scheme (Van Asseldonk et al., 2006). Indirect losses — including those arising from lower values for vaccinated animals and their products — are not eligible for compensation. As a consequence, of the covered cost a larger amount of the losses are borne by farmers under a vaccination strategy (Figure 2).

For an outbreak in a Densely Populated Livestock Area, non-eligible costs comprise 13% of total costs related to the Cul1 strategy; this share increases to 46% with a Vac5 strategy. A large part of the non-eligible costs have to be borne by a relatively small number of farmers whose animals were vaccinated. The farmers’ willingness to participate in a vaccination-to-live strategy might be determined by compensation mechanisms put in place to cover losses. Different compensation schemes are currently under discussion in the Netherlands. As described above, there are different ways to organise a cost and responsibility sharing scheme.
Financing mechanisms

When compensating farmers for direct losses during an FMD outbreak, most EU member states finance compensation entirely from their national budgets. Only in a few member states—e.g. Belgium, Germany, Lithuania and the Netherlands—does the animal production sector contribute to the funding for compensation of direct losses. These public-private financing schemes have a compulsory fund structure under which all farmers pay a levy.

Some EU member states have implemented a compensation scheme for all or part of the consequential losses, either by means of private funding (which is compulsory in Romania), public funding (as in Austria, Cyprus, Czech, Finland, France, Portugal and Sweden), or public-private participation (Denmark, Latvia, and Lithuania).

Statutory compensation schemes finance protection against losses for livestock farmers. These schemes are financed either by state or state-controlled public funds mutual funds with levies, or by ad hoc payments. In situations without state-established systems, only private insurance can be purchased (Koontz et al., 2006). Below, characteristics of public funds and insurance systems are briefly discussed.

Public funds are generally compulsory and guarantee reliable protection for all farmers. They are characterized by the following: catastrophes and disaster protection is state-guaranteed, and there are no financial capacity problems or needs for reinsurance protection. In general, only direct losses are compensated, and compensation is only available for farmers who culled their herds because of formal, state-advised acts. No compensation is paid to farms situated in restriction zones, and indirect losses remain uncovered. There is also limited input and lower incentives for loss prevention measures, and there is no possibility for an individual risk-adjusted contribution or claim settlement.

Risk financing with a levy system is based on pooling within the sector over time. Payments to the fund can be organised through up-front payments (deposit), assessment payments after an epidemic, or both. These latter two systems have no annually fixed levies, and the government will finance the compensation payments in advance. But government input will be repaid over the following years. When an epidemic breaks out, the levy is therefore set according to the amount that the government paid in advance for the sector. It is important to note that the levy can (and in most cases will) vary across livestock species.

In public-private co-financing, the amount financed by the private sector can be proportional or non-proportional. If risks are shared by means of a proportional (pro-rata)
contract between the government and the private sector, the levy is specified as a fraction of the coverage. With non-proportional contracts, the national government indemnifies only claims that are in excess of a particular threshold.

In some countries it is possible to insure consequential losses through private insurance as well as public-private compensation schemes. Private insurance offers compensation for both direct and indirect losses, as well as individual risk-designed contracts for farmers. Private coverage also includes protection against business interruption and loss of income. There are incentives for loss prevention, as well, since insurance protection is available only for farms that meet stringent sanitary standards under surveillance monitoring (e.g. by dairies or pig control units). Insurers have specialised staff for individual risk-adjusted premium and claim settlements. There are also mutual insurance companies that combine the advantages of both mutual funds and insurances. With insurances, however, there is freedom of contracting (not everybody has to participate), and there are no compulsory schemes.

However, private insurance poses some major drawbacks. In most member states, private livestock insurance is not developed, and the insurance industry has shown very little interest. There are problems with disaster coverage, as well, since reinsurance is available on a limited basis, and there are relatively high premiums due to tax and administration costs.

Financing the potential losses arising from devalued vaccinated animals is a challenge for livestock sectors and governments. Since the value loss is seen as a consequential loss, public-private arrangements for compensation might be seen as unwanted government support. An insurance system, meanwhile, may be perceived as expensive, and its freedom of contracting might result in moral hazards that affect non-insured livestock owners.

Conclusion

Research indicates that vaccination-to-live is a viable alternative to large scale culling. Acceptance of vaccination-to-live increases when regulation related to vaccination-to-live is harmonised with either culling or vaccination-as-delayed-culling. Simulation outcomes reveal that in the event of an FMD outbreak in a Dutch Densely Populated Livestock Area, vaccination within a radius of two kilometres would be as effective as culling within a one kilometre radius, with substantially smaller economic and social effects.

For SPLAs (Sparsely Populated Livestock Areas in which the farm density is less than two farms per km$^2$) absolute differences across analysed control strategies — differences that raise epidemiological, economic and social-ethical issues — are of less concern. Economic evaluations of FMD management options are likely to result in different solutions for different countries (e.g. due to differences in livestock population density, trade patterns, or acceptance of products originating from vaccinated animals). The decision making process should be supported by epidemiological and economic models. Agreements on mechanisms to finance both direct and consequential losses should be made before an outbreak occurs.

References


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 (McInerney 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; McInerney, 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 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 \(I_{\text{min}}\) 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 (\(S^\circ\) and \(I^\circ\)). 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 \(S^\circ/I^\circ/A2\), 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/](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.

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.
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 (Häsl er, 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 with and without 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.
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.” 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.

---

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 CO₂ 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, 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, 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 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.

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


THE OCCURRENCE, INTERVENTIONS AND SOCIO-ECONOMIC CONSEQUENCES OF BSE IN JAPAN

Katsuaki Sugiura, University of Tokyo, Japan
Ray Bradley, BSE Consultant, United Kingdom

Bovine spongiform encephalopathy (BSE) was first confirmed in the United Kingdom in November 1986. BSE is a progressive and fatal nervous disease found mainly in adult dairy cattle, and can result in changes in behaviour, mental status, posture, and gait. The first case of BSE in Japan was confirmed in September 2001. The Japanese government implemented several important interventions, though the disease nevertheless had serious economic and social consequences. We closely examine these consequences in this paper, as well as the interventions taken by the Japanese government. We use Japan’s experience to extract lessons on how best to communicate, implement, and standardise disease control interventions.
Introduction to BSE-related diseases and TSE including CJD

Bovine Spongiform Encephalopathy (BSE) was first confirmed in the United Kingdom in November 1986, though the first clinical case probably occurred in April 1985. BSE is a progressive and fatal nervous disease found mainly in adult dairy cattle. It can result in changes in behaviour, mental status, posture, and gait. BSE was subsequently reported in cattle in several EU Member States as well as Switzerland, but on a much smaller scale. BSE is a new member of the group of diseases known as transmissible spongiform encephalopathies (TSE), or prion diseases. The most well-known TSE include scrapie of sheep and goats, and Creutzfeldt-Jakob disease (CJD) of man. New forms of TSE have been reported in captive wild ruminant species in UK zoos, as well as in domestic cats and captive wild Felidae in the United Kingdom and elsewhere. These reports have been comparatively small in number, but have been shown to be aetiologically related to BSE.

Epidemiological studies (Wilesmith et al., 1988) conclusively demonstrated that the cause of BSE (and BSE-related diseases) was oral exposure to a scrapie-like agent. In the case of cattle and captive wild ruminants, BSE is transmitted through consumption of meat-and-bone meal (MBM). MBM is derived from unwanted animal slaughter products and fallen stock that are rendered (cooked) to evaporate water as steam. Fat (tallow) is then separated to leave a protein-rich material called greaves. Greaves is ground to form MBM, which was included in the concentrate rations of young dairy cattle. MBM was also fed to pigs and poultry, though neither species is naturally susceptible to BSE through oral transmission.

The mean incubation period of BSE in cattle is 60 months. It follows from this that UK cattle were first exposed to BSE around 1980, leading to the eventual epidemic. There was therefore a window between 1980 and 1988 (when controls were first established in the United Kingdom) during which infected feed or cattle could have been exported in the belief that they were not infected. Thus, all countries without BSE are at risk of the disease if they import BSE-infected cattle and retain them until the incubation period is complete. They also are at risk of introducing BSE into indigenous susceptible species if products from such cattle, infected MBM imports, or feed are fed to indigenous susceptible species. Risks to animals can be reduced by having an effective feed ban, for example, and by restricting imports of germ plasma to semen and embryos rather than live cattle, as these are not known to transmit BSE (even from infected donors). It is still not known how the BSE epidemic started in the United Kingdom.

Research has established that at the clinical stage of disease, the highest agent concentrations are found in the central nervous system (CNS), with lesser amounts in some lymphoreticular tissues such as spleen, tonsil and Peyer’s patches in the distal ileum, or any tissues contaminated by them. The latter tissues may be infected at an earlier stage of disease than the CNS, and before clinical signs are evident.

BSE attracted worldwide attention in March 1996, when the UK Secretary of State for Health announced the occurrence of the first ten human cases of a new variant form of CJD that was linked to BSE of cattle origin. Hitherto, sporadic CJD — the most common form of the disease in man — occurred mostly in elderly patients, with a worldwide distribution and incidence of around one per million. By contrast the new variant form of CJD (variant CJD or vCJD) found in the United Kingdom (and subsequently in a number of other countries) affected mostly young people below the age of 30 years. The most plausible exposure pathway is thought to be through consumption of meat products (e.g. mechanically recovered meat derived from the vertebral column) contaminated with BSE-infected tissue and, in particular, CNS. A small number of human-to-human vCJD transmissions have since been identified as a result of blood transfusions or use of blood products derived unknowingly from a vCJD-infected donor.
Simply put, interventions to control BSE might include the following.

- Removal and safe destruction of risk material (SRM) in BSE-infected tissues. If effectively enforced, this ban would protect all species, including man, from exposure to BSE-infected material.
- Active and passive surveillance for BSE
- Prohibition of the use of MBM in fertilisers
- Improved and safe control of rendering waste animal material to produce MBM
- Testing of brains from animals at risk of BSE to detect those infected and ensure their safe destruction

Geographical distribution of BSE and vCJD with dates

BSE was first identified in the United Kingdom in 1988, Ireland in 1989, Portugal and Switzerland in 1990, France in 1991, Germany in 1992 and most other EU member states in subsequent years. It was identified in Japan in 2001, Canada in 2003, the United States in 2005 and Brazil in 2012. More than 190,000 cases of BSE have been diagnosed worldwide. All these countries now have little or no BSE; the United Kingdom, for example, had three cases in 2012 and one case in 2013 (as of 30 June 2013). Data on the geographical distribution of BSE are available from the World Organisation for Animal Health (OIE) website (OIE, 2013a).

As of 30 June 2013, 225 vCJD cases have been identified worldwide since 1996: 177 in the United Kingdom, 27 in France, four in Ireland, two in Italy, three in the United States, two in Canada, one in Saudi Arabia, one in Japan, three in the Netherlands, two in Portugal, five in Spain and one in Taiwan. Most of these patients had been resident in the United Kingdom for more than six months during the period 1980-1996. Data on the geographical distribution of vCJD cases are available from the National CJD Research and Surveillance Unit website (NCJDRSU, 2013).

BSE in Japan

The first case of BSE in Japan was confirmed in September 2001, some 15 years after the first case in the United Kingdom. Following the experience with vCJD in the United Kingdom in 1996, the Japanese public was somewhat apprehensive about the future outcome in their country. The Japanese government’s position had been that the risk of BSE occurring in Japan was remote. To the public, it was unclear whether there were any contingency plans to be implemented in a worst-case scenario.

When the first BSE case occurred, the government made no attempt to conceal it. Consumers had little confidence in the government’s plans to arrest the progress of the disease, or to protect consumers from exposure, and panic soon set in. It was clear that to shift the balance from mistrust to confidence, rapid and strong action had to be taken. The government took the view that the cost of any intervention, while important, could not be the driver behind any decisions. It was imperative to restore public confidence in the safety of food and particularly cattle products, as well as in the ability of the Japanese government to manage risks by establishing effective control and elimination policies in the country. The government called upon the wealth of information and experience on BSE controls both in Japan and elsewhere — available from the OIE and EU Member States — resulting in rapid and commendable action.
The Japanese government introduced the following interventions within the month following the announcement of the first case of BSE.

- 27 September 2001: The mandatory removal and incineration of SRM from all cattle slaughtered for human consumption (MHLW, 2001). SRM includes the brain, the spinal cord, eyes and the distal ileum, and was expanded later to include the vertebral column. SRM definitions vary across agencies (Table 1).


- 4 October 2001: A ban on the importation and domestic use of all processed animal proteins (PAP) for the production of feed for ruminants, pigs and chickens, as well as fertiliser production (MAFF, 2001b).

- 18 October 2001: Mandatory reporting and investigation of all clinical BSE suspects (passive surveillance), testing of fallen stock and all cattle slaughtered for human consumption and active surveillance (using an OIE-approved test to detect prion protein PrPSc in the brain) (MAFF, 2001c).

Table 1. Definition of specified risk materials (SRM) in Japan, European Union and OIE Terrestrial Animal Health Code

<table>
<thead>
<tr>
<th>Countries</th>
<th>Definition of SRM which should be removed from food chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>Head (excluding tongue and cheek meat), brain, spinal cord, eyes, distal ileum and vertebral column from cattle of all ages slaughtered for human consumption*</td>
</tr>
<tr>
<td>European Union</td>
<td>Skull (excluding lower jaw and including brain and eyes) and spinal cord, tonsils, vertebral column and ileum from cattle over 12 months of age**</td>
</tr>
<tr>
<td>OIE Terrestrial Animal Health Code</td>
<td>Brains, eyes, spinal cord, skull and vertebral column from cattle over 30 months of age for human consumption, and tonsils and distal ileum from cattle of all ages***</td>
</tr>
</tbody>
</table>

* Definition of SRM as of September 2001 when systematic removal of SRM was introduced in Japan.
** Definition of SRM as of October 2000 when systematic removal of SRM was introduced in the EU.
*** Definition of SRM which should be removed from meat from countries, zones or compartments with controlled risk of BSE.


Collectively, these interventions led to a massive and no doubt unwelcome increase in government expenditure. Among other things, this stimulated the establishment of the Food Safety Commission in Japan, an independent agency for risk assessment, in 2003.

BSE results in both direct and indirect losses. Direct losses result from human deaths and the death or destruction of cattle affected by BSE. Indirect losses include the cost for destruction of cohort animals (cattle that, during their first year of life, were reared on the same farm and fed the same rations as cattle that later developed BSE) and the exclusion of MBM from animal feed and fertiliser. Other indirect costs result from the interruption in trade (both internal and external) and the reduction in beef consumption.

Thus, in Japan as in other countries, BSE has resulted in serious social and economic consequences.
Government agencies involved in BSE decision making

Until July 2003, the Ministry of Health, Labour and Welfare (MHLW) had been responsible for decision-making to protect public health from zoonoses, while the Ministry of Agriculture, Forestry and Fisheries (MAFF) was responsible for protecting animal health. After the detection of the first case of BSE, the MHLW and MAFF set up a committee composed of veterinarians, journalists and consumer group representatives to conduct an inquiry into the government’s decision-making process for BSE interventions, in order to glean lessons and formulate recommendations.

The committee submitted a report in April 2002 (Committee for Investigation of BSE Issues, 2002). They identified the following problems with the decision making process by the MHLW and MAFF:

- lack of crisis management system in the government;
- decision-making that prioritised producer interest over consumer interest;
- a lack of transparency in the decision-making process;
- insufficient collaboration between the MHLW and MAFF;
- decision making that did not reflect scientists’ comments; and
- insufficient disclosure of information to improve consumers’ understanding.

The committee emphasised the importance of a risk analysis approach composed of risk assessment, risk management and risk communication in food safety decision making. It also recommended that a new law be enacted to improve food safety based on a risk analysis approach, and called for the establishment of a new government agency for risk assessment. Based on this recommendation, the Basic Law on Food Safety was enacted and the Food Safety Commission, an independent agency for risk assessment, was established in July 2003.

At the same time, the MHLW and MAFF were re-organised to strengthen their risk management capabilities. Since July 2003, whenever a change to BSE interventions is proposed, FSC conducts an assessment of the risk mitigation effect of the proposed changes. However, cost-benefit analysis or other economic analysis is not within the scope of the FSC. In May 2005, for instance, the FSC assessed the revised BSE interventions at the request of the MHLW and MAFF, and recommended a more complete removal of SRM, a more robust implementation of the feed ban and more BSE research. This was done without analysing the additional cost involved and the economic benefits the revisions might bring (Food Safety Commission, 2005).

Cost and effect of BSE interventions

Annual government expenditure for these interventions amounted up to JPY 140 billion — equivalent to EUR 1.1 billion, USD 1.4 billion or GBP 0.95 billion — in fiscal years 2001 and 2002 (Table 2). These amounts included not only expenditure for public health and animal health interventions, but expenditure for market intervention, financial support to economically damaged farmers, renovation of slaughterhouses and rendering plants, and establishment of a cattle traceability system. These amounts do not include expenditure on interventions taken by local government and the private sector, such as the labour cost for BSE testing and costs for production of uncontaminated feed.

During the one-month period between the first BSE case and the initiation of BSE testing on cattle for human consumption, the government asked farmers to refrain from shipping
cattle older than 30 months of age to slaughterhouses, and isolated beef products from the market. These interventions were taken to regain consumers’ confidence in beef by removing all beef products produced from cattle that had not been tested for BSE. Beef consumption recovered in fiscal years 2003 and 2004, so there was no longer a need to support farmers financially. This reduced government expenditure to JPY 43 billion and JPY 29 billion respectively. Government expenditure for BSE intervention has since remained unchanged.

<table>
<thead>
<tr>
<th>Purpose of interventions</th>
<th>FY2001</th>
<th>FY2002</th>
<th>FY2003</th>
<th>FY2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSE surveillance</td>
<td>1 726</td>
<td>981</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Destruction of fallen stock</td>
<td>2 186</td>
<td>1 954</td>
<td>5 489</td>
<td>4 375</td>
</tr>
<tr>
<td>Cattle traceability</td>
<td>3 442</td>
<td>965</td>
<td>1 688</td>
<td>1 357</td>
</tr>
<tr>
<td>Information dissemination</td>
<td>2 155</td>
<td>3 003</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Slaughterhouse renovation</td>
<td>1 707</td>
<td>1 185</td>
<td>704</td>
<td>882</td>
</tr>
<tr>
<td>Market intervention</td>
<td>29 331</td>
<td>512</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Financial support to farmers and distributers</td>
<td>63 756</td>
<td>87 954</td>
<td>149</td>
<td>133</td>
</tr>
<tr>
<td>Incineration of MBM</td>
<td>15 418</td>
<td>19 930</td>
<td>23 200</td>
<td>15 163</td>
</tr>
<tr>
<td>Rendering plant renovation</td>
<td>20 043</td>
<td>11 329</td>
<td>7 317</td>
<td>3 813</td>
</tr>
<tr>
<td>Incineration of fertiliser</td>
<td>0</td>
<td>0</td>
<td>699</td>
<td>0</td>
</tr>
<tr>
<td>BSE testing at slaughterhouses</td>
<td>2 141</td>
<td>5 236</td>
<td>4 017</td>
<td>3 306</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>141 905</strong></td>
<td><strong>137 889</strong></td>
<td><strong>43 265</strong></td>
<td><strong>29 029</strong></td>
</tr>
</tbody>
</table>


These interventions reduced mortality among humans. In the United Kingdom, millions of infected cattle were consumed, and the maximum number of vCJD cases predicted was 5 000 (Aignaux et al., 2003). The Japanese Food Safety Commission predicted that considering the number of BSE cases predicted in Japan, the number of vCJD cases would be between 0.1 and 0.9 people (Food Safety Commission, 2004). This number represents the amount of people who could have contracted vCJD and died from eating BSE-contaminated beef in Japan, were it not for public health interventions. In fact, 177 vCJD cases were detected in the United Kingdom by August 2012, and no cases were reported in either 2012 or 2013. In Japan, only one case was detected, though the infected person was likely exposed to the BSE agent while travelling in the United Kingdom in the 1990s (MHLW, 2005). The Japanese government has not only taken interventions to protect the public from oral exposure, but has banned blood donations from people who resided in the United Kingdom for longer than one month between 1986 and 1996 (MHLW, 2005, 2009).

The average age of death in a vCJD case is 28 years (Andrews, 2012). The average life expectancy of a 28 year old in Japan is 55 years (MHLW, 2011). The number of life years saved (LYS) from the prevention of 0.9 vCJD is therefore 50 LYS, based on calculations. Assuming that the government spent JPY 20 billion on BSE testing to save 50 LYS over four years (data for the labour cost of BSE testing, and SRM removal and destruction are not available), the amount spent to save one LYS would be JPY 400 million, which is equivalent
to USD 4 million. Even though saving one QALY represents a bigger health improvement than saving one LYS, considering that the maximum cut-off value per quality adjusted life year (QALY) for public health programs is USD 50,000 in the United States (Goldman et al., 1992), CAD 20,000 in Canada (Laupacis et al., 1992), GBP 30,000 in the United Kingdom (Nancy and Parkin, 2004) and AUD 36,000 in Australia (George, Harris and Mitchell, 2001), the cost-effectiveness of BSE intervention in Japan deviates two orders of magnitude from regular health economics thresholds applied in these countries.

Animal health interventions, and the prohibition on the use of MBM in particular, contributed to the reduction in the number of BSE cases. The number of BSE cases in Japan peaked in 2006 and started to decline from 2007. No case has been detected since 2009 (Figure 1). An effective ban on the use of MBM as a ruminant feed supplement had been in place for eight years, and no BSE had been detected in cattle born during the previous 11 years. During this time, effective surveillance had been in place. As a result, Japan obtained the highest status of BSE risk (“negligible”) at the World Assembly of the OIE in May 2013 (OIE, 2013b).

Collectively, government interventions, in particular, the testing of 100% of cattle slaughtered for human consumption, helped improve public confidence in the safety of beef and cattle products and subsequently contributed to the recovery of beef consumption, which had slumped by 60% after the detection of the first case (Figure 1).

Figure 1. Number of BSE cases detected in Japan

![Graph showing the number of BSE cases detected in Japan from 2001 to 2009.](source: Japanese Ministry of Agriculture, Forestry and Fisheries.)

Figure 2. Evolution of beef consumption in Japan, August 2001-September 2002

![Graph showing the evolution of beef consumption in Japan from August 2001 to September 2002.](source: Japanese Ministry of Agriculture, Forestry and Fisheries.)
Discerning Japanese consumers who lost confidence in the government and in the safety of beef when the first BSE case was reported soon regained their confidence following the various government interventions. They observed that other countries affected by BSE appeared to have controlled the disease effectively. Importantly, they also noted that the interventions used in Japan were more comprehensive than those in the European Union or the international standard recommended by the OIE. This is despite the fact that any additional protection would be marginal at best, because cattle in the early stages of BSE incubation are undetectable using the currently available approved tests.

Conclusions

- BSE caused serious social and economic effects in Japan, as it did in many other countries. This indicates that zoonoses (diseases that can be passed from animals to humans and vice-versa) may cause serious social and economic effects, in particular when the disease is fatal and accompanied by uncertainties.

- The Japanese consumer was exceedingly sensitive to the risks associated with BSE following the first reported case in Japan, and was particularly sensitive to the public health risks associated with consuming cattle products contaminated with BSE-infected SRM. This is claimed to have resulted in panic, and certainly led to a loss of confidence in the government and the safety of beef, as well as a 60% decline in the consumption of beef.

- Interventions included SRM removal from, and BSE testing of, all cattle for human consumption. The government also implemented a feed ban for all farm species, and did so within days following the announcement of the first BSE case in Japan. Over time these interventions, coupled with effective active and passive surveillance, resulted in a rise in confidence, returning beef sales to their previous level.

- No economic analysis was conducted in Japan during and after adoption of these BSE interventions. The Food Safety Commission, an independent agency for risk assessment, has been established, but economic analysis is not within its scope.

- It would be useful to have an independent agency tasked not only with risk assessment, but with economic analysis of decision making, as well. This would ensure that proposed interventions are in the best interests of society.

- The results of these analyses can be presented in risk communication so that the stakeholders will know not only the risk associated with the food, but the costs and benefits of proposed interventions, as well.

- It is unnecessary and economically wasteful to exceed the BSE control interventions recommended by the OIE or those used in EU countries that had the greatest exposure to BSE, the largest epidemic and greatest experience of the disease.

- International standards should be accompanied by scientific supporting documents so that countries that adopted interventions based on international standards will know what level of protection they will provide, and that any additional interventions might provide only a marginally higher level of protection.
References


MHLW (Ministry of Health, Labour and Welfare) (2001), “Administrative instruction on safety assurance of food produced from bovine materials that may include specified risk materials”, Director-General of the Food Sanitation Department, Medical Affairs Bureau, MHLW, Tokyo.


A global overview of the livestock sector is presented, focusing on two important concepts: the livestock revolution and the “perfect microbial storm.” We review trends in global livestock production and consumption, and examine the economics of global surveillance systems. We conclude by presenting the World Bank vision for future investments, and a proposition to expand One Health global programs. We conclude by providing short-, medium- and long-term proposals for future economic work.

* This paper has been edited by Amar Toor based on a transcript of the audio recording of the Workshop.
In this paper we provide a global overview of the livestock sector. We focus on two important concepts: the livestock revolution that Christophe Delgado foresaw, and the “perfect microbial storm” that Lonnie King described. We then bring these two concepts together to discuss the need for a global program based on our recent experience with facilitating a global response to Avian and Human Influenza threat or the Food Security crisis.

We review the economics of global surveillance systems, showing that costs for these systems are far lower than those associated with disease outbreaks. We conclude by offering short-, medium- and long-term proposals for future economic work.

The livestock revolution

There are three primary drivers behind the increase in consumption of animal products. The first is population growth. By 2050, the global population is expected to reach 9 billion (Figure 1). The second is urbanisation; 70% of the world’s population is expected to live in urban areas by 2050 (Figure 2).

![Figure 1. Projected world population growth, 1970-2050](source: World Bank communication based on FAO data.)

![Figure 2. Trends in urbanisation, 1970-2050](source: World Bank communication based on FAO data.)
Income is the third driver behind increased consumption of animal products. Per capita income has evolved in different ways across developing and developed countries, though with the exception of Europe and the United States, it is generally on the rise (Figure 3). Per capita income in Asia, for example, is expected to rise at an annual rate of between 5% and 7% through 2050. Global meat consumption, meanwhile, has risen in parallel with income (Figure 4).

Figure 5 shows the world production of eggs milk and meat from 1970 to 2006, illustrating the “livestock revolution” on all livestock products that Christopher Delgado described nearly 15 years ago (Delgado et al. 1999). The livestock revolution continues to this day, as global meat production is expected to rise even higher over the coming decades (Figure 6). Much of this growth is expected to come from developing countries.

The increase in consumption of animal products has led to structural changes across the livestock sector, as the industry scales from smallholder mixed farms to large scale, specialised industrial production systems. Technological changes, meanwhile, have had significant impacts on everything from breeding, feeding and housing, to disease control, processing, transportation and marketing. Rapid consumption growth has also led to geographical shifts in supply and demand, as well as a shift in species, as the production of monogastrics has increased rapidly, while the ruminant production has slowed. Amid these changes, there has been an increasing emphasis on global sourcing and marketing.

Although the livestock revolution presents opportunities, it faces several challenges, as well. The livestock revolution has provided unprecedented perspectives on the global market, while offering a potential way out of poverty through the “livestock development ladder”. It has also made important contributions to improving nutrition and food security, though it faces issues related to the environment, sustainability and productivity. Other challenges include ensuring food quality and safety, animal welfare and traceability. As we have seen in the past, the sector impressive growth has been primarily fuelled by the private sector with insufficient public interventions. The void in public policy and investment has led to a series of negative impacts relating to the environment, public health and equity. In order to reverse this trend, we must devote more resources to public interventions, policies and investment for a safer, fairer and more sustainable livestock sector.

Figure 3. Per capita income, 1980-2009

Source: World Bank communication based on FAO data.
Figure 4. Relationship between meat consumption and income, 2007.

Per capita GDP (USD, PPP)

Source: World Bank communication based on FAO data.

Figure 5. Global production of livestock products, 1970-2006

Source: FAOSTAT.

Figure 6. Global meat production 2005-2007 and 2050

Source: World Bank communication based on FAO data.
The “perfect microbial storm”

Lonnie King (2004) described the “perfect microbial storm” as follows:

A group of factors are swirling and converging to create a perfect microbial storm. This metaphor helps explain the conditions and dynamics that have produced a new era of emerging diseases that began approximately 25 years ago. From the centre, or eye, of the perfect microbial storm, a group of zoonotic pathogens of significant public health concern are emerging.

Our experience with avian flu in the 20th century is an example of King’s storm. Avian flu had dramatic effects on all segments of the society, from smallholders to national economies, but fears of pandemic and concerns over public health were the primary reasons it garnered so much attention. This illustrates two important points. The first is that global attention to avian flu helped raise awareness of the importance of emerging and re-emerging animal diseases among the donor community. The second is that it is important to have a consolidated economic message when communicating with donors on these complex issues (this is something we are still struggling to achieve).

While the perfect microbial storm has significant effects on humans and economies, we do have solutions at our disposal. Early detection and rapid response proved to work well in combating avian flu, in adherence to international standards and guidelines from the OIE and other organisations. Rinderpest eradication is another success story. Global freedom from Rinderpest was declared in 2011, making it the first animal disease to be eradicated (following the eradication of smallpox in 1980 in humans).

Animal disease is very complex and difficult to assess with models, estimates or analyses. It is even more complex for non-OECD countries, where data can be poor, capacity may be weak, and risks remain high.

The economics of global surveillance

This section provides an overview of the economics of global surveillance and discusses a One Health system where both public health and veterinary systems would be strengthened and their collaboration improved. Country budget data on human and animal disease prevention and control systems are not in the public domain, and are generally not included in national Public Expenditure Reviews. Global estimations have been published in some reviews, including Contributing One World, One Health: A strategic framework for reducing risks of infectious diseases, prepared by a FAO, OIE, WHO, the World Bank and other international agencies. Estimates, however, are the result of “art” rather than “science”.

History could guide our rationale. A recent paper from the World Bank (2012) estimated the costs of eight recent outbreaks from six zoonotic diseases (BSE, Nipah virus, West Nile virus, SARS, HPAI and RVF). Over the period from 1998 to 2009, total costs were estimated at approximately USD 80.2 billion or USD 6.7 billion per year (Figure 7). Over the past decade, direct costs of global disease outbreaks amounted to USD 20 billion. Including indirect costs, this total increases to USD 220 billion, and is even higher if value chain-, trade- and tourism-related costs are taken into consideration.

The estimates of returns from investment in One Health systems (i.e. better collaboration between improved health and veterinary systems) from 139 client countries are enlightening. In a low prevalence scenario, yearly savings from One Health systems amount to USD 184 million, or about 10% of total costs. In a high prevalence scenario, savings total USD 506 million, approximately 15% of costs. Among all developing countries, savings amount to USD 37 million per year. Yearly costs of global surveillance systems total USD 852 million for 49 low income countries, and USD 1.3 billion for 149 non-OECD countries. For
developing countries, costs total between USD 2.9 billion and USD 3.4 billion per year. When compared to the high costs associated with global disease outbreaks, these data make a compelling case for investing in global surveillance.

**Figure 7. Economic impacts of selected diseases**

Collaborative approaches and joint strategies are crucial for success. Within the World Bank Group, we are in the process of developing a global livestock agenda for the next decade, incorporating approaches outlined in the on-going WB Agriculture Action Plan, including the cross-sectoral topics of climate smart agriculture and agricultural risk management. We have also taken a cross-sectoral approach with respect to human health, as demonstrated in the Public Health Policy Note and World Bank common work program on nutrition and One Health.

The World Bank would support the idea of a global program, implemented with our partners, and based on the principles of One Health. We are already building some partnerships with key international organisations, including the Global Alliance for a Safer, Fairer and More Sustainable Livestock Sector, and the Tripartite initiative to advance the One Health approach (a partnership with the WHO, OIE and FAO).

The aim of these initiatives is to focus on strengthening national animal health systems — a necessary condition for addressing challenges and taking advantage of opportunities. Risks associated with animal disease are interconnected with socioeconomic, environmental and public health risks. One Health offers a way to efficiently manage these risks at the animal, human and ecosystem interface.

The operationalisation of One Health requires internationally recognised tools and expertise to evaluate both animal and human health systems, and to establish joint programs for sustainable improvements that meet international standards. It also requires a framework that World Bank task teams can use to prepare and implement projects that strengthen animal
and human health systems. Finally, we must consider financial mechanisms to scale up One Health implementation across the globe, in partnership with the private sector and other stakeholders.

Specifically such a program would follow the same approach as the past Global Program for Avian Influenza (GPAI) by proposing a technical menu consisting of (i) solutions to apply the strategy formulated by the Tripartite to strengthen systems and their collaboration; (ii) solutions to tackle global priority issues: AMR, animal influenza and rabies; and (iii) response to specific requests from countries to address other national priority issues.

Areas for future economic work

We have short-term, medium-term and long-term recommendations for OECD and partners in order to move forward with a global program to improve health systems and prevent diseases. In the short term, we must better communicate the need to invest in a global program that would combine system support with disease prevention and control. For that to happen we need to get the top experts (economists and epidemiologists working together) issue a collective economic assessment as a rough global estimate of the cost of these major diseases or issues. In the medium term, there is a need for more cost-benefit analysis of national, regional and global programmes, and a clear methodology that can be used in regular economic analysis. This methodology would have to capture the complexity of investing in systems for a set of pre-defined global diseases and issues (for example the three topics selected by WHO-OIE-FAO for implementing one health: animal influenza; canine rabies; and antimicrobial resistance). Finally, in the long term, there is a need for further research on the costs of major diseases and the benefits of good governance of veterinary services and public health systems. This would help fine tune methodologies.

References


Understanding farmer behaviour assists in preventing and controlling infectious livestock disease while incentives are important to understanding and predicting behaviour. This paper examines the utility and insights from applying the principal-agent model to farmer behaviour with potential moral hazard (hidden action) and adverse selection (hidden information) in livestock disease management. Moral hazard may apply to biosecurity decisions while adverse selection may apply to disease reporting. The example of compensation policies illustrates the importance of creating appropriate incentives: compensation must be large enough to ensure early reporting, but not so large that it discourages appropriate levels of biosecurity effort.
Livestock disease is an important economic issue that affects trade, food prices, farm welfare and human health. Farm actions have both private and public benefits, but farmers generally consider only private costs and benefits. Economics can often be a useful framework within which to analyse problems. Economics is the study of the allocation of scarce resources by people, firms, governments and other organisations. Scarce resources include capital (e.g. money) as well as time, effort and natural resources. Governments do not have an endless supply of resources, and farm managers cannot devote unlimited time, effort and money to prevent disease. We must therefore consider economic efficiency in disease prevention and control.

In terms of livestock disease, a government’s primary objective is to maximise welfare. The government must consider public health, cost to consumers, cost to producers — including long-run investment and structural adjustment behaviour — and cost to taxpayers. Farm efforts and actions related to disease control are often costly or impossible to monitor, and even farmers may not have perfect information about whether animals are diseased.

Public policies affect farm incentives through indemnity payments for infected animals (or herds), movement and testing restrictions, and sanitary licensing requirements, output grades and standards (Wolf, 2005). In some instances, government policies have sought to prevent and control disease by implementing testing, quarantines and slaughter. Slaughter of the infected animal or herd is mandatory in some cases, and the farmer is reimbursed with an indemnity payment. In other cases — as in the example discussed below — farmers may have a choice in the course of disease control. When the farmer has a choice, the financial consequences associated with biosecurity and disease reporting are critically important. In terms of the incentives provided by compensation for diseased livestock, there may be trade-offs between biosecurity and disease reporting. One might reasonably expect that higher payments to farmers for disease animals will increase the likelihood of reporting. On the other hand, the higher the compensation provided for diseased animals, the less incentive provided to prevent the disease as the payment mitigates the damage from diseased livestock on the farm.

This paper explores the incentives that indemnities offer for diseased animals or healthy herds and animals that are at risk. We consider the utility of a principal-agent framework and information problems. This analysis is intended for a general audience and, as such, the model and results are presented without the rigorous mathematics that would normally accompany an economics paper. We highlight interesting and relevant findings from the economics literature. The reader is directed to examine these publications in detail for a more rigorous treatment of these issues.

The paper proceeds as follows. In the following section, the principal-agent model framework is laid out in general terms, and moral hazard and adverse selection issues are discussed. This framework is then applied to indemnity policy in disease reporting and biosecurity decisions at the farm level. Research related to these issues is reviewed, and general conclusions are highlighted as they apply to the problems discussed. The paper concludes with a discussion of the implications of managing information asymmetries with incentive-appropriate policies.

**Modelling economic incentives and behaviour**

Economists assume that people maximise utility — a concept that could be loosely translated as satisfaction or happiness. Since money can be used to buy things—including leisure time — it is common to assume that money can be used to index utility, though there are other factors related to satisfaction and happiness. Another common assumption is that firms exist to make profits, and that money can therefore be used to assess their performance.
Governments are usually assumed to maximise social net benefits for consumers, producers and taxpayers.

Economic models are abstractions from reality, whereby a given problem is stripped down to its core set of decisions. In doing so, it becomes necessary to ignore some less crucial aspects. One must also be careful to consider assumptions being made. For example, in classical economic models it is common to assume that all market actors have full information. If that assumption is incorrect, one must consider how the model will change. The potential for asymmetric information can lead one to the type of models considered in this paper.

The economics of information is an important area of research that considers incentives, contracts and behaviour. While perhaps not an explicit contract, in many countries there is a relationship between governments and farmers or livestock industries in preventing and controlling livestock disease. Governments, for example, control borders, negotiate trade agreements, and establish eradication and surveillance programs. Farmers, meanwhile, are responsible for their own herd health management, and must report diseases to eradication programs. For many contagious diseases — particularly those with human health implications or trade implications — the government will purchase diseased animals with an indemnity. Sometimes, the compensation includes further assistance to clean and disinfect, or even payments for business interruption (perhaps in the form of subsidised business interruption insurance). The relationship between farmers and the government could therefore be considered in terms of a contract. The farmer will make a reasonable effort to prevent disease or report the presence of disease, and the government will make efforts to prevent the introduction of the disease, provide surveillance in the country and pay for diseased animals in the event that disease is reported.

Further reflection on this relationship, however, reveals that there are many cases where the farmer might have relevant information about disease in his herd — as well as information about his or her efforts to prevent disease (e.g. the likelihood of disease) — that is unknown to the government. In cases with hidden information or hidden action, it is natural to ask, “What is the best contract that can be devised to solve this problem?” The question we address below is, “What is the best contract to encourage farmers to behave appropriately in terms of disease prevention and control?” In order to address this, we consider what is called the principal-agent model, with which we can formally solve for contracts where there is hidden action and/or hidden information.

The principal-agent model is concerned with structuring the contractual relationship so that the agent is motivated to act in the best interests of the principal. In the case of livestock disease, the government (or governmental agency or, perhaps, livestock industry) mandated with preventing, controlling and eradicating disease is the principal, while the livestock farmers (and perhaps others in the supply chain, such as processors) are the agents. In this paper, we focus on farmers as agents. Incentive problems arise when the principal wants to (or has to) delegate tasks to agents. The agents have information that is relevant to the transaction — such as how much effort the farmer is putting into biosecurity to prevent disease spread — that the principal cannot monitor perfectly.

These problems are probabilistic. For example, neither the principal nor the agents know with certainty whether the disease will happen or not. If they knew, then the appropriate response would be obvious (e.g. if it will not occur, prevention efforts may be ignored). There is also a possibility that the disease will still occur even if the farmer does everything correctly. Similarly, there is a possibility that the farmer will shirk his or her responsibilities, and the disease will not occur. Thus, we must consider expected costs and benefits.

We assume that the government’s (principal’s) objective here is to minimise the expected cost of disease. This cost includes the costs of detecting and eradicating the disease (likely
taxpayer costs), as well lost consumer and producer surpluses from trade restrictions and other market-related implications. The standard assumption is that the government is risk-neutral and can therefore minimise expected costs.

Farmers (agents) are assumed to be risk-averse. That is, they prefer a certain value rather than a risky proposition with the same expected payoff. For example, they would prefer a payment of USD 500 to a coin flip that pays either USD 1 000 or USD 0, depending on the outcome. In order to introduce risk aversion into the problem, it is necessary for the farmer to maximise expected utility of wealth or income from the livestock enterprise. Therefore, we introduce the financial ramifications of farm decisions on wealth or income, but we do so through a utility function.

When we deal with information problems, we arrive at what economists call “second-best” solutions. This is in contrast to “first-best” solutions, where an agent’s optimal behaviour can be elicited because information on effort and type are known. If the monitoring of biosecurity efforts and reporting is imperfect, or if there is imperfect information about the risks faced by farms (depending on factors such as size, location and type), we end up with a “second-best” solution. The first-best biosecurity choice is the one that the government would choose to make on its own, without having to rely on the farmer to make the choice. Accordingly, the first-best outcome arises when there are no constraints on the government’s problem.

In cases where the agent can choose to participate in the contract, we must ensure that the contract incentivises participation. This is known as the participation constraint, and is applicable in the case of voluntary disease management programs. In this case, this constraint requires that an agent’s expected utility from participating in the contract be at least as great as the expected utility from not participating. However, in the case of mandatory disease control and eradication programs, the agreement between the government and farmers operates as a de facto insurance contract, and this constraint may not be relevant.

All information problems aim to align incentives and encourage agent behaviour. We must therefore be concerned about the solution meeting what is called the “incentive compatibility” constraint. This constraint specifies that the agent’s expected utility from putting in the appropriate amount of effort (with all the cost implications that entails) must be at least as great under the contract terms as if he or she put in a lesser amount of effort (at presumably lower cost).

To formally solve a principal-agent problem for an optimal contract, we specify the agent utility function that meets certain conditions and includes, as a decision variable, terms related to the contract. This utility function is used along with the reservation utility (if participation is voluntary) to determine the participation constraint. The incentive compatibility constraint ensures that the agent puts in the desired effort by making sure that agent utility under high effort is at least as great as agent utility under low effort. The principal’s objective function is optimised subject to agent participation and incentive constraints.

If a government pays indemnities to farmers for diseased livestock, the government is the principal that wishes to minimise expected disease cost, subject to farmers to investing the appropriate amount of effort into disease prevention and control. The cost minimisation problem subject to at least the incentive compatibility constraint yields an indemnity schedule that aligns incentives. There are two types of information problems in the principal-agent framework that might apply to livestock disease indemnities: moral hazard and adverse selection.
Moral hazard

Moral hazard refers to a situation where the agent(s) can undertake actions that affect the value of the transaction with the principal, but the principal cannot perfectly monitor or enforce these actions. The idea is that if the agent can put in less effort without detection — and less effort decreases the likelihood of a desirable outcome — then we would expect the agent to shirk responsibilities. One way to look at it is that if others are willing to pay for mistakes you make, then you are less likely to consider the negative repercussions of your own behaviour.

The solution to moral hazard is for the principal to use incentives to share the risk related to the outcome. A classic example of moral hazard is automobile insurance. In this example, drivers might be inclined to drive recklessly if all expenses are covered in the case of an accident. Here, the insurance company (principal) uses deductibles (the portion of accident costs not covered by insurance) to incentivise the driver (agent) to take precautions. The deductible shares some of the risk with the agent.

Moral hazard issues can arise in livestock when an indemnity affects a farm’s biosecurity investment. While the government would prefer that farmers take every available precaution to prevent disease, budget and time constraints (and perhaps lack of information) combine to limit the amount that most farms allocate to these activities. Couple these constraints with the fact that public benefits may be larger than the private, on-farm benefits of disease control, and we can see how the farmer might rationally underinvest in biosecurity from a public point of view (at least with respect to the highly contagious diseases that have mandatory indemnity programs).

A solution here might be to make the potential farm loss under disease (i.e. the part that indemnities do not cover) so significant that the farmer has an incentive to put time and effort into an effective biosecurity program. We explore moral hazard and biosecurity investment in more detail below.

Adverse selection

Adverse selection refers to a case where the agent has information pertaining to the transaction that is relevant but unknown to the principal. The solution to adverse selection is to structure the contract so that the agents’ choice of the terms of the contract they purchase signals their type (i.e. high or low risk). A classic example is a life insurance program whereby the person purchasing insurance (agent) has more information about their current health status and family medical history than does the insurer (principal). One solution to this problem is to offer better benefits for initial years of the policy, thereby perhaps signalling current health status.

Adverse selection might arise when farmers are tasked with reporting disease. If the farmer reports disease, he or she will incur costs related to that reporting, but if the disease is hidden, another set of expected costs will be incurred. If the farmer perceives (perhaps incorrectly) that expected costs are smaller when disease is not reported, we expect him to choose this option. (It is important to note, of course, that not everyone would do act this way, but in the case of highly contagious diseases, only a few bad outcomes — perhaps even one — can cause significant economic damage.) If the costs of reporting depend on market-, industry- and farm-specific factors, we might expect behaviour to depend on these circumstances. For example, if reporting results in an indemnity payment that is set at an average market price, we might expect those farms with inferior quality livestock to be more amenable to reporting than those with superior quality livestock. Similarly, if reporting results in mandatory depopulation and business interruption, we might expect farms with relatively higher fixed costs (which must be paid during business interruption) to be more reticent to report than those with lower fixed costs (Wolf, 2006).
Papers that apply the principal agent model to moral hazard or adverse selection with rigorous treatments include, for example, Ross (1973), Holmstrom (1979), Myerson (1979), Milgrom (1981), Rogerson (1985), Hyde and Vercammen (1997), and Mirrlees (1999). Laffont and Martimort (2002) give a well written, accessible overview of available models. Here, the principal-agent model serves to frame the question in, and highlight key considerations of, both farmer and government decisions.

Biosecurity investment

Private and public incentives may also diverge around biosecurity measures to prevent disease. Farmers can manage livestock disease in several ways. Livestock disease management is a trade-off between ex ante prevention and ex post control (McInerney; Chi, et al.). In general, additional resources allocated to prevention should result in lower disease incidence and, thus, lower control costs. With respect to prevention, farmers can allocate operating resources or investments to biosecurity programs. Biosecurity includes both investment in infrastructure as well as labour and management to utilise these investments. These programs often involve limiting livestock contacts (e.g. through quarantines and controlled movement of livestock new to the operation) as well as preventing other potential vectors from entering farms (e.g. wildlife or human contacts). Biosecurity may also involve testing livestock and feed prior to purchase, strict sanitation of people and vehicles entering the farm, separation of newborns from infected dams, and protecting feed supplies from wildlife. Farmers may view these disease prevention activities as a form of risk management. Farmers control disease by monitoring and testing their own herd and reporting relevant infections to authorities. Treating disease is possible in some cases, and may involve vaccines, antibiotics and veterinary visits. In situations where recovery from the disease is impossible or treatment expense is economically prohibitive, culling animals may be the only recourse. Early involuntary culling has long term implications for livestock capital stock and significant costs related to animal replacement.

Farmers are motivated to control disease because they want to avoid livestock mortality and related replacement expenses, livestock morbidity and related production losses, increased veterinary and medicine expenses, and potential business interruption losses that arise when government programs mandate slaughtering the entire herd or flock. Farmer motivations to shirk disease control include time, labour, management and capital constraints, as well the increased cost of replacement animals. The fact that only the value of the animal is reimbursed under most governmental indemnity programs may also motivate a farmer to shirk disease control.

The farm may choose to maximise expected net profits (or utility as a function of expected profits) by choosing appropriate prevention and control management practices. A standard optimisation results in first-order conditions that equate the decline in marginal expected loss from disease (the marginal benefit from prevention measures) to the marginal cost of control measures (McInerney; Chi, et al.). The decline in expected losses is a benefit from farm biosecurity. This decline in probability of disease may apply to many diseases or pests (Gramig and Wolf, 2007). It may also spill-over, benefiting neighbours and associates by lowering their incidence of disease (Hennessy 2007), lowering the possibility of wildlife disease, or lowering the incidence of human health risk. It is desired that the farmer report disease quickly in order to limit its spread. Farmer reporting for contagious diseases with indemnity programs has large public benefits, protecting human health, food production and trade relations. These public benefits are one of the economic justifications for government involvement. Thus, for any animal even suspected of being diseased, the preferred farmer behaviour is to swiftly call a veterinarian or animal health official.
The private consequences of reporting disease, however, provide an array of disincentives. If the animal has a disease for which there are mandatory control or eradication programs, the herd or flock will be depopulated, resulting in lost genetics, potentially lost capital value (depending on indemnity payment relative to actual market value) and losses from business interruption, as fixed costs must be covered. In addition, other herds in the region or even the entire country might be subject to quarantine or movement restrictions, depending on the disease. These restrictions result in losses for other herds, and perhaps even for the entire industry. Even the suspicion of a diseased animal can shut off international trade for some diseases (e.g. bovine spongiform encephalopathy). The potential for consumers to associate (perhaps incorrectly) human health risks with the presence of disease can result in reduced demand. For diseases with mandatory control and eradication programs, government and media scrutiny is also expected and unpleasant. Thus, the farmer may be inclined to respond by waiting to see if recovery is possible, quickly sending the suspect animal to market, or destroying the animal without alerting authorities. In the case of contagious diseases, and particularly those that spread quickly, any obfuscation or delay can greatly increase the disease consequences.

In order to encourage reporting, the government could offer a higher indemnity. All things being equal, the higher the indemnity the greater the likelihood of disease reporting. In order to align incentives, the farmer must be compensated for reporting at least as well as they would be under the next best alternative. For example, if the farmer believes the alternative is to quietly market the animal and avoid business interruption, then the indemnity must be at least equal to the amount it would receive on the market.

Although the amount required to incentivise reporting is a function of current market conditions and a number of potentially farm-specific factors, we can frame the problem by considering several issues. If depopulation is required and a farm is ordered to abstain from livestock production for some quarantine period, then business interruption is a relevant consideration for the farmer. Business interruption losses include foregone revenues net of avoided costs. Economists discern between variable and fixed costs by labelling costs as fixed if they are unavoidable even when production does not occur. This concept is useful for understanding business interruption losses. When a livestock enterprise is removed from a farm, many (and perhaps most) variable costs of production are not incurred. For example, there is no need to purchase feed for those animals.

By definition, fixed costs cannot be avoided and do not vary when production ceases (over the time period considered). These include overhead expenses and other costs that accompany an operational farm. The standard list of fixed costs includes interest on investment, depreciation, property taxes and insurance. Because depopulated farms are assumed to resume operation, the fixed costs must be covered during the interim period. There are examples of farm business interruption insurance and other compensation schemes intended to separate the biosecurity decision from indemnities (Meuwissen, et al., 2000).

Other cost-related factors that might influence reporting include the operation type, size and financial status. One might align reporting incentives by making indemnities contingent upon farm disease reporting. Of course, this assumes that a reasonable manager would and could notice the disease, and therefore is more applicable to diseases with readily identifiable symptoms.

Disease reporting and biosecurity in the economics literature

Here, we consider examples from the literature which illustrate the application of these concepts and concerns to disease indemnities. Although not framed in a principal-agent model, the study by Kuchler and Hamm (2000) examined US farmer reporting of sheep infected with scrapie, a prion disease. The US government had an indemnity eradication
program from 1952 to 1992, at which point it was replaced with a voluntary flock certification program. Kuchler and Hamm examined 41 years of experience with indemnities as a natural experiment on the incentives created by prices. The authors recognised the potential for moral hazard, as farmers could essentially manufacture diseased animals if it was profitable to do so. Although the market price for sheep moved in response to supply and demand, the indemnity payment was set by fiat. Relative prices are important in this case, and when the fixed indemnity was higher than the market price for sheep, farmers “produced”, or found, more diseased animals. Similarly, when the indemnity was lower relative to market price, fewer animals were turned in for indemnity. Kuchler and Hamm found that the supply of diseased animals was not only upward sloping, but that it was price elastic, as well. Being price elastic here meant that a 1% increase in the indemnity payments relative to the market price for lambs yielded a greater than 1% increase in the number of confirmed scrapie cases.

Sheriff and Osgood (2010) also addressed the reporting of diseased animals, considering the disclosure of Rift Valley fever in an East African livestock market. In this case, the problem centred on a repeated interaction between farmers and buyers in a market, and it yielded interesting results. Shepherds have information regarding animal health that the buyer does not possess, and this information is costly to obtain through testing. For a shepherd to disclose disease, it must be incentive compatible. In a one period model, shepherds who reveal true disease prevalence all receive the same price. If the buyer believes there are too many diseased animals, the market collapses. Random disease testing can facilitate truthful disclosure. Allowing for multi-period interactions with inter-temporal correlation of livestock health changes the results. By revealing disease exposure today, sellers signal a higher chance of future exposure. If they believe the buyer will use this information against them, sellers with unhealthy animals must be compensated for future income loss, if they are to be willing to truthfully reveal disease today (i.e. the incentive compatibility constraint is more restrictive in the multi-period model than in a single period model). However, additional compensation cannot be so high that owners of healthy flocks claim their animals are diseased.

Gramig, Horan and Wolf (2009) considered a situation with both moral hazard and adverse selection. Farmer biosecurity investment was modelled as an ex ante moral hazard problem. Farm reporting of disease took place after disease either occurred or not (in which case reporting is unnecessary), and was modelled as ex post adverse selection. In this case, a simple one-size-fits-all indemnity payment could not deal with both problems. Instead, they showed that two distinct mechanisms were necessary. Indemnities were used to achieve desired levels of biosecurity, while fines (or a differential indemnity schedule based on reporting disease) were used to induce the disclosure of disease status. By using two distinct policy instruments — each designed to deal with a single information problem — it was possible to incentivise farmers to behave in a manner consistent with government objectives. Comparing these results to a simple indemnity reveals an important difference: Although standard indemnities increase with disease prevalence among a herd (i.e. the farmer is paid for each diseased animal), the solution here was to decrease disease prevalence over some range that reflected how long the farm was diseased before it was reported.

**Toward incentive-appropriate policies**

The primary message of this paper could be simply summarised as, “incentives matter.” When creating and implementing policies, it is advisable to consider incentives provided, or perhaps not provided. Because of public benefits and private costs, farmers may not be incentivised to behave as policy makers would prefer. Furthermore, farmer actions and relevant information about the farmer and farm operation are not generally perfectly observable. These concerns fall in the category of information problems. Economic models can help us frame the problem and point toward indemnity policies that account for information problems.
With respect to livestock disease indemnities, one price likely does not fit across diseases, farm sizes, farm types and other factors. Higher indemnity payments can encourage farmers to monitor and report diseased animals by compensating for the losses in animal value taken for disease eradication. For diseases where timely detection is crucial to minimising damages to the industry, economy or human health, higher indemnities are crucial. However, one must be mindful to not incentivise farmers to produce diseased livestock. Higher indemnity payments can discourage farmers from biosecurity measures to limit the possibility of disease occurrence and spread. Simply put, when someone else is paying for losses, there is less incentive to avoid risky behaviour. When designing policies for livestock disease control, it is critical to understand that farmers react to private incentives. The best course of action for an individual farm will depend on the farm type and size, as well as individual financial considerations. Also, government budgets are not unlimited, and must be balanced against these considerations.

The fair, disease-free market value of animals is necessarily greater than the true market value of diseased animals culled by the government. Paying market price — or even more — is often justified by its underpinning intent to create incentives for reporting. Governments have also recognised that unless farmers face some uncompensated losses as a result of outbreak, they cannot be expected to take preventive biosecurity measures. Therefore, governments generally do not compensate farmers for consequential losses when issuing indemnities. Animal health authorities have relied on a single mechanism — indemnities — to facilitate both ex ante biosecurity efforts and ex post reporting. Using a single mechanism to simultaneously induce biosecurity and reporting renders the incentives for each individual private action less clear.

Some countries have implemented policies that move toward sharing risk in interesting and appropriate ways. For example, if dead animals fetch no indemnity, there may be a penalty to delaying the reporting of a disease. This policy can help achieve incentive compatibility with reduced or eliminated monitoring costs. Partial compensation for already-infected animals shifts some of the risk to farmers. An indemnity plan that does not shift risk in this fashion may actually create incentives for infection.

There are some limitations and possible extensions worth noting. The first limitation is the political feasibility involved with possibly paying less than “market value” for diseased animals in order to encourage reporting. Reducing indemnities for diseased animals is consistent with the notion of “fair market value”, as these animals have little or no value. We have also not considered the externalities that occur because of private reporting and biosecurity decisions. It is clear that one farm’s decision to biosecure is likely influenced by perceptions about the likelihood of infection, and dependent upon their neighbour’s biosecurity choices. Finally, we could also consider multi-period interactions and inter-temporal correlations of agents which may have important consequences for incentives depending on political, economic and epidemiologic factors of the disease and country in question.

References


Ramsay, G.C., P. Philip and P. Riethmuller (1999), “The economic implications of animal diseases and disease control at the national level”, in The Economics of Animal Disease Control,


In animal agriculture, biosecurity decisions are dispersed across many herd owners. Choices affecting disease spread are determined by impacts on private economic values, as well as economic externalities. But not all externalities are alike. By way of three very distinct examples, we demonstrate how they differ, and what these differences mean for policies seeking to manage them. The examples examined include an endemic disease pool that can be managed by limiting sources and flows, an exotic disease that can be managed by way of coordinated communication, and an infrastructural support externality that can be managed by disease outbreak insurance. We pay particular attention to how concentration in animal herd ownership affects incentives for disease control.
By definition, an infectious disease is a disease that can spread from one biological entity to another. In profit-motivated agriculture, biosecurity decisions of relevance to a region are dispersed across many animal herd owners and will be determined by impacts on private economic values. Many biosecurity choices can be considered to be economic externalities because the decision maker does not face their full consequences, but externalities can differ greatly in form and implication. By way of three very distinct examples, we demonstrate how they differ and what these differences mean for policies intended to manage them.

The first example involves an endemic disease pool that can be managed by limiting infection sources and flows. In this context, we show why private disease control efforts substitute for one another, thereby reducing the incentive for each herd owner to manage the disease. In essence, efforts by neighbouring farmers reduce each grower's incentive to act. Each farm may happily lean on a disease reducing behaviour by other farms, but leaning on others' efforts leads to suboptimal outcomes. The extent of the problem is likely worst when animal ownership is least concentrated among many farms.

The second example involves preventing the entry of an exotic disease. We show that in this case, herd owners can be well incentivised to make private disease control efforts up to a certain point. If each farmer believes that the others will do their part, they have strong private incentives to act because the farmer's own action would constitute the weakest link and the marginal private benefit from acting would be high. If farms are similar, and so likely producing about the same amount, then this weakest link problem is not a concern because the weakest link is likely not much weaker in regard to biosecurity than any other production operation. On the contrary, if farmers believe that the weakest link lies elsewhere then private incentives become weak. A concentrated herd ownership structure likely exacerbates the problem because smaller (e.g. backyard) herd owners have the least incentive to take control efforts, and may be the weakest link. However these herd owners, with different goals and technology base, may not respond to being the weakest link.

The third example focuses on an infrastructural support externality. Here we show that when one farm (likely the least profitable) drops out, the fixed costs of supporting sector-related infrastructure fall on fewer farms, and profitability among remaining farms therefore declines. Disease outbreak insurance helps manage this externality although, in light of the role that government can play in deciding control measures, we argue that it would be difficult to sustain a private sector animal disease outbreak insurance market.

**Endemic disease pool context**

**Model**

In this case, our concern is with an infectious disease that a farm may contract in light of its presence in the ambient environment. Our reduced-form model of farm-level infection is as follows. There are \( n \in \{1, 2, \ldots, N\} \equiv \Omega_N \) growers. At any point in time, the \( n \)th firm contributes time invariant flow \( x_n > 0 \) to the stock of infection on the \( n \)th farm. This flow can be controlled, and our intent is to characterise incentives to do so. Farm input at level \( z_n \) directly reduces \( x_n \) so that net infection flow to the \( n \)th farm becomes \( x_n - z_n \), but we assume that incentives are such that \( z_n \geq x_n \). The stock of infection on the \( n \)th farm at time \( t \) is given as \( q_n(t) \), which is the share of the \( n \)th farm’s herd that is infected. Some of this can escape into the external environment, henceforth referred to as the ‘pool’. The rate of escape is \( \alpha q_n(t) \) with \( \alpha > 0 \), i.e. in proportion to stock \( q_n(t) \). Of course, escape does deplete the
stock of infection on the farm. The on-farm stock of infection decays at rate $\eta q_n(t)$ with $\eta > 0$.

**Figure 1. Model of animal disease, entry, spread and control**

Infection can also spread the other way: from the pool to individual farms. The pool’s stock of infection is $P(t)$ and the flow from pool to each farm is given by $\beta P(t)$, $\beta > 0$. Finally, the pool’s stock of infection changes at rate $x_p - z_p - \lambda P(t)$, $\lambda > 0$, where $z_p$ represents public efforts to reduce direct infection flow into the public pool. As Figure 1 depicts, the flow equations are:

\[
\begin{align*}
\frac{dq_n(t)}{dt} &= x_n - z_n - \eta q_n(t) + \beta P(t), \quad n \in \Omega_N; \\
\frac{dP(t)}{dt} &= \alpha \sum_{n \in \Omega_N} q_n(t) + x_p - z_p - \lambda P(t).
\end{align*}
\]

Now in equilibrium we have

\[
\begin{align*}
0 &= x_n - z_n - \eta q_n(t) + \beta P(t), \quad n \in \Omega_N; \\
0 &= \alpha \sum_{n \in \Omega_N} q_n(t) + x_p - z_p - \lambda P(t);
\end{align*}
\]

where we write the time-invariant solutions as $(\hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N, \hat{P})$. Label $\hat{Q} = \sum_{n \in \Omega_N} \hat{q}_n$, $X = \sum_{n \in \Omega_N} x_n$ and $Z = \sum_{n \in \Omega_N} z_n$ so that the first $N$ equations in (2) can be aggregated to $\eta \hat{Q} = X - Z + \beta N \hat{P}$. The last equation in (2) yields $\lambda \hat{P} = \alpha \hat{Q} + x_p - z_p$. Solve these two equations to obtain

\[
\begin{align*}
\hat{P} &= \frac{\alpha (X - Z) + \eta (x_p - z_p)}{\lambda \eta - \alpha \beta N}; \\
\hat{Q} &= \frac{\lambda (X - Z) + \beta N (x_p - z_p)}{\lambda \eta - \alpha \beta N};
\end{align*}
\]

1. Of course the linear form of the flow dynamics for $q_n(t)$ does not guarantee that $q_n(t) \in [0,1]$, so our model is to be viewed as an approximation.
where $\lambda \eta > \alpha \beta N$ is assumed to ensure interior solutions. This is a reasonable assumption because were disease decay rates low relative to disease spread rates then disease incidence would explode and management activities would not be of the form we consider here.

To identify the steady-state level of ambient infection, from (2) we have \( q_n(t) = \left[ x_n - z_n + \beta P(t) \right] / \eta \) and so

\[
\hat{q}_n = \zeta_1(x_n - z_n) + \zeta_2'(X_{in} - Z_{in}) + \zeta_3'(x_p - z_p); \quad X_{in} = X - x_n; \quad Z_{in} = Z - z_n;
\]

\[
\zeta_1 = \frac{\lambda \eta - \alpha \beta (N - 1)}{\lambda \eta^3 - \alpha \beta \eta N}; \quad \zeta_2 = \frac{\alpha \beta}{\lambda \eta^3 - \alpha \beta \eta N}; \quad \zeta_3 = \frac{\beta}{\lambda \eta - \alpha \beta N}.
\]

Equation (4) provides the equilibrium stock of infection on a given farm. One can reference Figure 1 for intuitive responses to the model’s parameters.

The key points are as follows. Efforts targeted at reducing some \( x_n \) (and so \( q_n \)) and efforts targeted at reducing some \( x_k \) (and so \( q_k \), \( k \neq n \), are substitutes. By this we mean that \( \partial \hat{q}_n / \partial z_k < 0 \) and \( \partial \hat{q}_k / \partial z_n < 0 \). Also, \( \zeta_1 - \zeta_2 = 1 / \eta > 0 \) so that the own-farm effect of targeting infection exceeds benefits derived from other farms targeting infection, i.e. the substitution is not perfect. Finally, this pooled infection problem is essentially one of managing an impure public good (Cornes and Sandler, 1986) where benefits from an individual’s provision of the good exceed benefits to others.

**On-farm choices**

We turn now to on-farm damage. Every herd owner seeks to protect potentially valuable \( V_n \) against infection by an endemic disease. Here, \( V_n \) represents net profit in a disease-free state, in the absence of biosecurity costs. The cost of action \( z_n \) is given as \( C(z_n) \) with marginal cost \( C'(\cdot) > 0 \) and second derivative \( C''(\cdot) > 0 \). Loss is given as share \( \hat{q}_n \) so that production is given as \( (1 - \hat{q}_n)V_n \). The Nash behaviour grower solves

\[
\max_{z_n} \left[ 1 - \zeta_1(x_n - z_n) - \zeta_2'(X_{in} - Z_{in}) - \zeta_3'(x_p - z_p) \right] V_n - C(z_n).
\]

with private optimality condition

\[
\zeta_1 V_n - C'(z_n) = 0,
\]

and Nash equilibrium choice (labelled superscripted ne) level

\[
\hat{z}_m^{\text{ne}} = H(\zeta_1 V_m); \quad H(\cdot) \equiv C'^{-1}(\cdot).
\]

Setting \( NV = \sum_{m \in \Omega} V_m \), the sum of surpluses is

\[
W = \left[ 1 - \zeta_3'(x_p - z_p) \right] NV - \sum_{m \in \Omega} \left[ \zeta_1 V_m(x_m - z_m) + \zeta_2 V_m(X_m - Z_m) + C(z_m) \right].
\]
Insert (7) into objective function (8) to obtain total surplus under private actions as:

\[ W^{ne} = [1 - \zeta_3(x_p - z_p) + (Z^{ne} - X)\zeta_2]N\bar{V} - \frac{1}{\eta} \sum_{m \in \Omega_N} V_m \left[ x_m - H(\zeta_1 V_m) \right] \]

\[ - \sum_{m \in \Omega_N} C[H(\zeta_1 V_m)]. \]

(9)

We seek now to measure concentration so that we can study its effects on private biosecurity incentives. The following approach to comparing concentration is from Marshall, Olkin and Arnold (2009).

**Definition 1:** Vector \( S^* \equiv (s_1^*, s_2^*, \ldots, s_N^*) \in \mathbb{R}_+^N \) is majorized by \( S^{**} \equiv (s_1^{**}, s_2^{**}, \ldots, s_N^{**}) \in \mathbb{R}_+^N \) (written as \( S^* \prec S^{**} \)) if \( \sum_{i=1}^k s_i^* \geq \sum_{i=1}^k s_i^{**} \forall k \in \Omega_N \) and \( \sum_{i=1}^N s_i^* = \sum_{i=1}^N s_i^{**} \) where the \( s_i^* \) are defined as order statistics, \( s_1 \leq s_2 \leq \ldots \leq s_N \).

Equivalently, if one transfers some of a small \( s_i \) value to a large \( s_i \) value so that the former is smaller and the latter is larger, the result is a vector that majorizes the initial vector. As an example, consider \( S^* = (3, 5, 4) \) and \( S^{**} = (5, 2, 5) \). Now \( 3 \geq 2 \), \( 3 + 4 \geq 2 + 5 \) and \( 3 + 4 + 5 = 2 + 5 + 5 \) so that \( S^* \prec S^{**} \). Of the two, \( S^{**} \) is the more concentrated because one can transfer one unit from a “5” to the unit with “2” to bring a “5” to “4” and the “2” to “3”, making the vector’s co-ordinates more uniform. If we think of the coordinates as herd sizes, then the approach allows for a comparison of different herd ownership concentrations.

In the endemic disease pool context we will use the definition to show that a few large herds, or a concentrated herd structure, reduces the extent of disease when compared with many small herds. Proof of the following is available upon request from the author.

**Proposition 1:** If we suppose that the flow of infection is constant across farms, or \( x_m = \tilde{x} \forall m \in \Omega_N \) then under Nash equilibrium, more concentration in potential value in the majorisation sense; i) decreases equilibrium extent of disease, \( \hat{Q}^{ne} \), whenever marginal cost is convex, or \( C''(\cdot) > 0 \); and ii) increases welfare, \( W^{ne} \).

The convex marginal cost — needed for item i) but not ii) — seems reasonable since costs associated with biosecurity likely increase dramatically with a small increase in observed effectiveness. Consider the simple case of erecting a perimeter wall. If the wall’s base scales with its height, then the material cost is proportional to the square of height. But construction cost should increase dramatically with height, because more elaborate scaffolding needs to be put in place to build at more elevated levels. On the other hand, it is hard to see why effectiveness against airborne biological invasion would increase dramatically with wall height. Point i) shows that animal stock concentration in a few herds promotes the internalisation of externalities if marginal costs become more convex as input use increases. Point ii) shows that increasing animal concentration results in a decline of disease loss while covering costs, thereby increasing welfare.

The first-best problem involves recognising total value when making biosecurity decisions, i.e. solving

\[ \max_{(\zeta_1, \ldots, \zeta_N)} \sum_{m \in \Omega_N} \left[ 1 - \zeta_1(x_m - z_m) - \zeta_2(X_{1m} - Z_{1m}) - \zeta_3(x_p - z_p) \right] V_m - \sum_{m \in \Omega_N} C(\zeta_m). \]

(10)
The social optimality conditions are
\[
\frac{V_n}{\eta} + \xi_2 N \overline{V} - C'(z_n) = 0, \quad \forall n \in \Omega_N,
\]
and the socially optimum value is
\[
z_{n}^{so} = H \left( \eta^{-1} V_n + \xi_2 N \overline{V} \right).
\]
Notice that \(z_{n}^{so} - z_{n}^{ne} = H(\eta^{-1} V_n + \xi_2 N \overline{V}) - H(\xi_1 V_n) > 0\) because \(H(\cdot)\) is an increasing function and \(\xi_2 N \overline{V} > 0\). Therefore, the socially optimum level of biosecurity exceeds the Nash equilibrium level and, furthermore, the difference depends on the value of \(\xi_2 = \alpha \beta / (\lambda \eta^2 - \alpha \beta \eta N)\). Thus the magnitude of the gap increases with how infectious the disease is, as reflected by the values of spread parameters \(\alpha\) and \(\beta\).

**Proposition 2:** Nash equilibrium biosecurity efforts are smaller than is socially optimal, and the magnitude of the difference depends on the magnitude of spread parameters.

Suppose that veterinary authorities can act to reduce spread, perhaps by managing hygiene in transportation and at sales barns, publicly administering disease control schemes, or through education and outreach. Proposition 2 points out that these actions would have a twofold effect on disease control. In addition to directly reducing the extent of the infection pool, such actions would help strengthen the private payoffs that herd owners receive for taking biosecurity actions.

**Weakest link in disease entry context**

Here we consider a case where a disease is not present in a region, but there is a risk of entry. For the sake of clarity, we present an extreme example of how disease can enter and spread. Probability of entry is greatest at the weakest link, which we define as the farm that is least motivated to take biosecurity precautions. The disease spreads instantly to all other farms in the region, but there is some probability that each farm can stop entry at its border. This is a generalisation of the well-known von Liebig and Sprengel law of the minimum technology, but in this case, each link is managed independently. Independent management suggests that private biosecurity costs will enter the decision calculus, but benefits beyond those falling upon the herd owner’s farm are ignored.

To illustrate numerically, suppose that farms A and B are in an isolated region. Farms A and B both avoid a USD 100 loss if the disease stays out. If either farm allows it to enter, then the disease will certainly spread to the other farm. Efforts to ensure that the disease does not enter a farm cost USD 20, which is borne by the herd owner. If neither farm makes the effort, there is a 0.25 probability that the disease will directly enter one of the farms. If Farm A knows that Farm B makes the effort, then Farm A will also make the effort, after comparing the expected loss of USD 100*0.25 = USD 25 with the cost of USD 20. If Farm A knows that Farm B will not make the effort, Farm A will expect a baseline revenue of USD 100*(1-0.25) = USD 75, and then compare the expected loss of 75*0.25 = USD 18.75 with the cost of USD 20. It is not rational for Farm B to take action, either. Thus, both farms could conclude that it is rational to biosecure, or both farms could conclude that it is not rational. Those seeking to coordinate disease management activities across the region are therefore presented with the task of helping both farms to coordinate on biosecurity.
A version of this context has been studied by Hennessy (2008). The natural response is to take no greater biosecurity precautions than any other grower in the region. But the herd owner who takes the least biosecurity action will be the one with least to protect (i.e. the smallest herd owner). Thus, smaller herd owners will determine the overall risk of disease entry. In the spirit of Definition 1, if some animals from larger herds are transferred to smaller herds, the smaller herds will be better incentivised to prevent entry. As they constitute the weakest link, in this context a less concentrated herd structure may reduce the likelihood of disease entry.

The weakest link setting raises other issues. If small farms are of primary concern, then targeting them may be an effective approach to reducing the overall risk of disease entry. This could be done through subsidies or other “carrots”, or through efforts to close these farms down. In addition, communication in and of itself may improve biosecurity levels across the sector. In Nash equilibrium, each herd owner assumes that everyone makes decisions independently and takes the actions of others as given. But herd owner actions complement, or reinforce, protection against a common external threat. If herd owners are of the view that others do not care, they may not care either. Similarly if herd owners are of the view that others do care then the owner may come to believe that his or her action will be important in deterring entry. Coaxing herd owners to protect their farms — and clearly communicating that others are doing so — may encourage herd owners to take biosecurity more seriously. Such communication could come in many forms.

A well-developed civic structure is a noteworthy feature of many industry sectors across much of the world. Adam Smith (1976) took a dim view of industry associations:

“People of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices. It is impossible indeed to prevent such meetings, by any law which either could be executed, or would be consistent with liberty or justice. But though the law cannot hinder people of the same trade from sometimes assembling together, it ought to do nothing to facilitate such assemblies; much less to render them necessary.”

The single-mindedness of Smith’s gaze may have been the product of a less technologically developed time. Business interests are not always in conflict with consumer interests. Efforts to pool information and coordinate on addressing technical problems that impede an industry can add to the welfare of all concerned. Such industry efforts are evident in animal disease management programs around the world (OECD, 2012). Communication can also be fostered through organisational structures that facilitate knowledge and technology transfer, as is the case with the cooperative and contracting business formats that are common in animal agriculture.

The matter of how alternative agricultural systems interact with the dominant system bears some thought. These growers may have goals and technology base very different from the dominant system. They may have limited incentives and capacity to respond to being the weakest link by shoring up their vulnerability. Efforts to communicate what others are doing may have limited impact on these growers, in some part because they are not seeking to solve the same problem as growers in the dominant system.
Business continuity, insurance and regulation moral hazard

Taiwan was the world’s third largest pork exporter during the mid-1990s, exporting about 30% of its production to the Japanese market. In 1997, a foot-and-mouth disease outbreak occurred on the island, closing its export markets. Since then, the country has suffered sporadic disease recurrences, and has never regained lost market shares (Felt, Gervais and Larue, 2011). The sector’s production structure has changed dramatically, in large part because sector players have lost confidence that any investments will be adequately rewarded.

Although Taiwan’s pork industry troubles are more complex, here we examine how business continuity risk can undermine a sector’s vitality. In particular, we focus on how insurance could secure business continuity in the event of a disease outbreak. There are \( N \) farms and each produces output of value \( V_n \). If a disease occurs, all farms are afflicted and output value declines to \( V_n - \delta \). The costs of an input with fixed costs \( F \) are shared equally among the farms, and can take many forms. Animal breeding and feed used to be provided on-farm, but are typically purchased in modern production systems. Animal agriculture has also come to increasingly rely on private sector management and information services that supply benchmark data, analytical tools and other inputs. Consultants seeking to minimise a herd’s environmental footprint may also be hired. In many cases, these inputs carry a large fixed cost component.

The hazard rate for the disease is given as the constant value \( b \) while the hazard rate for recovery is given as the constant value \( a \). It is readily shown that, with continuous time discount rate \( r \), the capital values for diseased and disease-free states are

\[
\Phi^{DF} = \frac{V_n - F/N}{r} - \frac{\delta b}{r(r + a + b)}; \quad \Phi^D = \frac{V_n - F/N}{r} - \frac{\delta(r + b)}{r(r + a + b)}.
\]  

(13)

See Hennessy (2007) for details.

Firms with negative capital value in the diseased state exit. These are the firms with

\[
V_n < \frac{\delta(r + b)}{r + a + b} + \frac{F}{N} \equiv \Psi^{jec}(N).
\]  

(14)

If one such firm exits, the floor below which another firm will exit increases to \( \Psi^{jec}(N - 1) \) (Figure 2). The unbroken curve represents \( \Psi^{jec}(N) \) and is declining in \( N \) toward asymptotic value \( \delta(r + b)/(r + a + b) \). The less steeply sloped line represents output values in descending order. The curves intersect at value \( N^{jec} \) so that firms with output values \( V^{jec} \) or higher will participate. The further the participation rate moves beyond \( N^{jec} \), the more profitable high-value farms will be. If fewer than \( N^{jec} \) farms participate, none of the other farms will either.
An alternative is for firms to support an actuarially fair insurance program in which amount \( \rho \) is put aside each year, and amount \( \nu \) is returned in the diseased state. The fair premium, set up in a disease-free environment, satisfies \( \rho = b \nu / (r + a + b) \) so that (13) becomes

\[
\Phi^{DF, \text{Ins}} = \frac{V_n - \rho - F / N}{r} - \frac{(\delta - \nu)b}{r(r + a + b)}; \quad \Phi^{D, \text{Ins}} = \frac{V_n - \rho - F / N}{r} - \frac{(\delta - \nu)(r + b)}{r(r + a + b)}.
\]

(15)

In this case, firms with negative capital value in the diseased state are those for which

\[
V_n < \frac{(\delta - \nu)(r + b)}{(r + a + b)} + \rho + \frac{F}{N} \equiv \Psi^{\text{Ins}}(N).
\]

(16)

Now

\[
\Psi^{\text{Ins}}(N) - \Psi^{\text{DF, Ins}}(N) = \rho - \frac{\nu(r + b)}{r + a + b} < 0.
\]

(17)

Insurance lowers the floor, meaning that more firms remain in business. Figure 2 also depicts \( \Psi^{\text{Ins}}(N) \), as the intermittently broken curve below that for \( \Psi^{\text{DF, Ins}}(N) \). This curve intersects the output value curve at value \( N^{\text{Ins}} \) the new, lower threshold participation rate below which the regional production system collapses. In this way, insurance is a means to secure support for input and output networks so that the supply system does not collapse before recovery.

But consider now the actual environment in which a private sector insurance market for highly contagious animal diseases would exist. Almost inevitably, government representatives will decide emergency plans to manage the disease. Government costs can take many forms, including costs to the exchequer and damage done to political support. If no market insurance is available, a government may have to provide indemnities for political reasons, or perhaps also as a matter of promoting efficiency through avoiding the sector’s collapse. These costs may affect other management decisions, such as the number of animals to condemn for immediate slaughter. If market insurance is purchased widely by herd owners, the government may decide to condemn more animals for slaughter because it does not cover the cost of...
indemnification. This would increase the likelihood of ultimately stamping out the disease, thereby avoiding the repeated recurrences that Taiwan faced. This is an instance of regulatory moral hazard, where behaviour adjusts to the incomplete internalisation of consequences.

No government could commit to keeping disease management-related costs low, nor could any government be bound by some independent review of policy choices — even if it were possible to conduct such a review within given time constraints. The possibility that disease management choices would change to the detriment of the insurer could affect the extent of insurance coverage offered and the rates charged. Regulatory moral hazard might, in and of itself, undermine the market’s viability.

Conclusion

By their very nature, infectious diseases that can be managed by changing behaviours involve externalities. This paper has characterised some of these externalities, and has sought to point toward implications for disease management. Two central points can be drawn. The first is that in order to be effective, coordinated centralised disease management strategies must recognise the implications of decentralised production. Many biosecurity actions and pertinent information lie with private enterprises. Centralized disease management authorities have only limited ability to monitor and influence private biosecurity actions while growers have private incentives that are not wholly consistent with the collective interest of growers or of society as a whole. A more concentrated production system may be easier to work with as far as disease management is concerned, as suggested by our analysis of endemic disease flows. But that supposition should not be taken for granted because the analysis of weakest link in disease suggests that a production structure which involves very large and very small farms may be vulnerable to disease entry.

The second point is that context matters. Biosecurity risks and the actions taken to control these risks come in many forms. Although broad stylisation of disease problems is inevitable when extracting meaningful general lessons, a one-size-fits-all characterisation does not exist. We have pointed to instances where public and private goals can be quite strongly aligned — as with the task of keeping a pest out of a region — and to instances where they can diverge — as with free-riding to better control the extent of an endemic disease.

If one generality does exist, it is that patiently communicating and listening can help when educating herd owners about how they can contribute to a sector’s general well-being. An economist’s view on why is that it may help transform herd owners’ views on how forward-thinking other herd owners are, and that transformation can be mutually reinforcing. If public animal health infrastructure can strengthen a farmer’s view that other farmers and responsible public authorities are involved and intend to stay the course in managing an infectious disease then the farmer may see the point in doing so too. In this way all growers may come to see the benefits of vigorous disease management. Public animal health authorities are already aware that patient, persistent communication is needed to encourage grower biosecurity, although they tend to frame it as one of education and trust building rather than as an endeavour to engineer stronger grower incentives to manage disease. The point bears repetition, however, because much damage can be done to long-run disease management programs in an animal health emergency.
References


COST SHARING IN COMPENSATION SCHEMES FOR LIVESTOCK EPIDEMICS

Frank Alleweldt*
Civic Consulting, Germany

An overview of recent studies on cost-sharing compensation schemes for livestock epidemics conducted for the European Commission, OIE and OECD. Examples are taken from three existing schemes: the Emergency Animal Disease Response Agreement in Australia, the Tierseuchenkassen in Germany and the Animal Health Fund in the Netherlands. After introducing the key characteristics of cost-sharing schemes, we will examine whether they provide the right incentives, and whether they work in practice. We conclude by listing key principles for cost-sharing schemes, accounting for proper incentives and cost-benefit structures.

* This paper has been edited by Amar Toor based on a transcript of the audio recording of the Workshop.
Key characteristics and objectives of cost-sharing schemes

Cost-sharing schemes can vary across countries and regions, though they share some basic characteristics. This short paper is based on several studies by Civic Consulting for the OECD, the European Commission and the OIE on this topic. They are listed at the end of this paper.

Cost-sharing schemes are here defined as public-private schemes, which means that costs (and to some degree also responsibilities) related to livestock epidemics are shared between the government and affected sectors. They are also relatively rare, from a global perspective. Cost-sharing schemes exist only in a small number of countries, and are the exception even among EU countries.

These schemes also differ in important areas. Institutional arrangements, for instance, can vary depending on national or regional circumstances, such as institutional structures and traditions. In some cases, schemes are managed by a single ministry, at the state level (in federal countries such as Germany), or at the national level. Although all cost-sharing schemes involve stakeholders, the nature of their involvement can differ. Some involve private insurers, for example, though such schemes are very rare and not discussed in this paper. Other important differences include the degree of cost sharing, and the types of costs and losses covered under each cost-sharing scheme.

The objectives of cost-sharing schemes differ for farmers and governments. For farmers, these schemes can make the risk of outbreaks more manageable, because costs are distributed over a longer period. They also increase their involvement in prevention and outbreak management, and can generate incentives for risk reduction. For governments, cost-sharing schemes offer lower risks for public purses. Compensation can be very expensive — especially in the case of large or prolonged outbreaks — and can therefore put a strain on public budgets. Cost-sharing schemes also aim to improve the cooperation of farmers with disease control and eradication measures, and typically target high-impact diseases that have significant effects on public health or the economy. It is important to note that cost-sharing schemes generally do not cover price risks (e.g. if the market price of meat falls considerably during an outbreak) or losses in other sectors (e.g. losses incurred in transport or feed sectors).

From 1997 to 2010, the European Union spent more than EUR 1.1 billion from to the so-called “veterinary fund,” largely for the co-financing of costs and losses related to foot-and-mouth disease (FMD), classical swine fever (CSF) and avian influenza. But this sum only represents direct costs; overall losses (including indirect costs) were much higher. Cost-sharing schemes can reduce the risk and costs of outbreaks by creating incentives for early reporting and increased biosecurity. In Australia, for example, farmers have 24 hours to provide notice of an outbreak on their premises. There are similar time limits in other schemes, though some require farmers to provide notice immediately or as soon as possible, rather than within a specific time frame. If farmers do not comply, they face penalties. Some schemes also reduce compensation amounts for dead or visibly sick animals, if a herd has to be culled. In the Netherlands, for instance, sick animals are compensated at 50% of a healthy animal’s value, while animals that die prior to notification to the veterinary authorities receive zero compensation.

Australia’s scheme requires all relevant sectors to commit to biosecurity plans, while hygiene and disease prevention standards are included in schemes in Germany and the Netherlands. In some German states, a herd’s disease-free status is taken into consideration when determining the levies that a livestock holder must pay. In the Netherlands, farmers face penalties if their negligence causes an outbreak, though this is very difficult to prove, in practice.
Other incentives are less common among cost-sharing schemes. They rarely involve contributions based on individual risk levels, because such differentiation is not very popular among farmers. As we have suggested in previous works, bonuses for prevention measures may offer the most acceptable type of differentiation, including for example for “all-in-all-out” management practices for restocking. Disease-free bonuses are another alternative, offering lower levies to farms that have not had an outbreak for several years. Another possibility is to differentiate levies so that contributions are higher in high-risk regions. While high-density areas with large numbers of livestock in a specific region do not necessarily have a higher risk of disease outbreaks (due to high bio-security standards), it is clear that in the case of an outbreak, losses will be greater and outbreaks may be more difficult to contain. It is therefore legitimate to demand higher contributions from farmers in these areas, though this is rarely done.

Higher _ex post_ compensation for implementing farm-level biosecurity measures is another incentive that is rarely implemented. In this case, the compensation a farmer receives would be contingent upon the biosecurity measures he or she implements. In developing countries, community-based compensation could be used to address the issue of backyard livestock holders. Under these schemes, compensation would not be provided to the individual, but to the community, thereby increasing social pressure for risk-reducing behaviour. Thus far, however, there has been very little experience with this approach.

Compensation schemes (which include both pure compensations schemes, where the government pays the full compensation amount, and cost-sharing schemes) can also create adverse incentives. Overcompensation, for instance, can lead to moral hazard and, in some cases, compensation schemes may inadvertently reward those who cause losses. During the FMD outbreak in 2001, for example, livestock farmers who broke movement restrictions and hid their outbreaks faced fines and were summoned to court, but were still eligible for full compensation. This exposed a serious problem in the legislative framework, which has since been changed, though it underscores the need to be aware of such loopholes when designing indemnification rules. Also, compensation schemes may transfer funds from low-risk to high-risk areas, as the EU veterinary fund did between 1997 to 2010, when 77% of its funds went to two countries (the United Kingdom and the Netherlands) with very high livestock densities. A separate problem is that in some cases farmers with infected or culled herds may be better off (due to compensation payments) than those with healthy herds under veterinary restrictions (because they typically do not receive compensation, but cannot bring their livestock to market). This is rather problematic and may create adverse incentives, especially during outbreaks that extend for long periods.

There are several ways to mitigate the adverse incentives of compensation schemes.

- Livestock identification and databases remain critical, though they are not often present in developing country contexts.
- Penalties for late notification or low levels of biosecurity are currently in place across many cost-sharing schemes, and are widely accepted.
- Rapid intervention, _ex ante_ agreements with companies involved in veterinary measures (such as destruction of carcasses, disinfection), less culling and optimised restrictions can also be used to reduce losses — which, in turn, reduce adverse incentives.
- Bio-economic modelling, meanwhile, can be used to predict how a disease will spread and which containment strategy is associated with the lowest costs, thereby allowing decision makers to designate appropriate veterinary restriction zones. If the zones are smaller, the problem of adverse incentives will diminish, as less farmers are affected.
Compensation of culled animals at current market values is a very complex issue, but one that must be addressed in order to mitigate adverse incentives. Market values for meat tend to fall during a prolonged animal health crisis. Therefore, compensation values for a variety of animal types have to be constantly revised, as higher compensation values than market values may lead to a situation where a farmer with an infected herd, which is culled and compensated, may be in a better situation than a farmer with a healthy herd.

Compensation of business interruption losses of farmers in veterinary restriction zones is another complex issue. In this case, we recommend compensating the value of culled animals at the same rate as business interruption losses in restriction zones, to avoid the above described adverse incentives.

Do cost-sharing schemes work?

In practice, cost-sharing schemes make risks more manageable for farmers and the public. They can be fine-tuned according to disease categories, as is the case in Australia, and have led farmers to take on greater responsibility. Interestingly, cost-sharing schemes have a very high level of acceptance in countries where they are currently in place. Such schemes have been in place in Germany for 100 years, and there has been no desire to abolish or diminish them. The Netherlands introduced its cost-sharing scheme after the CSF outbreak in 1997, and acceptance there remains quite high. However, there is extremely high resistance in countries which do not currently have a cost-sharing scheme (but already compensate farmers in case of outbreaks) and where the government plans to implement a cost-sharing scheme, and this is important to consider.

It should also be noted that cost-sharing schemes currently provide only partial incentives for prevention. Adjusting contribution levels to individual risk, for example, is not a widely applied practice. We must acknowledge, however, that there is very little evidence on how these incentives work in practice. When we discuss this issue with farmers or their representatives, they often react (understandably) negatively to the suggestion that a herd owner might intentionally infect his or her livestock if adverse incentives are present. Of course, we do not mean to imply this in any way to be a typical reaction, as most people would likely not do this, for moral and other reasons. However, as any insurance scheme and the literature regarding moral hazard indicate, some individuals may react to adverse incentives, and in the case of livestock epidemics irresponsible behaviour of a few may have dramatic consequences. A cost-sharing scheme’s incentive structure should therefore be compatible with the aim of such a scheme, which is to reduce the overall costs of disease outbreaks by reducing risks and creating incentive for farmers to engage in risk-reduction.

Key principles for cost sharing

There are basic principles to make cost-sharing schemes work. These principles are certainly not exhaustive, and others may draw different conclusions from the experiences of existing schemes and the literature available, but in our view, they best summarise what manageable and pragmatic cost-sharing schemes should encompass.

In short, cost-sharing schemes should be mandatory (as most currently are), rather than voluntary. All operators who contribute directly to the overall risk of disease should pay into the schemes, in order to mitigate the threats posed by an outbreak. It is important to note that in our view there is no reason to require downstream industries (such as food retailers) to pay into these schemes, because doing so would introduce greater complexity, and it is difficult to argue which industries should or should not contribute, if both do not contribute to the risk of disease outbreaks. As a second principle we would suggest that all those who pay levies...
should also receive the benefits from a given cost-sharing scheme, if they are directly affected by an outbreak, thereby laying the groundwork for a pragmatic and manageable system.

Cost-sharing schemes should cover direct costs and losses related to outbreaks of relevant livestock diseases. Schemes should adjust levies according to individual risk levels, with the most workable system probably consisting of offering bonuses and maluses, depending e.g. on the level of bio-security measures implemented at a farm. As is current practice, cost-sharing schemes should not cover price risks. However, we recommend that they do cover business interruption losses in restriction zones, as well, to be incentive compatible. As mentioned before, the problem arises from the fact that if a culling policy is implemented, farmers under movement restriction may be worse off than those whose herds have been culled, thereby creating adverse incentives. The same is not true in situations where vaccination policies are put into place instead of widespread culling, and this is an area that deserves more detailed examination. If vaccination policies gain importance, the issue of adverse incentives created in restriction zone may lose relevance. In addition, overall costs of an outbreak are lower if less animals are culled (not considering animal welfare benefits), which also would reduce the potential burden of compensation for farmers and governments (and in consequence, for tax payers).

For the same reason it appears sensible that prevention measures are incorporated in cost-sharing schemes, with targeted approaches to reduce risk (e.g. by financing specific disease prevention measures, such as vaccination programs). Finally, stakeholder involvement remains essential to all cost-sharing schemes. As we have seen with schemes currently in place, stakeholder involvement creates a sense of ownership over animal health, while allowing farmers and governments to share the burden of disease management. This can lead to greater awareness and beneficial changes in behaviour.

References


Improper risk financing solutions for market losses may withhold farmers to punctually participate during an epidemic in so-called “vaccination-to-live strategies.” This paper shows that although market losses are not straightforward to insure, loss parameters can be assessed. It also demonstrates that recently introduced EU subsidies can act as a catalyst for agriculture-related risks that are difficult to insure, thereby promoting more efficient eradication strategies, including “vaccination-to-live.” Findings of this paper are useful for policy makers and chain actors to jointly design risk-sharing solutions for market losses.
Public concerns over destroying large amounts of animals spurred policy makers to adopt so-called “vaccination-to-live” strategies to control future outbreaks of livestock epidemics (Hop et al., 2012). This strategy, also known as protective vaccination, includes destruction of infected and contact herds coupled with simultaneous vaccination of susceptible herds within a certain radius. Under this strategy, products from vaccinated animals are not destroyed, but marketed “as usual” (European Commission, 2003). In the Netherlands, contingency plans foresee protective vaccination for future outbreaks of classical swine fever (CSF) and foot and mouth disease (FMD). Yet after nearly ten years of debates, the question of selling products from vaccinated animals remains unresolved, with policy makers recently associating market losses from vaccination with entrepreneurial risk. Nevertheless, public-private solutions to finance these losses may be needed for farmers not to frustrate vaccination programs. Similar arguments have been put forth to find public-private financing solutions for direct losses (Meuwissen et al., 2003a).

Market losses can result from supply and demand distortions arising from special heat treatments applied to meat stemming from vaccinated animals. They can also result from consumer concerns over the safety of products from vaccinated animals. Market disruptions are expected for non-vaccinated regions, as well, though little is known about the size of market losses under protective vaccination regimes. In epidemics where stamping-out or suppressive vaccination strategies were deployed, market losses were only described in qualitative terms.

For instance, Vrolijk and Poppe (2008) state that in November 1988, about six months after the end of the CSF-epidemic, “prices came at the lowest levels after the Second World War Market”. Huirne et al. (2002) estimated that more than half of the FMD farm-level losses arriving from business interruption came after the epidemic ended. With regard to AI, Mourits et al. (2008) state that substantial income losses were incurred by multiple partners of the supply chain.

The limited information about the size of risk and the catastrophic nature of market losses hinder the design of a viable public-private risk financing solution. In this context, this paper aims to discuss the insurability of market losses in general, to elicit expert judgments on the expected size of market losses, and to review the experience of re-allocation of EU subsidies to facilitate insurance uptake for catastrophic risks in agriculture.

The insurability of market losses is assessed along the set of idealised conditions from the viewpoint of the insurer (Rejda, 1998). For reasons of completeness also the already covered direct losses are included as well as business interruption losses. For the latter, for some sectors and in some member states private insurance already exists (Van Asseldonk et al., 2006). With regard to the to date experience of using EU premium subsidies for catastrophic insurance, assessments focus on the Netherlands and address extreme weather as well as disease insurance.

**Insurability of epidemic disease losses**

Before a risk can be financed with a pooling system, certain basic requirements must be fulfilled (Rejda, 1998). Each item is addressed below, both in a general context as well as with a focus on the various damage components of livestock epidemics (Table 1). Not all idealised conditions hold for the various loss components, with problems arising due to the number conditions. Yet this does not mean that a pooling system is impossible, since the

---

1. In the Netherlands, pig farmers could insure business interruption damage from CSF and FMD outbreaks through a mutual (founded in 2002). In 2012, the mutual was discontinued due to lack of interest (Meuwissen et al., 2013).
problems can be partially overcome with a sound design of the risk sharing tool, as discussed below.

### Table 1. Extent to which loss components of livestock epidemics in a protective vaccination framework fulfil risk pooling requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Veterinary losses</th>
<th>Business interruption</th>
<th>Market losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>There must be a large number of exposure units</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>The loss must be accidental and unintentional</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>The loss must be determinable and measurable</td>
<td>+</td>
<td>+</td>
<td>--</td>
</tr>
<tr>
<td>The loss should not be catastrophic</td>
<td>-</td>
<td>+</td>
<td>--</td>
</tr>
<tr>
<td>The probability of loss must be calculable</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>The rates must be economically feasible</td>
<td>+</td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>

Scale applied: -- = requirement violated; - = requirement somewhat violated; + = requirement somewhat fulfilled; ++ = requirement fulfilled.

**Large number of exposure units.** Ideally, there should be a large group of roughly similar (but not necessarily identical) exposure units that are subject to the same peril or group of perils. The loss can then be spread over all participants in the underwriting class (Rejda, 1998). Although the susceptibility for a specific disease agent differs across types of livestock production, these discrepancies can be easily addressed by setting up specific pools, or through premium differentiation. Additional risk-determining factors include the animal and herd densities, the incidence of wildlife that may be carriers, and the proximity of airports and seaports as sources of infection. The expected size of epidemics varies across areas, as well, depending largely on animal and herd densities. Differentiating premiums according to the location of a farm is likely to increase interest in insurance among farmers from outside hazard-prone areas, thereby giving the insurer potential for risk spreading.

**Accidental and unintentional loss.** In an ideal situation, the loss would be fortuitous and outside the participant’s control, thereby preventing moral hazard (Rejda, 1998). With moral hazard, exposure units change their behaviour in a manner not predicted by the owner of the system after signing the contract — for example, by becoming more careless (Arrow, 1996).

A livestock farmer can influence the expected probability of the herd becoming infected. Factors that influence this probability include the sanitary barriers and hygiene on the farm, the number of animal contacts and whether stock is purchased from sources with known health status or from markets and dealers. A farmer’s influence on the size of risk is likely to cause problems of adverse selection and moral hazard in an insurance scheme. Adverse selection can be minimized by differentiating premiums according to measurable risk factors. Moral hazard can be minimized with contract specifications on “due diligence” and with deductibles. Moreover, establishing an appropriate legal framework covering epidemic fraud (with appropriate penalties) reduces incentives to be dishonest.

Governments can also influence losses through the control strategies they deploy. Governments decide on — and are held responsible for — the control measures taken during an epidemic. Relatively extensive movement standstills and elaborate protective vaccination programs are effective strategies to eradicate an epidemic. Veterinary costs decrease at the expense of market losses. Therefore, transparent and systematically-applied control measures
are necessary. Governments and insurers must also reach agreements about the control strategies to be applied under various circumstances in order to avoid debates on this issue during an epidemic.

**Determinable and measurable loss.** “Determinable” means that the amount of loss can be limited and clearly expressed if a certain expense is within the defined loss. “Measurable” means that the loss is financial and that its amount can be determined, either through calculation or estimation. Compensation of the veterinary costs can be based either on a preset animal value or actual market value at the moment of culling. The indemnity for business interruption losses should be based on the actual incurred loss or a proxy of the loss (for example, indemnity could be based on duration times average gross margin). Quantifying market losses *a priori* is fairly cumbersome and can be problematic, since there are hardly any claim experiences available. Linking expert elicitations to simulation studies, as described by Longworth et al. (2012a, b), seems useful in this respect.

**Not catastrophic.** In order to make the pooling technique workable, a large proportion of the exposure units must not incur losses at the same time. With systemic or correlated risks, multiple participants can suffer losses at the same time (Skees and Barnett, 1999). Livestock epidemics generally involve many farms at the same time, and a massive protective vaccination program only amplifies this problem. Problems arise with respect to pooling within a year, as adequate reinsurance capacity is not typically available when the scale of systemic risk is large (Jaffee and Russell, 1997; Miranda and Glauber, 1997). The capital market is also not well acquainted with epidemic disease risks. Losses resulting from a decrease in product market value are therefore difficult to transfer. Limited subsidies may be justified in order to encourage private markets to design risk-sharing solutions (Arrow, 1996; Meuwissen et al., 2003b). In the European Union, such subsidies have been available since 2009, as discussed below.

**Calculation of probability of loss.** To set an appropriate rate, one must accurately calculate the cumulative distribution function of both the frequency and severity of losses (Rejda, 1998). Historical data on disease outbreaks and associated damage figures are too scarce to derive the cumulative distribution function, and may not be fully relevant if, for instance, the control measures have changed. Historical data on the probability of protective vaccination being applied, and the circumstances under which this would happen, remain scarce. Nevertheless, risk models estimating the impact of outbreak scenarios can be helpful.

**Feasible rates.** The farmer must be willing to pay the rate, but research shows that people typically have problems in assessing the probability and potential magnitude of such risks (Kunreuther, 1976). Because of such cognitive failure, farmers’ willingness to pay for insurance is less than the actual premium required (Skees and Barnett, 1999). However, there are business interruption coverages that compensate farmers at times of an outbreak (Van Asseldonk et al., 2006). In this context, effective risk communication remains crucial.

**Elicited size of market losses**

Expert judgments on the size of market losses originate from 2004. During that time, i.e. in the aftermath of the 1997/98-CSF, 2001-FMD and 2003-AI epidemics, policy makers and chain actors were jointly assessing the expected impact of protective vaccination. Expert panels were interviewed sector-wise, i.e. one panel for the pig sector, one for the dairy sector and one for the beef, veal, sheep and goat sector. Experts were from private companies as well as from public organizations. Groups ranged from 4 (dairy panel) to ten experts (pig panel). As a point of reference, participants were first presented with price data from the 2001 FMD epidemic during which suppressive vaccination was applied. They were then asked to estimate aggregate market loss percentages, i.e. we did not ask experts to differentiate between various market loss items, chain participants, or time frames. Percentages were...
assessed in an FMD context and specified with regard to farm-gate price levels (only for dairy and white veal, factory-gate and slaughterhouse-gate prices were used respectively).

Table 2 shows the results of the expert elicitations. For vaccinated animals, expected market losses are especially high for pork, including piglets and hogs, and some white veal, including an expected price decline of 75% and 80%, respectively. With regard to pigs and hogs, the Netherlands, as a net exporter, is expected to see severe supply and delivery problems, and would incur high costs of temporarily storing large amounts of labelled meat. High loss percentages for veal mainly arise from the necessity to sell meat without bones after vaccination; normally, 80% of white veal is sold with bones. Similar arguments apply for marbled veal, as well as meat from sheep and goats. For the percentage of meat already deboned under normal circumstances, prices are mostly expected to decline to world market levels for matured meat from vaccinated animals (which is 35% below normal market prices). With respect to dairy, experts expect lost markets to be reflected by a price decline of about 10% of the default price. (However, in the event of a large epidemic with extensive vaccination zones, they expect prices to even decrease by 20%).

Table 2. Elicited market loss parameters for protective vaccination in the Netherlands

<table>
<thead>
<tr>
<th></th>
<th>Default price²</th>
<th>Vaccinated animals (8 months)³</th>
<th>Other animals in affected region (length of epidemic)³</th>
<th>Animals in non-affected regions (8 months)⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Production affected (%)</td>
<td>Price impact (%)</td>
<td>Production affected (%)</td>
</tr>
<tr>
<td>Dairy³</td>
<td>0.57/kg</td>
<td>100</td>
<td>-10</td>
<td>100</td>
</tr>
<tr>
<td>Beef</td>
<td>2.50/kg</td>
<td>100</td>
<td>-35</td>
<td>100</td>
</tr>
<tr>
<td>Piglets (25 kg)</td>
<td>41.50/piglet</td>
<td>100</td>
<td>-75</td>
<td>100</td>
</tr>
<tr>
<td>Hogs (110 kg)</td>
<td>1.27/kg</td>
<td>100</td>
<td>-75</td>
<td>100</td>
</tr>
<tr>
<td>Marbled veal⁶</td>
<td>2.62/kg</td>
<td>80/20</td>
<td>-60/-35</td>
<td>100</td>
</tr>
<tr>
<td>White veal⁶</td>
<td>5.65/kg</td>
<td>80/20</td>
<td>-80/-55</td>
<td>100</td>
</tr>
<tr>
<td>Sheep &amp; goat⁶</td>
<td>2.25/kg</td>
<td>80/20</td>
<td>-60/-35</td>
<td>100</td>
</tr>
</tbody>
</table>

1. Protective vaccination includes destruction of infected herds, limited pre-emptive culling of contact herds, and emergency vaccination of all susceptible herds in a 2-km zone around infected herds. Vaccinated animals and their products are marketed. Estimations are for foot and mouth disease epidemics in the Netherlands.
2. Farm-gate prices. Only for dairy and white veal other prices are used, i.e. factory-gate and slaughterhouse-gate prices respectively.
3. Period during which market losses occur.
4. Includes non-vaccinated animals from affected region from end of epidemic until abandoning of restrictions at the national level (8 months).
5. The 80/20 difference relates to percentage of produce normally delivered to Dutch and EU markets (80%) and other markets (20%).
6. The 80/20 difference relates to percentage of produce normally not deboned (80%) and deboned (20%).

Elicited loss percentages in the other columns of Table 2 — for non-vaccinated animals in affected regions and for animals in non-affected regions — are generally much lower, though substantial losses are expected in some sectors. For instance, experts from the pig sector expect that 100% of piglets and hogs in non-affected regions would face lower prices, for the same reasons as mentioned above. Dairy experts also expect considerable losses in non-affected regions, as the percentage of dairy products normally exported to third countries (20% and, in this case, outside the European Union) is supposed to face severe problems due to decreased demand. In general, all sectors in non-affected regions are believed to face market losses. Experts do not believe these regions would benefit from the occurrence of an epidemic, as was temporarily the case during the 1997/98 CSF epidemic in the Netherlands.
EU premium subsidies for agricultural insurance

After many years of debates among opponents and proponents of EU support for agricultural insurance, Article 68 of EC 73/2009 opened the pathway for EU contributions to insurance schemes (European Commission, 2009). More specifically, the regulation supports premiums for weather and disease insurance. It is also possible to receive support for setting up mutual funds, and for the compensation paid by such funds to farmers for losses suffered. Approval of Dutch and EU governments is required to obtain support. A 30% deductible must also be implemented, and subsidies are to be paid directly to involved farmers.

So far, insurers in the Netherlands have applied for the premium subsidies rather than the other types of support available. Moreover, it has been mutuals (not commercial insurers) who have actually applied for premium subsidies (Meuwissen et al., 2013). As shown in Table 3, these mutuals cover greenhouse and field crops, fruits, and breeding and rearing stages of the broiler chain. (Although the European Union had already approved broiler insurance and support, the price risk coverage was ultimately not provided by the broilers mutual, as members could not agree on the exact scope of the insurance — e.g. whether it should apply exclusively to farmers in restriction zones or to the Netherlands as a whole.)

Lack of commercial interest may arise from uncertainty surrounding the subsidies. After CAP reforms, they are likely to move from Pillar 1 (production support) to Pillar 2 (rural development), and it is not entirely certain what the impact of this transfer will be.

Table 3. Insurance schemes in the Netherlands using EU premium subsidies

<table>
<thead>
<tr>
<th>Insured commodities</th>
<th>Perils to which subsidy applies</th>
<th>Premium subsidies since</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse and field crops</td>
<td>Multi-peril weather risks</td>
<td>2010</td>
</tr>
<tr>
<td>Fruits</td>
<td>Multi-peril weather risks</td>
<td>2010</td>
</tr>
<tr>
<td>Broilers (breeding and rearing)</td>
<td>Market losses AI epidemics</td>
<td>(2012)(^2)</td>
</tr>
</tbody>
</table>

1. Premiums are subsidised up to 65%. Support originates from EU (75%) and Dutch (25%) governments.
2. Subsidy for AI-losses was approved in 2012, but coverage was finally not provided by the mutual.

Discussion and conclusions

Designing insurance solutions for market losses is a challenge plagued by uncertainties. Will protective vaccination actually be applied? How will the market respond? From a risk management perspective, it is important to find solutions in order to provide farmers with the necessary incentives to punctually participate in vaccination programs.

This paper illustrated that market losses are not easy to insure, as they do not fulfil all conditions of an insurable risk. The size of the risk and its catastrophic nature are especially problematic. At the same time, we demonstrated that insight into the potential size of losses can be obtained, and that EU subsidies recently became available to facilitate the design of schemes. Loss assessments show that market losses can be substantial for pigs and white veal calves, in particular. Although figures originate from 2004, marketing channels have remained fairly unchanged since then.

Results are useful in bringing policy makers and chain actors together once again. The 2009 introduction of EU subsidies is expected to enhance and accelerate this process, since, as the broiler mutual demonstrated, price impacts of livestock epidemics are eligible for subsidies. However, experience in the Netherlands also demonstrated that EU subsidies for agricultural insurance are not yet widely applied. They could be steered by the relative

LIVESTOCK DISEASE POLICIES: BUILDING BRIDGES BETWEEN SCIENCE AND ECONOMICS © OECD 2013
newness of the subsidies, and the uncertainty about CAP reforms and the related repositioning of insurance subsidies.

If chain actors and policy makers want to make progress in developing insurance for market losses, “peace time” seems to be the best time to do so. This paper clearly identifies major difficulties, the sectors that should be prioritised, and the role that subsidies could play as a catalyst for difficult-to-insure risks in agriculture.

References


EC (2009), Council regulation establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers, EC, No. 73.


Market incentives to participate in, and contribute to, public-private cost-sharing compensation systems are examined. Using Mexico’s recent experience with avian influenza as a case study, we examine how to inform policy makers about different market incentives to increase private sector involvement. We conclude by describing the role that OECD can play in uncovering incentives for private and public actors to participate in the design of cost-sharing mechanisms.

* This paper has been edited by Amar Toor based on a transcript of the audio recording of the Workshop.
There is an important human component to animal disease control policy making, especially in Central America and other developing regions (Figure 1). Policy agendas in these regions often revolve around issues of poverty reduction, food insecurity and inequality. It is therefore important to clearly establish how the work we do can help governments achieve these objectives.

National compensation systems are one of the key public incentives for early reporting, and can therefore reduce the costs of controlling animal disease outbreaks. Fiscal budgets, however, remain a primary constraint in many countries, and especially in developing economies. One dollar spent on a disease control instrument is a dollar that could have gone toward other policy objectives, such as education. It is therefore important to avoid disincentives for the private sector to contribute to the establishment of national compensation systems. In developed countries, 80% to 90% of the budget for cost-sharing schemes is supplied by the public sector, though it is not clear whether this could be a feasible option for developing countries as well.

In this short paper based on Acosta (2013), we explore market incentives to participate in, and contribute to, public-private cost-sharing compensation systems. Using Mexico’s recent experience with avian influenza as a case study, we examine how to inform policy makers about different market incentives to increase private sector involvement. We conclude by describing the role that OECD can play in uncovering incentives for private and public actors to participate in the design of cost-sharing mechanisms.

Case study: HPAI-H7N3 outbreak in Mexico

Mexico is the world’s largest per capita consumer and second-largest producer of eggs. On 21 June 2012, Mexico reported a highly pathogenic avian influenza outbreak. This resulted in significant economic losses, including elevated control costs, a reduction in productive capacity, reduced supply of meat and eggs, job losses and real income reductions.

National compensation systems can offer benefits, though developing countries are faced with the challenge of establishing collaborative mechanisms between the public and private sector. Here, we examine how price dynamics change before and after an outbreak, and identify very clear market incentives for other sectors to participate in the establishment of collaborative mechanisms. There is an important opportunity for retailers, in particular, to participate in this process.

In Mexico, egg prices increased by approximately 40% following the outbreak, rising from about MXN 20 per kilogram to nearly MXN 35 per kilogram. From the data, it is not immediately clear whether this was a real increase or one fuelled by speculation. In September 2012, the Mexican government announced the elimination of egg import tariffs, resulting in a drastic reduction in egg prices. It was recently revealed that no eggs were imported, so it is reasonable to assume there was some speculation, otherwise prices would have remained high.

In our analysis, we examined how the outbreak affected retailers’ price margins, and whether there were significant differences before and after. We will not treat the model in detail here, but the results show that price margins for retailers declined by about 41% after the outbreak, and that the magnitude of transmission between prices increased by 23%. We also found that prices adjusted faster during an outbreak period, with speed increasing by 10%. Price stability is a main incentive for different actors to contribute to the establishment of a national compensation system. When actors attempt to maximise utility, they try to equalise marginal costs of production and prices. If prices are stable, they can allocate resources more efficiently. Based on these data, we conclude that there is a very clear
incentive for other actors (outside of producers and the industry) to participate in the establishment of these mechanisms.

These results can be interpreted as follows. If wholesalers’ egg prices were to increase by MXN 1 per kilogram under a normal regime, retailers’ prices would increase by MXN 2.7 per kilogram. 24% of this increase would be transmitted directly to retailers in the following week, with the remaining MXN 2.05 transmitted over future periods at a rate of 32% per week. Under an outbreak regime, retailer prices would rise by MXN 1.57 per kilogram for the same increase in wholesale prices. Retailers would receive 47% of this increase within the following week, and the remaining MXN 0.83 would be transmitted over future periods at a rate of 42% per week. It is therefore clear that margins are reduced, which suggests that retailers could play a prominent role in the establishment of national compensation systems.

Conclusions

There are several conclusions to draw from Mexico’s experience with avian flu. The first is that early identification and immediate action are critical to reducing the spread of HPAI. To reduce disease spread in developing countries, it is important to establish collaborative, public-private compensation mechanisms. Finally, there are clear market incentives for private actors to be more involved in the design, implementation and funding of national compensation systems. OECD can play an important role in uncovering the potential economic incentives for both public and private actors to participate in the design of these mechanisms.

Reference

SOCIAL ISSUES, RISK PERCEPTIONS
AND ANIMAL HEALTH POLICIES

Julie Barnett
University of Bath, United Kingdom

The challenge of accounting for public sensibilities about risk when developing policy is the focus of this paper. It aims to provide an overview of the main insights from research on the public perception of risk. We consider the policy making context within which public perceptions of risk are taken into account, and outline key dimensions of public responses to risk. We also explore recent trends concerning engagement with the public, examining the question of whether policy development should be sensitive to the nature of the risk. We conclude that increased attention to the social aspects of managing animal health issues can be informed by the substantial literature concerning public risk perception. Challenges arise in the integration of this literature with changing behaviours and, perhaps more importantly, with the practical processes of policy development.
This paper focuses on the challenge of accounting for public sensibilities about risk when developing policy. This challenge is a familiar one, particularly among policy domains that implicate the public, involve multiple stakeholders, and have an evidence base that draws on uncertain or contested science. Policymakers face the question of how public values and perspectives will be taken into account — or, in some cases, whether they should be at all. Previous OECD work on chemical risks has considered one aspect of this: the role of risk communication in risk management decision making and implementation (Renn and Kastenholz, 2000).

This paper aims to provide an overview of the main insights from research on the public perception of risk. The question remains, of course, as to exactly how these can, or should, be accounted for during policy development. At this stage, understanding public perceptions of risk is not simply a matter of using this knowledge to enhance communication at the end of the process. Nor is it a matter of communicating risk in a way that is most likely to garner public acceptance, or avoid or dilute opposition. Public perceptions of risk should instead inform policy development at a much earlier stage. This may mean taking account of public interpretations of the risk during the process of risk assessment itself.

The paper will unfold as follows. First, we consider the policy making context within which public perceptions of risk are taken into account. Having considered how the public is defined, we then outline key dimensions of public responses to risk, while considering the position of the risk communicator as well. We then explore recent trends concerning engagement with the public, examining the question of whether policy development should be sensitive to the nature of the risk. Following an extended consideration of the Social Amplification of Risk Framework (SARF), the paper concludes by reviewing recent work on behaviour change, using the example of Lyme disease.

The policy process and “the public”

When developing animal disease management policies, policy makers are faced with challenges concerning shared responsibilities and costs, ensuring resilience and managing crises. The economic implications of developing policy options in these areas are hugely important to any consideration of a policy’s viability. As a discipline, economics has a well-established role in policy development, but this is not quite the case for social sciences such as sociology or social psychology. It is important to consider these disciplines more closely, as history bears witness to the consequences of ignoring the social contexts in which policies are implemented. Even a cursory survey of the animal health context reveals social issues that are likely to impact the effectiveness of policies. For example, what motivates farmers to report disease? Why does the public “panic”? Why doesn’t the public seem to listen to, or act upon authoritative scientific evidence?

Social issues should be considered throughout the policy development process. The diagram below, drawn from work done at the Department for Environment, Food and Rural Affairs (DEFRA) in the United Kingdom, presents an “ideal type” of this process.

In reality, the policy development process is much messier than depicted here (Delborne, Schneider, Bal, Cozzens, and Worthington, 2013). For example, “defining the issue” and “identifying and prioritising evidence needs” are inherently political activities that are constrained by past definitions, and their effectiveness may be rarely evaluated. However, the diagram suffices as an articulation of the various activities that (more or less explicitly) take place in the policy development process, and of the points at which publics and stakeholders — their actions, habits, values, and perceptions — might be taken into account. The diagram also makes clear that it is vital to consider the social context and the possibilities for engagement with publics and stakeholders at the outset of the policy development process. It is almost a truism now to cite genetically modified foods as an example where policy
development was led by the science, with publics excluded from discussion about the implications these products might have for their food supply.

Before establishing the policy making context in more detail, it is worth considering what we mean by “the public.” Who are the public? Why do we refer above to “publics” in the plural? How are they different from stakeholders?

Although the term “the public” is often used when considering reactions to risk issues, in reality it is inaccurate and unhelpful to think of the public as a single, homogeneous body. In any consideration of public perceptions of risk, it is vital to acknowledge that there are multiple publics (Renn, 2006). Even if they broadly concur in identifying benefits of a particular course of action (and they may not), their rationales for doing so may be very different (Gross, 2007).

Renn (2008) describes a helpful set of distinctions to differentiate publics from stakeholders. Stakeholders are defined as “socially organised groups who are or who will be either affected by or have a strong interest in the outcome of the event or the activity from which the risk originates and/or by the risk management options taken to counter the risk”.

Publics can be divided into three groups: those who are directly affected; the general public — those who are not directly affected but are part of emerging public opinion on the issue; and observing publics, which includes the media and opinion leaders who may comment on the issue and influence emerging public opinion. We will return to some possible implications of these divisions at a later point in this paper.

Both stakeholders and publics are generally compared with “experts”. This is not a homogeneous category either, but for the purposes of this paper, experts can be considered as those who are knowingly contributing to, or drawing upon, an evidence base for the purposes of developing policy. In this sense, they can be contrasted with both stakeholders and publics,
which are similar to each other (in principle at least) in the sense that both could be affected by a certain policy. This broad distinction will serve to orient the following parts of the paper, where we consider the predispositions of those receiving risk information from policy officials and those responsible for communicating risk information.

Responses to receiving risk information

There is a well-established and extensive literature that sheds light on the way in which the public makes sense of risk information (see Maule, 2004, and Pidgeon, et al., 1999, for helpful overviews). It is clear that the public values trustworthiness. People are concerned with whether they can trust those who are responsible for managing and regulating risks (Van Kleef, et al., 2009). The trustworthiness of those managing risk or communicating risk information is likely to override the risk information per se, as well as any estimates of its likelihood and consequences. Frewer, et al. (1996) write that “trust in risk information about food-related hazards may be as important a determinant of consumer reactions as the content of the risk information.”

Much research has been carried out on trust in information sources, and how this can shape consumer responses — particularly where there are long term uncertainties or challenges to social and ethical values (Siegrist, 2000; Siegrist and Cvetkovich, 2000; Siegrist, et al., 2000). Lack of trust is thus seen as a key factor underlying public disquiet, rendering risk prevention or assurance messages less effective (Bennett, et al., 1999).

The quality of information sources is hugely important when seeking to determine the veracity of that information. Ellis (1992) writes that “it is doubtful if any receiver of information can separate the message being communicated from the source of the communication.”

What are the characteristics of trust? One crucial factor is whether people think they share the same values as those managing risks. This partially explains why doctors generally attract higher trust ratings than politicians. Credibility, expertise and honesty are also important (McComas and Trumbo, 2001; Renn and Levine, 1991).

Transparency about the presence, magnitude, consequences and nature of a risk is often aimed at increasing trust (Frewer, et al., 2002; Krebs, 2001). But as Marris et al. (2001) note, it is often necessary to reorient policy institutions as well, underscoring an important balance to simply focusing on trust deficits among the public.

Secondly, lay publics will likely be sensitive to differences in the framing and presentation of numerical information. Behavioural economics has developed some of the early insights from prospect theory to show the difference in response depending whether same information about choice options is presented or “framed” as a gain or a loss (Kahneman and Tversky, 1979): people tend to be risk averse when a decision is framed in terms of gains, and risk seeking when framed in terms of losses. Similarly, the presentation of information (for example, whether in numerical or percentage format) can affect its reception (Gigerenzer et al., 2005). It is important to remember that experts may also misinterpret risk information (Gigerenzer and Edwards, 2003) and are not immune from the biases and errors that citizens are subject to (Brest, 2013).

Perhaps one of the most well-established findings in risk perception literature is that public reactions to risk are not irrational. On the contrary, they are actually quite systematic and predictable. In addition to valuing the trustworthiness of those managing and communicating risk, people attend to several qualitative dimensions of risk, dubbed by the UK Department of Health and others as “Fright Factors” (Department of Health, 1998). They are most concerned about risks that are, for example, dreaded, involuntary, unfamiliar,
inequitable and inescapable. Verbeke et al. (2007) allude to this idea when discussing the role of such factors in the formation and onset of a crisis.

Finally, it is important to recognise that people make judgments about risk in the context of their everyday lives. They are therefore responding to risks alongside a range of other priorities, experiences, practices and values, framing the risk in a way that makes it relevant to these everyday beliefs and practices (Horlick-Jones and Prades, 2009; Horlick-Jones et al., 2007; Marcu et al., 2011).

Communicating risk information

Bodies responsible for managing and communicating risk sometimes rely upon unhelpful models of public responses, focusing instead on perceived shortcomings and deficits, with little recognition of the systematic ways in which public perceptions of risk are generally structured (Barnett, Cooper, and Senior, 2007; Sturgis and Allum, 2004). It is certainly the case that the public may not attend to, or correctly calibrate, risk probabilities. However, it does not follow that the public is ignorant, sceptical, or worried “because it does not understand the science” (Irwin and Michael, 2003). Filling a perceived deficit in knowledge with information does not mean that public judgments about the risk will be different, or that the public will show increased acceptance of the risk (Sturgis and Allum, 2004). On a related point, bodies may attribute public concern to risk when it may in fact stem from broader societal values or priorities. There has been a move in more recent literature to include a wider scope of risks and benefits when thinking about assessment and communication. Cope, et al. (2010), for instance, argue that economic, ethical, social and environmental impacts should all be considered in risk and benefit assessments.

Engaging with the public

In the wake of a series of high-profile risk issues — most notably, BSE and genetically modified food — and amid a climate of public scepticism, disconnection and distrust, it is generally recognised that it is not enough to simply tell people about risks. Consequently, governments and other organisations concerned with managing risk have shown an increasing focus on more inclusive or deliberative ways in which the public can be engaged (Fischhoff, 1995; Leiss, 1996). A singular focus on top-down communication will rarely suffice as a tool to manage risk, and consultations have the reputation for being a box-ticking exercise, rather than a meaningful way of incorporating public and stakeholder views into policy.

As Barnett et al. (2007) write, “informing the public remains an important goal in order to facilitate informed debate and decision making, but alongside this it is recognised that scientists and policy makers have much to learn from attending to public opinions, attitudes and values.”

Agreement on the necessity (if not the value) of engaging with the public is now widespread. The Royal Commission on Environmental Pollution (RCEP) in the United Kingdom exemplified this when it called for the development of “more direct methods to ensure that people’s values, along with lay knowledge and understanding, are articulated and taken into account alongside technical and scientific considerations” (RCEP, 1998).

Earlier, we drew attention to the distinctions within and between the categories of stakeholders and publics. We now return to the significance of these distinctions in the context of engagement. These distinctions are significant because it may be important to involve these groups in the governance of risk, depending on the nature of the risk problem (IRGC, 2005).
What is meant by “the nature of the risk problem”? The IRGC distinguishes between simple, complexity-induced, uncertainty-induced and ambiguity-induced problems. It is in the latter category, where there are major ambiguities associated with a risk problem, that it is advisable to provide opportunities for publics (both those that are, and are not directly affected), stakeholders and experts to contribute to discussions about how the risk should be managed. This means engaging in an open discussion about competing arguments, beliefs and values. As an example of this, Defra recently commissioned a research project to engage a wide range of citizens and stakeholders in understanding and debating the future strategic direction of Bovine Tuberculosis policy. Starting in late 2013 this engagement exercise will include stakeholder and public workshops as well as a digital engagement stream.

The nature of the risk problem is also important in determining the way that policy is made. At the heart of an influential framework developed by Stirling lies the importance of acknowledging incomplete knowledge, and of avoiding “the temptation to treat every problem as a risk nail, to be reduced by a probabilistic hammer” (2010).

With uncertainty, unlike risk, knowledge of probabilities is problematic. As Stirling explains, this has implications for the development of policy, requiring that recognition of the plural and conditional nature of knowledge be met with plural and conditional methods of science-based advice. A single interpretation masks uncertainty, as well as the assumptions that have been made in order to arrive at that interpretation (rather than others that may have been equally plausible).

In addition to risk and uncertainty, there are two other types of incertitude: ambiguity and ignorance (Stirling, 2007). The state of knowledge about a novel agent like transmissible spongiform encephalopathy, for example, is (or certainly was) best characterised as a state of ignorance — a state where knowledge about both probabilities and outcomes is problematic. Stirling, (2007) makes a persuasive case that the development and presentation of policy options should reflect the completeness of our knowledge.

The social amplification of risk

Risks related to animal health, as with many other risks, are subject to dynamic social processes. These processes are brought together for consideration within the Social Amplification of Risk Framework (SARF) (Kasperson et al., 1988; Pidgeon, Kasperson, and Slovic, 2002). Perhaps the most fundamental tenet of SARF is that reactions to risk are a function of the social processes through which risk is communicated and interpreted. When risks are communicated, their impacts are rarely local. Indeed, with the advent and growth of social media, this communication can often be instant and global in reach.

SARF was developed to explain why public attention to a given risk is often of a different order than experts consider to be warranted. A hazard may garner concern among the observing public (e.g. the media), the directly-affected public and the general public as well as stakeholders, yet experts may consider the risk to be low. This phenomenon is known as risk intensification. Conversely, hazards that experts consider to be serious receive comparatively little attention — a situation known as risk attenuation. The risk perception literature is replete with examples of events where public attention was broadly considered to be either intensified or attenuated. Relatively common, yet sometimes very serious hazards (e.g. salmonella) linked to everyday food preparation and hygiene practices provide an example of the social attenuation of risk perceptions. Health experts may expend considerable resources trying to raise awareness and stimulate change in relevant behaviours, but often to little avail. BSE provides the most commonly cited example of risk intensification because the nature and extent of societal impacts were far in excess of expert risk assessments.
A focus on intensification and attenuation should not lead to conclusions about the apparent irrationality of public perceptions. As we established earlier, there is a well-established literature highlighting the systematic ways in which people attend to particular characteristics of risk. SARF also describes and seeks to explain observations that the effects of an event are often not confined to the domain in which they originate. The authors describe these secondary consequences in terms of ripple effects, which include impacts on the market. Tourism, for example, declined significantly during the 2001 foot-and-mouth disease (FMD) outbreak in the United Kingdom, and the associated economic impacts resulted from government advice that the public should avoid visiting affected areas of the country (Pidgeon and Barnett, 2013). Thus, organisations can serve as “stations of amplification” insofar as they represent the risks in ways that may intensify or attenuate risk signals.

Unsurprisingly, the media plays a key role in representing risk, typically focusing on certain characteristics of an issue that attract attention (DoH, 1998). The media tend “to concentrate on rare but dramatic hazards, and often fail to report more common but serious risks” (Wahlberg and Sjoberg, 2000). Its focus is often personalised, focusing on victims or survivors with little reference to the structural cause of the event (Kuttschreuter, et al., 2011). The rising use of social media enables coverage that is “in the moment,” and citizen-generated images of hazardous events are becoming ever more common (Mythen, 2010).

Media coverage may focus on images that come to be strongly identified with particular risk events and can trigger public sentiment (Joffe, 2008). The images of piles of dead animals burned during the FMD outbreak, for instance, remain memorable. Images elicit stronger emotional engagement and trigger greater concern than do texts (Boholm, 1998) and have a greater capacity to confirm the ‘truth value’ of an event (Joffe, 2008). In addition, metaphors used as part of risk communication sometimes attain unwanted significance. During the 2001 FMD outbreak, a war metaphor was used as part of a call to action. This later became associated with images of a war zone (Nerlich, 2004).

**Influencing behaviour**

In the final section, we turn our attention to what is often a goal of communicating risk: influencing behaviour. There are many animal health-related scenarios in which policy aims to influence the behaviour of stakeholders (e.g. adopting new husbandry practices, managing cattle suspected of having TB, or disposing of dead animals) or publics (e.g. eating food products from vaccinated animals or shifting patterns of access to the countryside). As mentioned previously, influencing behaviour is not simply a matter of communication. Communication may raise awareness, but for many reasons, this does not necessarily lead to a change in behaviour. It is not solely a question of trust, either. For example, people may consider that the risk does not apply to them, they may exhibit optimistic bias (Weinstein, 1989), or the behaviour to be changed may be habitual or enjoyable.

Recent years have seen a great deal of work exploring the change and maintenance of behaviour within a policy context and on a one-to-one basis. The Behavioural Insights team, located within the UK cabinet office, has produced several reports and initiatives in this area, keeping with the UK government’s tendency to encourage behavioural change in ways that do not necessitate regulation (Boyce, Robertson, and Dixon, 2008). Among these works, the “nudge” agenda has been prominent (Thaler and Sunstein, 2008). Incorporating some of the insights from behavioural economics, this approach examines how change can be encouraged by addressing the “choice architecture” (including, as we noted above, changes in the loss- or gain framing of information). The MINDSPACE report provides perhaps the most comprehensive overview of policy approaches in this area (Dolan, et al., 2010). Not surprisingly, the nudge approach has been subject to critique and interrogation (Goodwin, 2012).
Early on, the role that behaviour change might play in managing a risk should be considered in relation to all other options. A paper by Quine et al. (2011) uses the management of Lyme disease (LD)-related risks as an example. Changing public behaviour has to be considered alongside other options such as targeted control (which has little viability in the case of LD) or medical intervention (also of limited applicability to LD, at least at the pre-infection stage). Research and monitoring is not a priority to assist with management, largely because LD’s lack of impact on animal health and its generally low impact on human health mean that it is not a priority for those who own and manage land. In the case of LD, then, the most proportionate strategy is to seek to influence the behaviour of those at risk of tick bites. For other risks, the most proportionate strategy will be different. In terms of planning behavioural interventions, the MINDSPACE report outlines the approach developed within DEFRA, known as the “four Es”. This approach is based on the premise that effective behavioural change means enabling, engaging, exemplifying and encouraging. First outlined in the context of changing behaviours to be more sustainable (HM Government, 2005), this was further developed in the context of Lyme disease by Quine et al. (2011). The authors developed a framework that set the four levers of change against a consideration of who is being targeted, the places where change is sought, and the significance of the points in time when change is sought.

Having outlined the policy focus on behaviour change which is broadly based around psychological theory, it is important to note that there is an increasingly visible and influential sociological body of work where the focus is on theories of practice rather than theories of behaviour. The work of Elizabeth Shove is most pertinent to consider here (Shove, 2010). She draws attention to the different perspectives that theories of behaviour and practice embody: for example, the basis for action for theories of behaviour is individual choice whereas for theories of practice it is shared social convention.

Conclusion

In conclusion, this brief and selective review of the substantial literature concerning public risk appreciation suggests that increased attention to the social aspects of managing animal health issues is vital. Social scientists have an important role to play in informing policy development by contributing to the evidence base as to how animal health risks should be managed. The social amplification of risk framework in particular makes clear the value of being attuned to social aspects of risk management and the potential unwanted consequences of simply considering public responses to the risk as disproportionate and irrational. The communication of uncertainty is key but going beyond this it is also important that policy options are developed that reflect knowledge that is often uncertain and incomplete.

References


HM Government (2005), “Securing the future”


Marris, C. et al. (2001), Public Perceptions of Agricultural Biotechnologies in Europe, Final Report of the PABE research project, Commission of European Communities FAIR.


This paper collects ideas suggested by the participants in the roundtable on policy making. It is an informal document that provides insights about the communication, institutional, knowledge and media challenges faced in day-to-day policy experiences. It is based on the presentations and discussions by Yukiko Yamada, Hans Wyss, Alberto Laddomada and Gemma Harper, all of whom hold animal health policy responsibilities in their respective countries (Japan, Switzerland, European Union and United Kingdom).

* This paper has been edited by Amar Toor based on a transcript of the audio recording of the Workshop.
Institutional developments in Japan following the BSE outbreak

Yukiko Yamada, Chief Scientific Advisor. Ministry of Agriculture, Forestry and Fisheries of Japan

Background on BSE in Japan

The first BSE case was reported in Japan in 2001. Prior to this, there was little concept of food safety in the Ministry of Agriculture, Forestry and Fisheries (MAFF). Of course, MAFF had experience in addressing animal health, though at the time, little was known about risk analysis of animal health and food safety. The government also adhered to a policy whereby it would release information to the public only when the relevant ministry wanted to do so. As a result, MAFF had little experience in communicating to the public the risk that BSE posed. Animal health specialists, meanwhile, frequently communicated using a technical jargon that was very difficult for the public to understand. The Vice Minister of Agriculture, Forestry and Fisheries then even went so far as to publicly declare in the Japan’s Diet, “BSE will not occur in Japan.”

Despite Europe’s experience with BSE, it took MAFF and the Ministry of Health (MHLW) a long time to recover facts and retrieve records. (Some, in fact, were never found.) MAFF was eager to provide information to the public, but sometimes this information was misleading — which, in turn, confused consumers. It took MAFF and MHLW also a long time to make decisions, and in many cases, actions were chosen based on politics, rather than science. The government did not communicate well with stakeholders, leading consumers to lose confidence.

Three months after Japan’s first BSE case, we conducted a questionnaire survey of randomly selected citizens in three prefectures around Tokyo. To our surprise, price remained the most important factor in buying food for those surveyed. Food safety, by comparison, was the third most important. Consumers expressed concern over whether it was safe to eat beef, but they were not interested in animal diseases. Consumer groups were better informed, and were therefore more concerned about the well-being of farmers. At the time, most consumers held the perception that the government protected the animal industry at the expense of public health, even though that was not the case.

Farmers at the time were worried about BSE’s effects on the price of beef, and the financial losses that could arise. Politicians, meanwhile, were primarily concerned with votes. Some expressed support for extreme measures based not on science, but on a desire to garner support from their constituents. The outbreak also provided the media with a good opportunity to attack the government for perceived wrongdoings.

Implementation of food safety risk analysis

In 2003, the government created the Food Safety and Consumer Affairs Bureau under MAFF, and called for some restructuring in MHLW. As part of this restructuring, the animal health division was transferred from the Production Bureau to the Food Safety and Consumer Affairs Bureau, to put animal health in the same bureau as food safety. The government also implemented food safety risk analysis, with a particular emphasis on risk communication. This had a significant influence on animal health policy making. At the time, risk communication was not included in the OIE code. Risk analysis was completely new to everyone at the bureau, so the MAFF organised seminars and training courses to help officers understand and implement risk communication.

This was a positive development. However, subsequent outbreaks of avian flu, BSE and FMD highlighted the increasing need for better communication among stakeholders, the media and politicians. It was clear that such communication should be timely and frequent,
and that it should provide all stakeholders with the information they need. Good risk management and communication should combine scientific and technical knowledge with the ability to explain this knowledge in a way that is easy to understand. This applies to both risk communication and crisis communication.

Recently, various ministries have started working together more closely. The Veterinary Authority has set up a dedicated website where users can find data, information on measures and financial assistance. The page also features a section where users can ask questions, and it is regularly updated with a support from food safety experts and communication officers. The Veterinary Authority issues pamphlets with photographs for farmers, as well, in consultation with communication experts. In the case of FMD, teleconsultation in affected areas was conducted not only by veterinarians but also by communication officers, as well.

**Achievements and remaining challenges**

To date veterinary officers improved communication skills, and can now engage more effectively with laypeople. Japan’s experience has also taught them to avoid using jargon, relying instead on simple, easy-to-understand terms. Today, veterinary officers know that it is always better to use positive expressions when communicating with the public. They have increased communication during peacetime, and have become faster in responding to inaccurate articles or rumours. Collaboration with non-veterinary officers has also vastly improved over the past decade.

Despite these achievements, significant issues remain though they are related more to hazard than risk. We should put more emphasis on prevention, and understand that veterinary officers do not always have the same common sense as consumers or other stakeholders. Science remains extremely important, of course, but science alone cannot provide solutions to consumer concerns. We must constantly find ways to build consumer confidence. For that matter, communication should not be only “one-way”. Instead, it should include thorough and regular two-way communication that should be reflected in policy if appropriate. Because consumer concerns tend to be driven by the media, it is important to provide good information and to communicate regularly with journalists.

The definition of good communication may be culture- and context-specific, and therefore can be difficult to generalise. However, there are important lessons to be learned from Japan’s experience. In order to prevent future outbreaks, we must conduct increased and regular communication with farmers and local governments. We must provide guidance, advice and recommendations, while conducting regular visits to farms, holding training courses and workshops, and listening to farmers’ wishes.

It is equally important to find the right people to conduct communication and to establish a single public voice, in order to avoid disseminating inconsistent information. We must be familiar with the characteristics of those with whom we are communicating, and should communicate more closely and frequently during peacetime. It is helpful to disseminate information before the media does, though we should also leverage the media to inform a broader range of stakeholders. Above all, we must remember to have sympathy for those affected because, in terms of communication, a good heart is often more effective than good techniques.
Credible communication in Switzerland

Hans Wyss, Chief Veterinary Officer, Swiss Federal Veterinary Office

This paper discusses the role of communication in animal disease control, and ways it can be improved. Strong communication is critical to disease control, though the complex nature of the issues we face can make it difficult to convey information to decision makers, stakeholders, farmers, or the public. Despite this challenge, it is important to express these issues in simple ways, and to establish credibility with the media, the public and all stakeholders. Below, we identify key characteristics of strong communication policies, drawing on personal experiences at the Swiss Federal Veterinary Office and from the field of journalism.

It is important to truly understand the person with whom you are communicating. Researchers and decision makers could profit more from each other if they strengthened cooperation and communication, as has been made clear during this conference. There is great value in communication among veterinarians, scientists and economists, and this communication must be fluid, not uni-directional.

There is a tendency to discuss science and decision making in terms of risk analysis — including risk assessment, management and communication — but it is important to consider the influence of political decision makers, as well. Decisions are based on both science and political views, so we must have a clear message when presenting this knowledge to decision makers.

Here, we present some hypotheses about communication. Today, every business needs a communication strategy, regardless of its industry or sector. There are still many organisations and enterprises today that do not have a real communication strategy, and many decision makers still do not realise the importance of communication. Over the past 15 years, our office has invested heavily in communication — perhaps more than in any other area. We will likely have to invest even more in the future, because communication will become even more important with the rise of new media. We must be prepared for this, though it is not clear whether we are. The Internet has made it easier for consumers to find conflicting or false information, and it is therefore important for us to have clear public messages.

Based on our experience at the Swiss Federal Veterinary Office, credibility is the most important attribute in communication. It is critical that we have strong credibility with farmers, the public, the media, stakeholders, consumer organisations and our collaborators. To earn credibility, we must not only communicate with our partners, but fulfil our promises, as well. As we have seen, though, earning trust and credibility with the public remains a significant challenge.

It is crucial to remember that the media and journalists are not our enemies. They may not be our partners, but they are our clients. They need information from us and can be very helpful. We must to learn to explain complex problems in simple ways, because when we are not able to, the media will do it for us. Very often, the media will not only simplify the message, but change its content in misleading ways.

It is also important to involve experts from the very beginning. For every problem we face, we must first think about which experts to consult, and then engage them in meaningful dialogue, ensuring that our message to them is clear. The aim should not be to influence the experts, but to harmonise knowledge about a given problem.

We end this paper with a lesson that can be learned from the field of journalism. If you can successfully explain complicated issues in a simple way to the public, the experts will be astonished. But if you successfully explain complicated issues to the experts, the public will
not understand you. It is therefore necessary to find the simplest ways to explain the issues we face, even if they are very complex.

The need to follow international standards: the experience of the European single market

Alberto Laddomada, Head of Unit for Animal Health, DG Health and Consumers, European Commission

The cost of animal disease

There are several losses that can arise from animal disease and food safety problems. This loss can be categorised into three groups: those arising from epidemic diseases, endemic diseases and international trade restrictions. The first two are relatively well known, though the costs of international trade restrictions are more difficult to explain. Trade safety is a major issue, and will become increasingly important with globalisation and because of political trends. The European Union, for example, recently announced that it has begun negotiations with the United States over a proposed free trade agreement, and progress in the same direction is also being made with Japan. Free trade remains difficult to achieve as animal diseases and food safety risks cannot be ignored, but the political push is clearly there.

Policies should aim to minimise the negative impacts of animal disease and trade restrictions, while maximising the positive impact of actions taken by governments. Here, we consider the case of the EU single market and the challenges it poses. The single market remains the major achievement of the European Union and its 27 member states, and it has resulted in significant economic benefits. Trade in animals and animal products occurs through a harmonised system of rules and controls, and it works reasonably well. Even Switzerland, a non-member state, has worked closely with EU member countries to develop and adhere to veterinary regulations that apply to all member states.

The single market is a major achievement, but it was not achieved for free. The first ten years proved particularly challenging, due to outbreaks of BSE, swine fever and FMD. The following ten years were smoother, while at the same time the European Union successfully expanded from 15 to 27 member states, that will soon become 28 with the forthcoming accession of Croatia. The EU successfully addressed the H5N1 crisis during this period, and although the recent horse meat scandal raised concerns earlier this year, it was not a food safety issue it was a fraud issue that was largely amplified by media. And we all know that media tend to ignore good news, such as the 50% reduction of human cases of salmonella in the European Union. This means that about 100 human lives have been saved every year thanks to EU co-financed eradication programs.

Evidence-based policy and impact assessment

After 20 years, the European Union can be reasonably satisfied with its achievements, though it is important to note that these achievements would not have been possible without solidarity and financial support to improve animal health status. One cannot achieve the goals of a single market without uniform animal health.

The European Union is also looking to improve its response to emerging diseases, while
implementing risk-proportionate measures, risk-based surveillance and official controls. As the world’s most important importer and exporter of agricultural products and food, the European Union must align its policies with international standards, as well.

This progress is underscored by two on-going initiatives. On 6 May 2013, the European Commission adopted a proposal for a new animal health law and official controls. We have also adopted a proposal that pertains to EU expenditure on food chain safety, though it will not make major changes to the existing system.

Communication

In order to mitigate the losses arising from animal diseases, we must better inform policy makers and the public. There is still a lot of improvement to be made in communication, and in two areas in particular: crises and overreaction. Preventing or controlling overreaction could significantly reduce the costs arising from animal disease and food safety problems. In general, there is no better way to do this than with awareness and preparedness. It is very important to maintain strong communication during peacetime because it can be difficult to sway public opinion when a crisis is on-going. Policy makers must therefore convince the public that everything is ready and under control before a crisis breaks out.

Cost of non-implementation of international standards

There are of course many international standards governing animal disease control, though compliance is still lacking. Countries may deviate from international standards in accordance with the principles of the SPS agreement, but we believe this should be an exception to the rule. Countries should adhere to international standards and deviate only when it is justified with valid reasons.

Nowadays, international trade is addressed at the highest levels of public office. This suggests that trade is politically sensitive, but it does not change the fact that countries should adhere to international standards. Simply put, there is no better solution than to stick to the rules, whether they be SPS principles, EU legislation, or the standards of OIE or Codex.

What to expect from international organisations

Going forward, scientists, economists, sociologists, veterinarians and epidemiologists must work together to better understand lessons from past experience. Models have value, of course, but experience can often shed light in areas where quantitative analysis cannot. For example, when swine fever broke out in the Netherlands in 1997, policy makers conducted many studies, and have since improved their control policies based on their findings.

In particular, we should examine the cost not only of previous crises, but also of emotion and overreaction. These costs are generally very high, as it can be difficult to affect change in the face of overwhelming public opinion. For example, studies may show that some measures implemented during a given crisis were not fully appropriate or proportioned, but politicians may be reluctant to change or abandon them due to public opinion. In some cases, decision makers may pay too much attention to public opinion, and too little attention to expert recommendations.

Finally, international trade in animals and animal products is becoming increasingly important. Political authorities worldwide should adhere to principles of science-based standards and proportionality set out in the Sanitary and Phyto-Sanitary Agreement of the WTO, and they should not ignore or misuse international standards for protectionism or other reasons. Indeed, standards like those laid down by the OIE are fundamental to ensure the smooth functioning of international trade, but too often they are not properly followed. In order to improve this situation, the costs of non-implementation of international standards...
should be properly assessed, because politicians must know the costs they will face if they choose to ignore certain rules.

Social and human impact and interdisciplinarity

Gemma Harper, Chief Social Researcher and Deputy Director for Animal and Plant Health, Evidence and Analysis (APHEA), DEFRA, United Kingdom

It has been encouraging to see discussions of livestock disease focus increasingly on social and human dimensions. This is especially true of the discussions held at the livestock disease policies conference at the OECD. This paper includes general observations and reflections from this conference, while focusing on three issues, in particular: why we care about livestock disease, how we should work together in the future, and the importance of policy impact evaluation.

Why do we care about livestock disease?

Many at this conference have stressed the importance of minimising costs of disease and disease control, as well as the importance of evaluating all impacts associated with various policy options. This allows us to describe the economic impacts of various policies, and to use economic techniques to estimate non-monetary market impacts. We have also seen improvements in evaluating environmental impacts, and have heard of the importance of ecosystem services and biodiversity.

There are, however, other factors that can have an impact on both policy making and outcomes. We have heard a lot at this conference about trust and social capital. For farmers, in particular, identity can be very important. The question of “what makes a good farmer?” is not necessarily a commercial or financial issue, and can differ across cultures.

We should therefore work harder to integrate both monetary and non-monetary evidence to assess the true costs and benefits of policy options. We should also assess these impacts in economic, environmental and social terms.

Working together

Co-operation, or “building bridges”, has been a strong theme of this conference. As we have learned, multi-disciplinary approaches, while valuable, are actually insufficient when used to address complicated problems. We cannot simply examine a complex question from different perspectives in parallel or in sequence. Instead, we should focus on interdisciplinary approaches, whereby we would work together to frame an issue, define the problem, devise questions, design research, and collectively mitigate any uncertainty in our knowledge base.

Epidemiology is an exemplary case of a “bridging” discipline. It has many different dimensions, but can connect and bridge the natural veterinary sciences with social sciences, including economics. This capability is very intriguing, though we must not underestimate the challenge posed by technical language and jargon. In order to facilitate communication, we must strive to use simple and straightforward language.

Policy evaluation

Finally, we must focus our efforts on identifying effective policies and understanding why they work. Simply put, we must conduct robust policy evaluation. This does not entail simple predictions or assumptions about policy impacts, nor is it limited to assumptions about what may happen in the absence of government, civil and private sector intervention. Rather, robust policy evaluation requires strong interdisciplinary techniques to assess the real impact of our interventions.
Going forward, it would be interesting to see examples of randomised control trials or quasi experimental designs to determine which interventions are most effective. Of course, this would be hugely challenging during outbreaks, but more feasible during peacetime. Today, we have an opportunity to empirically experiment with intervention designs, as well as the information that we provide to the public. These experiments would maximise our confidence and ability to design effective interventions, while identifying the type of evidence that would be needed *ex post.*
Annex A.

List of Contributors

Frank ALLEWELDT
Managing Director
Civic Consulting
Berlin, Germany

Marcel A.P.M. van ASSELDONK
Agricultural Economics Research Institute (LEI)
Wageningen UR,
The Netherlands

Julie BARNETT
Professor of Health Psychology
University of Bath, United Kingdom

Ron BERGEVOET
LEI part of Wageningen UR
Wageningen, The Netherlands

Ray BRADLEY
BSE consultant
United Kingdom

Tim E. CARPENTER
EpiCentre, Massey University
Palmerston North, New Zealand

Nigel GIBBENS
Chief Veterinary Officer
DEFRA, United Kingdom

Gemma HARPER
Chief Social Researcher and Deputy Director for Animal and Plant Health, Evidence and Analysis (APHEA)
DEFRA, United Kingdom

Barbara HÄSLER
Royal Veterinary College, Hawkshead Lane
North Mymms, United Kingdom
Leverhulme Centre for Integrative Research on Agriculture and Health, London, United Kingdom

David A. HENNESSY
Professor of Economics at the Department of Economics and Center for Agricultural and Rural Development
Iowa State University, United Kingdom

Keith S. HOWE
Royal Veterinary College, North Mymms
United Kingdom
Centre for Rural Policy Research
University of Exeter, United Kingdom

Lovell S. JARVIS
Department of Agricultural and Resource Economics
University of California, Davis, United States

Alberto LADDOMADA
Head of Unit for Animal Health
DG Health and Consumers
European Commission

François LE GALL
Program Co-ordinator, Agriculture and Rural Development Unit of the Africa Region
World Bank, Washington D.C.

Miranda P.M. MEUWISSEN
Business Economics, Wageningen University
Wageningen, the Netherlands

Philip L. PAARLBerg
Professor, Department of Agricultural Economics
Purdue University
W. Lafayette, United States

Jonathan RUSHTON
Royal Veterinary College and Leverhulme Centre for Integrative Research on Agriculture and Health
Hatfield, United Kingdom

Katharina D.C. STÄRK
Royal Veterinary College, Hatfield, United Kingdom
Safe Food Solutions (SAFOSO)
Bern, Switzerland
<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Organization</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. Katsuaki SUGIURA</td>
<td></td>
<td>Global Animal Resource Science</td>
<td>Tokyo, Japan</td>
</tr>
<tr>
<td>Yukiko YAMADA</td>
<td>Chief Scientific Advisor</td>
<td>Ministry of Agriculture, Forestry and Fisheries</td>
<td>Japan</td>
</tr>
<tr>
<td>Pablo VALDES-DONOSO</td>
<td></td>
<td>School of Veterinary Medicine and</td>
<td>University of California, Davis, United States</td>
</tr>
<tr>
<td>Kurt A. ZUELKE</td>
<td>Director</td>
<td>CSIRO Australian Animal Health Laboratory</td>
<td>Geelong, Australia</td>
</tr>
<tr>
<td>Hans WYSS</td>
<td>Chief Veterinary Officer</td>
<td>Swiss Federal Veterinary Office</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Christopher A. WOLF</td>
<td>Professor, Department of Agricultural, Food and Resource Economics</td>
<td>Michigan State University, United States</td>
<td></td>
</tr>
</tbody>
</table>