Economic assessment of veterinary surveillance programmes that are part of the national control plan of Switzerland

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DECLARATION

I declare that all work presented in this thesis has been carried out by me except where acknowledged. This thesis has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education.

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ABSTRACT

The aim of this project was to facilitate the allocation of scarce resources and to support decision-making by providing a practical tool for the economic assessment of surveillance programmes that are part of the Swiss national control plan.

A classification system for surveillance is presented and discussed that looks at disease mitigation from a policy perspective and divides the mitigation process into three stages: sustainment, investigation and implementation. It facilitates the understanding of the technical relationship between mitigation as a source of economic value, and surveillance and intervention as sources of economic cost.

A theoretical framework elaborates the economic principles of resource allocation for disease mitigation. It describes criteria for the optimal level of disease mitigation for surveillance and intervention according to whether they are economic complements or substitutes. Further, it highlights the impact of externalities and explains the practical significance of economic criteria.

The potential of empirical analyses is explored and discussed using four case studies of selected Swiss surveillance programmes that are part of the national control plan, namely those for avian influenza virus in wild birds and poultry, bluetongue virus serotype 8 in ruminants, bovine viral diarrhoea virus in cattle, and salmonella in laying hens. It was found that the economic assessment of implemented surveillance programmes is subject to a variety of practical limitations that only allow determining acceptability, but not optimisation criteria. Nevertheless, the outcomes provide important insights into the relationships between surveillance, intervention and mitigation and the boundaries to the application of economic principles.

The lessons learned from the theoretical and empirical research are combined in a practical guide that helps decision-makers to plan, design, and conduct or commission economic assessments of current and future government veterinary surveillance programmes. Flow charts guide decision-makers step by step through a set of relevant questions that helps them to identify a suitable approach and data requirements for the economic analysis.

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ACRONYMS AND ABBREVIATIONS

ACER	Average cost-effectiveness ratio
AI	Avian influenza
AIV	Avian influenza virus
BT	Bluetongue
BTV-8	Bluetongue virus serotype 8
BVDV	Bovine viral diarrhoea virus
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CER	Cost-effectiveness ratio
CHF	Swiss francs
CVS	Cantonal veterinary service
ECDC	European Centre for Disease Prevention and Control
ELISA	Enzyme linked immunosorbent assay
EU	European Union
FMD	Foot-and-mouth disease
FVO	Federal Veterinary Office
HPAIV	Highly pathogenic avian influenza virus
LPAIV	Low pathogenic avian influenza virus
OIE	World Organisation for Animal Health
PBS1	Prospective baseline scenario 1
PBS2	Prospective baseline scenario 2
PCR	Polymerase chain reaction
PCS	Prospective comparative scenario
PI	Persistently infected
UK	United Kingdom

RBS	Retrospective baseline scenario
RCS	Retrospective comparative scenario
TI	Transiently infected
WHO	World Health Organisation

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Background, aim and objectives

Emerging animal and human disease threats, increasing international trade and changing environmental conditions have resulted in a rising demand for animal health surveillance systems that are firmly grounded in science, reliable, and adaptable in the light of changing circumstances. Policy makers responsible for programmes to prevent, reduce or eradicate disease depend on reliable information concerning the status of a hazard in the population in order to react appropriately. Resources are scarce, and so choices have to be made to achieve most efficient resource allocation for the greatest benefit of society as a whole. Both surveillance and intervention are resource-using activities that are part of a mitigation strategy[1]. There is increasing pressure on policy makers to provide sound economic evidence to justify mitigation programmes and thereby to ensure that public money invested in surveillance and intervention delivers value for the taxpayer.

The aim of this project funded by the Swiss Federal Veterinary Office (FVO) was to facilitate the allocation of scarce resources and to support decision-making by providing a user-friendly, practical tool for the economic assessment of surveillance programmes that are part of the Swiss national control plan. So far, the investment of public funds in surveillance systems in Switzerland has not been subject to systematic economic appraisal. Only a few intervention programmes have been financially assessed and there is a growing need for structured, transparent and logical frameworks that allow the comparison of mitigation options for decision-making and facilitate science-based priority setting.

The FVO's vision is to promote and protect human and animal health, to produce safe food and to consolidate international trade. The main tasks of the FVO are to create and enforce legislation on national level, coordinate and promote the implementation on cantonal level, perform public relations work, create and promote programmes to protect human and animal health, cooperate with national and international organisations, and facilitate import, export and transit of animals and animal products

[1] Definitions of key terms used relating to mitigation and economics can be found in the glossary

(Rüsch and Kihm, 2003). Moreover, it initiates and funds research projects to generate a scientific, factual basis for appropriate policy and hazard mitigation decisions. The FVO's research strategy for the years 2008-11 places emphasis on interdisciplinary research that integrates economic, social, and epidemiological measures (www.bvet.admin.ch/org/01028/01029/index.html).

Surveillance provides data that allow tailoring of intervention strategies to protect and promote both human and animal health. Veterinary surveillance systems in Switzerland cover multiple purposes and differ substantially in their organisational structure and scale of analysis. Their fields of activity include endemic and epidemic animal diseases, as well as hazards to human health, and reflect the diversity of the veterinary public health responsibilities of the FVO. The Swiss multi-annual national control plan, which is developed in close collaboration between the Federal Office of Public Health, the Federal Office for Agriculture and the FVO, sets out arrangements for the enforcement of feed and food law requirements as well as animal and plant health and animal welfare rules. It is based on the European Union's (EU) Regulation 882/2004/EC on official controls performed to ensure the verification of compliance with legislation on feed, food, animal health and welfare and the EU's 'guidelines to assist Member States in preparing the single integrated multi-annual national control plan'. According to the objective and type of surveillance programme, various units of the veterinary service (federal, cantonal, communal) may be involved in the surveillance process. A list of surveillance programmes that are part of the national control plan appears in Appendix I.

A tool to facilitate the economic assessment of surveillance and the allocation of scarce resources needs to take into account both theoretical and practical aspects. Therefore, the following objectives were defined:

i. to develop a conceptual framework and a generic approach to assess the costs and benefits and economic efficiency of surveillance programmes
ii. to explore the conceptual framework and generic approach by applying it to programmes that are part of the national control plan
iii. to describe and analyse the outcome of objective ii and to give recommendations for the improvement of surveillance systems from an economic point of view

The development of generic models for empirical economic assessment of all kinds of surveillance systems for different pathogens, animal species and purposes must begin from a robust foundation of economic principles. Therefore, the following section introduces economics and its use in animal health research. Technical characteristics of surveillance are described and discussed in the subsequent section. Chapter 1 concludes with a review of studies that conducted economic assessments of surveillance and an overview of the following chapters.

1.2 The economic setting

1.2.1 The role of economic analysis

Economics is a discipline concerned with making choices between alternative uses of limited resources. It provides well-established frameworks to assess how decisions about the allocation of resources impact on the well-being of different groups of people in society (Howe, 1992). The unifying underlying principle of all economic analyses is to provide a measure of the relative value attached to competing alternative strategies and thereby facilitate the decision about the allocation of resources (Heady, 1952). A pre-requisite for such analysis is to describe and understand the relationships, data and principles which impact on measures that inform choice (Heady, 1952). This in turn helps to understand complex interactions and

the possible effects of a decision – an essential element in facilitating decision-making (Ramsay et al., 1999).

The application of economics to animal health problems is concerned with the efficient allocation of resources in relation to disease and its mitigation in complex systems, namely animal populations (Howe and Christiansen, 2004).

1.2.2 Animal disease and its mitigation as an economic problem

In economic terms, animal production systems exist to provide goods or services to people in society. People not only derive substantial value from animal products such as eggs, meat, wool, or leather, but also from animals kept as pets, used for sport, work, or research. Animal disease is of concern because it reduces the economic benefit people gain from the consumption of animal goods and services. In the past, disease was mainly seen as a problem in livestock, because it decreased the productivity of animals and therefore the goods available for human consumption. Because major epidemic diseases have been mitigated in most developed countries, the focus has gradually shifted to diseases with less evident economic impact at farm level and complex epidemiological patterns (Otte and Chilonda, 2000). For instance, a policy directed at mitigating a zoonotic disease like salmonella in animals does not primarily aim to avoid production losses, but to reduce the risk of human illness.

As a result of disease, additional resources are needed for surveillance and intervention aimed at mitigating negative disease effects. Effective surveillance helps to offset negative effects of hazards on animal and food production by promoting successful interventions. In assessing the rationality of any resource-using decision, the key criterion is whether the value of outputs consequently recovered is at least sufficient to cover the additional resource costs. Thus the cost of resources committed to mitigation should at least be compensated by the value of the resulting recovered outputs and, ideally, the net benefits to society should be maximised (McInerney et al., 1992).

1.2.3 Economics and public policy

Public policy making is a complex population-based approach characterised – in the context of animal health – by a mixture of epidemiological, economic, political and technical information combined with knowledge on resource limitation and risk (Ramsay et al., 1999). When considering a national mitigation programme, policy makers want to know what strategies should be adopted and when and how they should be implemented. An important element in rational decision making is to weigh and compare the relative costs and benefits of each strategy to come up with measures that allow allocating limited funds to projects in a way that guarantee the best outcome for society as a whole (Rushton, 2009).

There are always constraints to the choices about resource use. These are either due to scarcity of resources or also because prior decisions set additional boundaries to choice. Decision-makers must not only comply with national and international requirements and guidelines, but also consider what is technically possible in the existing setting (structure and organisation of the veterinary services and industry), follow political visions and address widespread public scares that may impact on consumer confidence (e.g. bovine spongiform encephalopathy or avian influenza, AI). Further, they are expected to consider concerns of livestock holders and base their decisions on scientific evidence.

1.2.4 Economic techniques and valuation approaches

A wide range of economic techniques has been proposed to assess and compare the impact of diseases and potential mitigation strategies and thereby facilitate decision-making. They include techniques that can be applied at the farm and household level (e.g. gross margin analysis or partial budgeting) or at sector, national, and international levels (e.g. cost-benefit analysis, CBA; economic surplus analysis) (Rushton et al., 1999).

Cost-benefit analysis has been widely used to assess animal disease mitigation strategies. It attempts to quantify the social advantages and disadvantages of a project in monetary units. Its rigorous approach helps complex interactions to be better

understood and, most importantly, to highlight the possible outcomes of a given decision – an essential component of sound decision-making. Less frequently, cost-effectiveness analysis (CEA) is used. If two or more alternative programmes are available to reach the same effect, the programme with the least cost is the most cost-effective. The results are presented in terms of cost per unit of effect, e.g. cost per life year gained or cost per abortion avoided (Drummond, 1997).

Increasingly, economic surplus analysis is used in animal health economics to quantify the impacts of a shift in the supply curve because of disease and its mitigation and the resultant economic surplus (Howe and Christiansen, 2004). Other economic techniques applied to animal health problems include linear programming, partial and general equilibrium, and input-output models (Rich et al., 2005). However, only by understanding the strengths and limitations of such techniques with respect to their ability to model relationships in economic theory, is it possible to choose the best techniques for empirical analysis to inform decision-making.

1.2.5 Economics and epidemiology

The process of decision-making under real world conditions of uncertainty does not only depend on economics, but also other social sciences, such as sociology, politics and ethics (Heady, 1952). While economics specifies how resources should be used, other sciences specify the limitations within which economic decisions have to be made. Thus, it is indispensable to have a profound understanding of the relationships that underpin economic analysis.

A conceptual framework to assess the economic value of surveillance needs to integrate the technical relationships of surveillance, intervention and mitigation outcomes (e.g. prevalence or incidence reduction). Technical efficiency refers to the physical relation between inputs used and outcomes. It is reached when the maximum outcome is achieved from a given set of inputs. In contrast to technical efficiency, economic efficiency is measured by the relationship of values of inputs and outcomes. In other words, economic assessment requires that mitigation is translated from a technical perspective into a value perspective. Such relationships are often expressed with respect to price ratios that define the economic optimum, where an extra cost

unit of the resource (marginal cost) equals an extra benefit unit of the resource transformed into product (marginal benefit) (Heady, 1952).

Value choices are always made subject to technical constraints, which can be quantified using epidemiological approaches. Veterinary epidemiology studies disease and other health-related events in populations and investigates factors that determine their occurrence (Thrusfield, 2005). It uses frameworks, tools and techniques to describe patterns of health and disease and to assess the impact of mitigation strategies. Epidemiological modelling techniques that capture the dynamics and complexity of disease in populations are often used to deliver important input data for economic analyses (Perry and Randolph, 2004). Such input is indispensable when conducting empirical research to investigate the economic efficiency of mitigation strategies. For example, knowledge of the frequency of disease and clinical signs (e.g. abortion or mortality rate) and the effect of mitigation strategies is critical in estimating avoidable disease costs. The assessment of avoidable disease costs (as opposed to total disease costs) has been advocated by McInerney (1996) as the basis to assess the true potential benefits from intervention strategies.

Thus, economics and epidemiology can be viewed as part of an interdisciplinary framework (Max-Neef, 2005), which complement each other for the purpose of policy making (Figure 1-1). Ideally, epidemiological and economic analyses should be planned together from the start. Only then can the respective models on which empirical work is based be made fully compatible with the objective of providing decision-makers with the comprehensive technical and economic information they require.

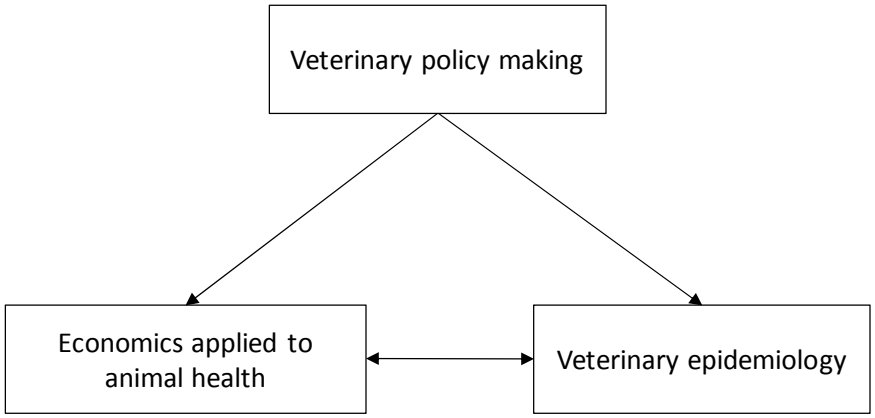


Figure 1-1: Interdisciplinary structure of veterinary policy making, economics applied to animal health and veterinary epidemiology.

The combined use of economics and epidemiology can assess value implications for society of decisions made about allocating scarce resources to disease mitigation with the objective of improving society's well-being. On this basis, the next stage is to consider surveillance from the perspective of epidemiology and its role in disease mitigation, and as a resource using activity.

1.3 Veterinary surveillance

Surveillance is used for early warning when disease (re-)occurs, to detect infection or disease, to measure prevalence or incidence of pathogens or hazards found in animal populations or along the food chain, to inform intervention activities to reduce or eradicate disease, and to document freedom from disease, infection or the level of 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 control (Thacker, 1996).

1.3.1 The definition of surveillance

Several authors offer definitions for both surveillance and monitoring that include the elements collection, analysis, interpretation and communication of data to those who have the responsibility and authority to act on them (Ingram et al., 1975; 1996; Anonymous, 2008, 2010c). Surveillance is amongst other things an important tool to

ensure compliance with international legislation to document the absence of disease or infection and hazard free food products, which in turn facilitates trade. Thus, for the purpose of this project the definition used by the European Centre for Disease Prevention and Control (ECDC) (Anonymous, 2008) is extended to describe veterinary surveillance as:

"*The ongoing 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"*.

1.3.2 Surveillance systems, approaches, designs and classification

1.3.2.1 Systems

Surveillance systems are defined as "a method of surveillance that may involve one or more component activities that generates information on the health, disease or zoonosis status of animal populations" (Anonymous, 2010c). Each surveillance system component has its self-contained surveillance protocol that focuses on a particular data source, such as serological bulk milk surveillance and surveillance of pathological lesions in the abattoir (Martin et al., 2007).

1.3.2.2 Approaches

The surveillance approach chosen for a surveillance system component can be passive or active. A passive approach generally involves minimal input from the competent veterinary or public health authority to solicit case reports. Statutory case reporting is the most broadly used passive surveillance (Doherr and Audige, 2001). In active surveillance, the central unit of the system is intensively involved in the process of obtaining information. Procedures to gain information are initiated in a systematic and regulated way, focusing on a designated pathogen or disease or a group of diseases for

a specific surveillance objective (Salman, 2003). The selection of the surveillance approach is a key design decision because of its impact on bias and cost.

1.3.2.3 Designs

The surveillance design describes activities and methods selected for implementing, analysing and communicating surveillance system components, e.g. populations, sampling, diagnostics, statistics and case definitions.

Random sampling implies choosing the sampling unit (e.g. individuals, herds, farms, administrative areas) such that each unit has the same chance of being chosen (Thrusfield, 2005). However, on population level, when the disease occurrence is rare, this type of active data collection quickly reaches its financial and operational limits, because the lower the prevalence in a specific population, the larger the sample size required for detection (Salman, 2003). Therefore, for rare disease events, non-random sampling approaches are often used, where the probability of a unit being selected depends on some of its characteristics such as location (Thrusfield, 2005).

One approach towards non-random sampling that has attracted a lot of attention in the past and is now widely adopted is so-called risk-based surveillance (Stärk et al., 2006). In contrast to conventional surveillance programmes that consider a population or disease in a uniform manner, risk-based surveillance takes into account the probability of a hazard, its consequences, management, and perception to detect cases in a population or sub-population. Risk-based surveillance has been defined as “a surveillance programme in the design of which exposure and risk assessment methods have been applied together with traditional design approaches in order to assure appropriate and cost-effective data collection” (Stärk et al., 2006). It takes into account spatial factors (e.g. climate, population density), host factors (e.g. age, species), management factors (e.g. bio-security, antimicrobial usage) and other factors (e.g. history of cases or risky practices) shown to be associated with the risk of infection or disease. Assuming that the event of concern is less common in the general population than in the targeted group, and specific risk factors are known, targeted surveillance was defined as “focusing the sampling on high-risk populations in which specific

commonly known risk factors exist" (Salman, 2003). Because the sub-population is selected according to specific risk factors, it was suggested that targeted surveillance forms part of a risk-based surveillance approach (Stärk et al., 2006). A different definition has been proposed by the United Kingdom's (UK) Department for Environment, Food and Rural Affairs. It specifies targeted surveillance as detection activities which answer a specific question about a defined disease or condition, while scanning surveillance is used to monitor populations to detect undefined or unexpected threats by using indicator changes (Anonymous, 2003).

A design based on case-definitions is syndromic surveillance (Henning, 2004). It uses animal or human health-related data that precede clinical diagnosis that indicate sufficient probability of a change in the health of the population to trigger a response. This is based on monitoring non-specific syndromes (e.g. respiratory or gastrointestinal illness) and other measures such as purchase of medication or feed additives that may increase before clinicians, livestock owners or laboratories recognise and report an unusual pattern of illness.

Sentinel surveillance aims at early detecting (re-)emerging diseases or their vectors by selecting a limited number of units according to attributed risk factors. A sentinel herd is defined as a cohort of animals at a pre-determined location, which is monitored over a specified period of time with respect to a specified disease agent (Ward et al., 1995).

In laboratory-based surveillance, collaboration among national and international laboratories enables sharing various types of epidemiological and pathogen-specific information to produce high quality data. Serotyping or molecular subtyping of pathogens provides important epidemiological information of the infectious agent and contributes considerably to the detection of outbreaks and the investigation of the source and risk of infection (Scallan and Angulo, 2007).

1.3.2.4 Classification

Even though descriptions of surveillance approaches and designs are manifold, only a few classification systems have been proposed. They mainly focus on surveillance approach, design, management, networking and epidemiological criteria.

One such system is based on network classification and lists seven criteria for classification: 1) endemic or exotic disease, 2) focused or broad-based networks, 3) local, national or international coverage, 4) suspect or susceptible animals, 5) sample-based or exhaustive sampling strategy, 6) passive or active data collection, and 7) autonomous or integrated management (Dufour and Audige, 1997). Further, an event tree for complex surveillance systems was suggested as a tool to assess the effectiveness of the system and to guide the allocation of resources. It includes three primary branches: 1) sequence of events for clinical case reporting, 2) testing regimens, and 3) path of detection in the absence of clinical signs (Hueston and Yoe, 2000). A review conducted by Doherr and Audige (2001) classified active surveillance systems based on four main criteria: 1) target population for testing, 2) sampling scheme, 3) repetition (e.g. single cross-section, continuous sampling), and 4) frequency measure (e.g. point prevalence, cumulative incidence).

Even though these systems are useful in understanding the approach, structure and design of surveillance systems, they do not allow for straightforward inclusion of elements of mitigation that impact on the economic value of surveillance.

1.3.3 International surveillance

As a consequence of globalisation, international trade in animals and products thereof has increased substantially in the past years. Several international organisations stipulate standards for the safe, fair and flexible trade of animals and their products. The large variety of guidelines and international projects to coordinate activities and share surveillance data reflect the need for integrated modern surveillance systems. The main international systems are as follows:

- The World Organisation for Animal Health (OIE) provides general information about surveillance principles, approaches, and methods as well as specific guidelines for the surveillance of certain diseases such as bluetongue (BT), foot-and-mouth disease (FMD) or rinderpest. Since the beginning of 2006, the OIE operated a global electronic reporting system for animal diseases, the World Animal Health Information System. All member states are obliged to enter

immediate, semi-annual and annual reports of animal diseases into this web-based system. The system is designed to improve the transparency, efficiency and speed with which animal health information is reported and disseminated to member states and the general public.

- The internet-based Global Early Warning and Response System (www.glews.net) for major animal diseases, including zoonoses has been established in 2006 by the OIE in collaboration with the World Health Organisation (WHO) and the Food and Agricultural Organisation of the United Nations. The programme aims to predict and prevent animal disease threats better through sharing of information, epidemiological analysis and joint field missions to assess and control outbreaks in animals and humans.

- The Codex Alimentarius is a text collection of standards, codes of practice, guidelines and other recommendations. Certain texts deal with detailed requirements related to a type or group of foods; others deal with the operation and management of production processes or the operation of government regulatory systems for food safety and consumer protection. These guidelines also include recommendations for setting up and running surveillance systems along the food chain.

- The ECDC is an EU agency established in 2005 which aims to strengthen Europe's position in the prevention and control of infectious pathogens by identifying, assessing and communicating infectious disease threats to human health. It works in collaboration with national health protection bodies of EU member states and public health experts across Europe to enhance continent-wide disease surveillance and early warning systems. The European peer-reviewed, web-based journal Eurosurveillance has been integrated into the ECDC in 2007 and acts as a platform for the dissemination of scientific information from the ECDC. In 2007, Enter-net, the international surveillance network for human gastrointestinal infections in Europe was also integrated into ECDC activities.

- The EU has implemented a wide range of animal health legislation that includes general provisions on surveillance as well as detailed requirements for specific hazards, such as BT, salmonella or AI. Further, surveillance of infectious disease in the EU is supported by the Basic Surveillance Network and other disease specific surveillance networks.

- The WHO's Global Salm Surv programme (www.who.int/salmsurv) comprises a global network of laboratories, public health institutes and individuals involved in surveillance, isolation, identification and antimicrobial resistance testing of *Salmonella* spp. and other foodborne pathogens. It aims to support national and regional laboratories in the surveillance of major foodborne pathogens and antimicrobial resistance.

- The Program for Monitoring Emerging Diseases (www.promedmail.org) is a global internet based reporting system for outbreaks of emerging infectious diseases and toxins, set up by the International Society for Infectious Diseases. It collects information on outbreaks of infectious diseases and toxins in humans, animals and plants from a variety of sources, such as official or media reports and local observers. The information is distributed electronically to provide early warning of disease outbreaks among members of the international infectious disease community.

1.4 Economic assessments of surveillance in the scientific literature

Few studies have been concerned with the economic or financial assessment of surveillance. In contrast, many have assessed the efficacy and effectiveness of surveillance systems with different purposes, designs, and target hazards, which provide important information about the technical characteristics of surveillance. For example, Chriel et al. (2005) and Yamamoto et al. (2008) investigated the sensitivity of surveillance programmes to detect disease outbreaks. Hadorn et al. (2002) and Knopf et al. (2007) considered sample size in relation to documenting disease freedom, and Martin et al. (2007) to support claims of disease freedom by integrating random and

non-random surveillance data. The studies which have focused on economic and financial aspects of surveillance are as follows.

In the United States, Elbasha et al. (2000) assessed the societal costs and benefits of a surveillance system for identifying *E. coli O157:H7* outbreaks in Colorado. The monetary costs for installing and operating the surveillance system were compared with the monetary benefits, which were the savings accrued from human *E. coli O157:H7* cases averted. It was found that if the surveillance system averted five cases annually, it would recover all its costs for the five years of start-up and operation. Carpenter (2001) modified the sets technique (a surveillance technique measuring the time intervals between two subsequent events) to evaluate early warning surveillance in terms of effectiveness and financial impacts. The capacity of the surveillance system to trigger an alarm was linked to the probability of an epidemic occurring, the costs for setting off an alarm and implementing response measures, and the magnitude of the outbreak. Assuming arbitrary monetary values for the alarm and epidemic cost, it was shown that for rare epidemics the most beneficial strategy was to avoid a false alarm, while for common epidemics the most sensitive detection system was more cost-effective. Kompas et al. (2006) developed a stochastic optimal control model to determine the optimal level of surveillance activity against a disease incursion. The model minimised the value of direct and indirect costs of the disease, as well as the cost of the surveillance and disease management and eradication programmes. It was applied to the case of a potential entry and spread of FMD in the United States. The optimal level of surveillance determined in this study would cost 40.3 million US dollars, about five times more than the expenditures for the implemented surveillance programme. The latter two studies both provide important insights about the relationships between surveillance expenditures, the probability of disease incursion, time of detection and the consequent production losses and response expenditures.

In the Netherlands, Klinkenberg et al. (2005) used epidemiological and financial models to simulate classical swine fever epidemics and the impact of five existing surveillance programmes on the disease dynamics. The effectiveness of surveillance was measured by the time from introduction of the virus to its detection, which determined the number of infected herds at the time of detection and thus the epidemic costs. The

annual costs per surveillance programme and outbreak related costs accruing from culling of detected herds, contact tracing, establishment of protection and surveillance zones and preventive culling were estimated. It was reported that the surveillance programme implemented averted very expensive outbreaks with a high probability. It was stated that the precise value of the benefit of surveillance depends on the frequency of entry of the virus into the Netherlands; predictions of such an event vary between once every two years to once every 18 years. Van Asseldonk et al. (2005) built a stochastic bio-economic model to identify the most efficient of six surveillance options for bovine tuberculosis. The stochastic optimisation model aimed to minimise the expected surveillance and response costs, while keeping the number of infected herds below a defined threshold. The chance of a primary outbreak in the Netherlands was assumed to be once in three years. It was found that visual carcass inspection in the abattoir was the optimal strategy to minimise costs with a risk-neutral attitude of decision-makers. Velthuis et al. (2010) investigated the financial consequences of the BT epidemic in the Netherlands in 2006 and 2007. Surveillance and intervention costs as well as production losses and treatment expenditures were calculated. It was found that in 2006 the intervention cost accounted for 91% and surveillance for 7% of the net costs of the epidemic. In 2007, the net costs mainly comprised production losses and veterinary treatment expenditures, while intervention and surveillance cost were only a small proportion. This shift was caused by the relaxation of mitigation measures in 2007.

In the UK, Gunn et al. (2008) assessed a surveillance programme for early detection of BT incursion. The analysts developed an economic model to identify, measure and value disease costs for various scenarios of BT introduction and spread in Scotland and to evaluate disease mitigation strategies. Baseline costs of surveillance and prevention were estimated over a 5-year time period and it was found that the benefits of avoiding disease incursion exceeded the costs of surveillance and prevention. Carrasco et al. (2010) developed an epidemiologic transmission model for BT in the UK and linked it to economic and info-gap analyses. It aimed to identify robust surveillance and vaccination policies that would keep the total costs resulting from surveillance, vaccination, insecticide treatment and production losses below a defined threshold. Results demonstrated that case reporting by farmers, vaccination in high risk areas,

and surveillance in high risk areas were robust strategies. Moran and Fofana (2007) conducted a CBA of disease surveillance for three notifiable fish diseases in the UK. They compared costs of public and private surveillance efforts with the benefits of private and social costs avoided from low-range, mid-range and high-range disease outbreaks with a probability of incursion modelled as a Poisson distribution. The disease costs avoided included response expenditures as well as costs due to changes in consumer demand, export restrictions, and welfare impacts on anglers in society. It was found that the investment of public funds in surveillance and intervention was worthwhile for infectious salmon anaemia and viral haemorrhagic septicaemia, but not for infectious haemorrhagic necrosis. Importantly, the non-use value of the angling community contributed most to the total disease costs, highlighting the impact such non-market values may have on decision-making.

For Denmark, Carpenter et al. (2007) evaluated the efficacy and financial implications of an early-warning system for abortion in Danish cattle. The two-stage method was used to develop an algorithm that would trigger an alarm if the number of abortions exceeded a pre-determined level. This was linked to a model that integrated the costs of measures following an alarm, the benefits of avoiding abortions and their associated probabilities. The model allowed determining the most beneficial strategy depending on the efficacy of the alarm and associated costs.

In overview, the techniques most frequently used for the economic assessment of surveillance are optimisation models and CBA. Most of the studies summarised above focused on the ability of a surveillance system to detect disease outbreaks and relied on complex mathematical models to capture the technical impacts of mitigation on disease dynamics. By investigating surveillance expenditures in relation to the probability of disease incursion and the consequences of an epidemic (e.g. response costs, production losses), they indicate that surveillance can only be meaningful when linked to interventions.

1.4 Conclusions and outline

Even though the studies described use a variety of techniques, they rarely elaborate on the theoretical principles underlying the economic assessment of surveillance. Generally, the scientific literature provides limited insights regarding the economic assessment of surveillance programmes from a conceptual point of view. This conclusion is corroborated by the fact that the economic assessment of surveillance does not feature in textbooks of animal disease surveillance nor economics applied to animal health problems (Salman, 2003; Rushton, 2009).

Even though descriptions of surveillance approaches and designs are manifold, there is no generic framework available that allows classification of a wide range of surveillance programmes with different approaches and purposes for economic analysis. Therefore, a classification system for surveillance is presented in Chapter 2 that facilitates the understanding of the technical relationship between surveillance, intervention and mitigation from a policy perspective. In Chapter 3, the implications of technical and economic relationships between magnitudes of lost production and the use of surveillance and intervention resources are investigated. The economic principles outlined allow recommendations to be made about how to achieve economic efficiency in disease mitigation. The application of these principles to a series of four case studies for bluetongue virus serotype 8 (BTV-8) in sheep, cattle and goats, bovine viral diarrhoea virus (BVDV) in cattle, AI in wild birds and poultry, and salmonella in laying hens is presented in Chapter 4. The lessons learned from the combination of theoretical principles and empirical research are summarised in Chapter 5 in form of a practical guide for the economic assessment of surveillance tailored to the needs of policy makers. Finally, outcomes of the project are discussed and conclusions and recommendations presented (Chapter 6).

CHAPTER 2

CLASSIFICATION OF VETERINARY SURVEILLANCE TO INFORM ECONOMIC ANALYSIS

2.1 Introduction

The development of a generic economic framework independent of the pathogen, animal species, and surveillance approach or design, demands a classification system that integrates relevant components of mitigation that impact on the economic value of surveillance.

The purpose of surveillance is to provide information to guide decisions about the nature and scope of interventions aimed at prevalence or incidence reduction. In general, an information system is designed for problem solving in a social system. The data collection and analysis that contribute to the provision of information to policy makers should be built on a solid conceptual base (Bonnen, 1975). Factors such as the frequency and method of data collection and the related level of personnel and institutional infrastructure needed depend on the quality and scope of information required by policy makers to support decision-making.

Similarly, a classification system must be consistent with its purpose. Classification of surveillance to inform economic analysis must explicitly acknowledge the relationship between disease mitigation, a process that enhances economic benefits, and mitigation resources, a source of economic costs.

The objectives of this chapter are to outline a generic classification system for veterinary surveillance, and to discuss its key characteristics, implications for economic analysis and practical applications. Further economic dimensions of surveillance as a resource for disease mitigation are considered in Chapter 3. The proposed classification system is based on practices observed in government veterinary services and the legal, political and administrative context they are operating in.

2.2 The classification system

2.2.1 Overview

The proposed classification system (Figure 2-1) is closely linked to the changing mitigation objectives. It does not replace, but complements, existing classification systems for surveillance. The mitigation process is divided into three stages: sustainment, investigation and implementation. Each stage is defined by a specific mitigation objective and requires different technical characteristics of surveillance and intervention as they impinge on economic objectives.

The mitigation objective is independent of the pathogen, animals and animal-derived products, or surveillance approach or design. At any stage, the principal surveillance objective is to inform intervention decisions.

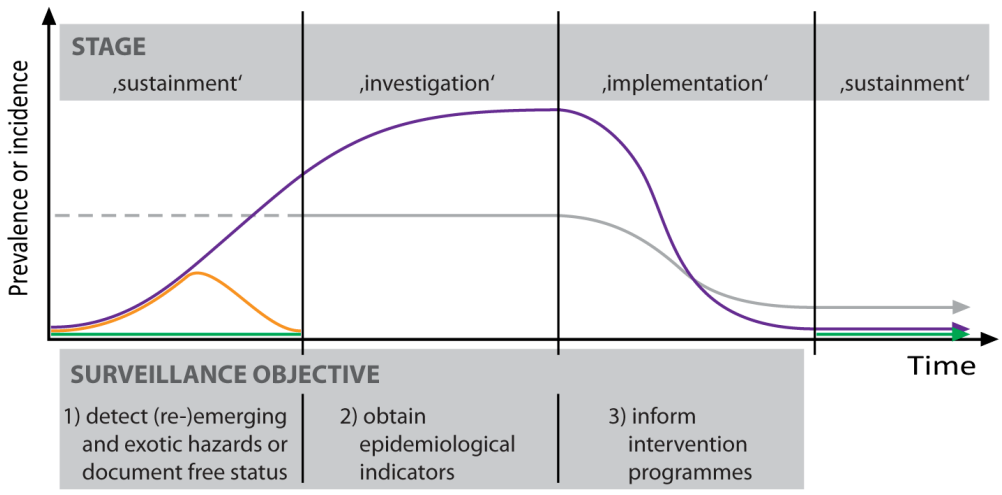


Figure 2-1: Schematic illustration of a classification system for surveillance based on a three stage mitigation system. (Re-)emerging or exotic epidemic hazard that is not controlled by response measures in the sustainment stage, (re-)emerging or exotic epidemic hazard that is controlled by response measures in the sustainment stage, continuous free status, endemic disease, dotted line: true value unknown.

At the start of the mitigation cycle (sustainment stage), a hazard is viewed either as not present in the unit of interest (e.g. farm, region, country) or present at an acceptable level. In this stage, the mitigation objective is to sustain the free or

acceptable status by preventing an increase in incidence of a hazard or eliminating a hazard quickly when it occurs. The corresponding surveillance is therefore to document that a hazard remains below a defined threshold, and to provide early warning of an increase in incidence or other significant changes in risk (e.g. higher pathogenicity, new subtype). An early warning may trigger a rapid response to contain an increase in incidence of the hazard (e.g. disease outbreak). If the response measures are insufficient to contain the hazard, a change in strategy is needed and mitigation activities switch to the investigation stage. The objective of this second stage is to re-assess the situation as a forerunner to provide guidance for intervention activities in the implementation stage. 'Investigation' surveillance is to obtain critical epidemiological information, for example disease incidence or prevalence and the direction and rate of dispersion. Such information is used to make decisions about the intervention strategy appropriate to reduce or eradicate a hazard. In the implementation stage, the objective is to reduce the prevalence of a hazard in relation to a defined target by implementing intervention measures. The target may be set based on epidemiological, economic and/or political criteria. The corresponding surveillance is used to inform the choice, timing and scale of interventions and to document the progress of interventions. Finally, after successful intervention the mitigation objective may again be the sustained absence of disease.

In the following sections, the three mitigation stages, related surveillance and intervention as well as the transitions between the stages are described in more detail.

2.2.2 Surveillance in Stage I mitigation (sustainment)

A. Mitigation objective

Stage I mitigation aims at preventing an increase in incidence of a hazard or to eliminate a hazard quickly when it occurs. In this stage, the level of risk is perceived to be acceptable by decision-makers. The ideal risk would be zero, but in the absence of zero risk, an acceptable level of risk is generally defined where no special intervention activities need to be directed at the hazard (Slovic, 1999). The acceptable status may be a historically free status, freedom from disease, freedom from infection, or

contamination of food products below a defined threshold. Policy makers may be aware of certain endemic hazards, but categorise them as low priority and therefore do not tackle them. In short, the Stage I mitigation objective is to sustain the acceptable status. Additionally, compliance with international regulations to document disease freedom allows gaining facilitated access to foreign markets.

Targeted hazards include highly contagious infections in animals, zoonotic diseases, food-borne hazards, vector-borne infections, and emergence of resistant pathogens and resistance genes. The categorisation of such hazards into (re-)emerging, endemic or exotic depends on the disease status of a country. Certain endemic hazards may have been present for a long time, while others may have emerged and become endemic, because there were no or insufficient mitigation measures in place. Examples of hazards that emerged in the past 25 years and became endemic in animal populations in many countries worldwide are postweaning multisystemic wasting syndrome in pigs (Segales and Domingo, 2002; Chae, 2004) and *Neospora caninum* in bovines (Dubey et al., 2007).

B. Surveillance and intervention

Surveillance information is used to document that a hazard is not present or only in less than a specified proportion of the population, that an endemic status remains stable and to give an early warning signal if there is an increase in incidence or another significant change in risk. Even though intervention measures are generally not needed in this stage, they are anticipated to combat a hazard quickly when it occurs. They are generally laid down in national contingency plans or equivalent regulations. If surveillance gives an alarm, response measures will be implemented to contain the hazard and prevent further spread (e.g. outbreak control). In such cases, the free status may be (temporarily) suspended until response activities effectively contain the hazard. Classical intervention measures for infectious diseases include testing-and-culling, movement bans, quarantine, and emergency vaccination.

According to the OIE, a country, region or zone can declare itself historically or officially free from infection provided it presents the required evidence which is

generally based on surveillance information (Anonymous, 2010c). European Union regulations stipulate specific requirements for their member countries to document disease freedom using surveillance. Due to the continuing costs of such surveys, these requirements have triggered efforts to demonstrate disease freedom using novel, more efficient designs such as risk-based sample size calculation of consecutive national surveys (Knopf et al., 2007) or the integration of multiple sources of random and non-random surveillance data in stochastic scenario tree models (Martin et al., 2007).

The approach and design of surveillance chosen may vary over time. Changes in external factors such as the international disease situation (e.g. increase in geographical distribution and worldwide incidence of a specific disease) or environmental or behavioural patterns that facilitate the introduction and spread of a hazard (e.g. establishment of new insect vectors due to climate change, conversion of rain forests into farmland) as well as political priorities and trends may impact on real and perceived risks. Hence, there may be a shift from a situation with a minimal risk for a hazard incursion or augmentation and consequently a low level of alert to a situation where higher vigilance is required. Many surveillance designs, such as sentinel, risk-based or syndromic surveillance have the ability to detect rare cases and are highly sensitive.

Some endemic diseases of public health relevance are notifiable, but are not subject to systematic surveillance. In such cases there are sporadic surveillance data about cases occurring in the population, but the true prevalence is generally not known. For example, toxoplasmosis in animals in Switzerland is notifiable, but is not subject to systematic surveillance.

C. Transition

If surveillance and response measures fail, an adaptation of mitigation to contain the epidemic will be required and the Stages II and III may have to be considered. The transition in that case is not clear-cut and depends on various factors, the most

important one likely being the ability of decision-makers to assess the situation and promote a change in strategy.

For endemic hazards that are not of high priority in Stage I, no specific surveillance information will be available. However, endemic hazards may move up the priority list due changes in the international disease situation (e.g. neighbouring countries successfully implementing intervention programmes), an increase in knowledge about the hazard, the eradication of other public health hazards and/or the availability of new technologies. Another reason for a shift in priorities may be political preferences and the availability of resources. A change in priorities will cause a transition to Stage II.

2.2.3 Surveillance in Stage II mitigation (investigation)

A. Mitigation objective

Stage II mitigation aims at assessing the present situation and to make a decision regarding possible Stage III mitigation. For both endemic and epidemic hazards, problem analysis is needed to understand the problem and guide decision-making regarding Stage III mitigation. In the process, a set of alternative strategies is assessed taking into account technical, social, economic, institutional and/or management considerations. Finally, a decision is made about whether to implement Stage III mitigation or not.

B. Surveillance and intervention

Surveillance is used to obtain epidemiological indicators such as prevalence or incidence, morbidity, mortality, geographical distribution, and frequency of risk or preventive factors. The information provided forms a quantitative basis that helps policy makers to decide if intervention measures are needed and to inform the selection of the intervention strategy to reduce prevalence of a hazard. It describes the initial condition and serves as the foundation for future intervention. Response measures from the previous stage may continue, while surveillance data are collected

to inform alternative or complementary strategies. Sometimes, intervention measures may be pilot tested in that stage to assess the effectiveness of putative interventions.

National or international surveys are used to establish baseline and comparable values for prevalence or incidence of hazards found in animal populations or along the food chain. Moreover, they are used to assess the geographical distribution, quantitatively assess risk or preventive factors or other relevant epidemiological indicators. Depending on the hazard and national characteristics, such as the quality of the veterinary service and the availability of animal databases and resources, the surveillance design may be probabilistic or non-probabilistic.

C. Transition

The surveillance information feeds into technical, social, economic, institutional and/or management considerations that impact on the decision to implement an intervention programme and thus the transition to Stage III. In case the information collected during Stage II surveillance demonstrates that there is no immediate need to act, decision makers may decide to wait and gather more surveillance information over time that potentially informs future intervention programmes. If there is insufficient knowledge about a hazard and/or the technical or financial resources necessary are not available, surveillance information will contribute to the general body of knowledge and increase disease awareness and laboratory expertise, but there will not yet be a transition to Stage III. If the implementation of Stage III mitigation is shown to be feasible and beneficial, the decision is made to shift to the next stage.

2.2.4 Surveillance in Stage III mitigation (implementation)

A. Mitigation objective

Stage III mitigation aims to reduce the prevalence of a hazard in relation to a defined target. The focus now lies on problem resolution, where the planned intervention strategies are implemented to reduce or eradicate a hazard. The strategy and targets are well-defined and necessary elements to support the mitigation process, such as

finances, infrastructure, expertise, information networks, and data flow have been taken into account. Further, surveillance and intervention activities have been clearly defined.

B. Surveillance and intervention

Surveillance provides essential input for programmes established to reduce or eradicate hazards and to enhance food safety. It is an essential tool throughout the whole stage and its objective changes over time. First, it is used to identify animals or herds eligible for intervention. Surveillance data can classify animals or holdings as infected or non-infected and thus mark them as intervention subjects. Second, it is also used to monitor the progress and effectiveness of intervention measures (mid-term evaluation) and to ultimately verify their success (final evaluation). For example, it can be used to check the proportion of immunised animals after a vaccination campaign or to test newborn animals that are expected to be free from infection for antigen. There is a wide range of intervention measures available to reduce or eradicate a hazard. They include culling or medical treatment of diseased animals, vaccination, vector control, promotion of resistant breeds, and deliberate exposure to infected animals to promote natural immunisation. They are often flanked by information and awareness-raising campaigns, on-farm bio-security and re-organisation of structures that impact on disease spread, such as live animal markets or transportation systems. If surveillance data suggest that the change in prevalence is not as large as expected, the necessary steps can be taken to implement corrective measures.

The surveillance design needs to be flexible over time depending on the hazard, mitigation target, and progress of the intervention programme. The lower the prevalence, the larger the sample size required for detection (Salman, 2003), which can make a case for non-random designs.

C. Transition

The attainment of the mitigation target defines the endpoint of Stage III. However, after many years of Stage III mitigation activities, such programmes may become

institutionalised and stagnate in Stage III instead of moving to Stage I. Surveillance that constantly reviews the effect of the intervention will inform the decision about the right time to cease the programme. If decision-makers support the transition to the next stage, mitigation activities will focus once again on sustaining an acceptable level of a hazard.

2.2.5 The cycle is complete

The favourable free status shall be kept for a prolonged time period and possibly indefinitely. However, all hazards that are not present or only at a very low level, because of historical freedom or successful mitigation, have the potential to recur, occur, spread and become endemic if mitigation measures are not adequate or sufficient. It is essential to keep mitigation and related surveillance activities flexible and to respond adequately to dynamic challenges. Thus the classification system is better envisaged as a circular instead of a linear relationship as graphically presented in Figure 2-2.

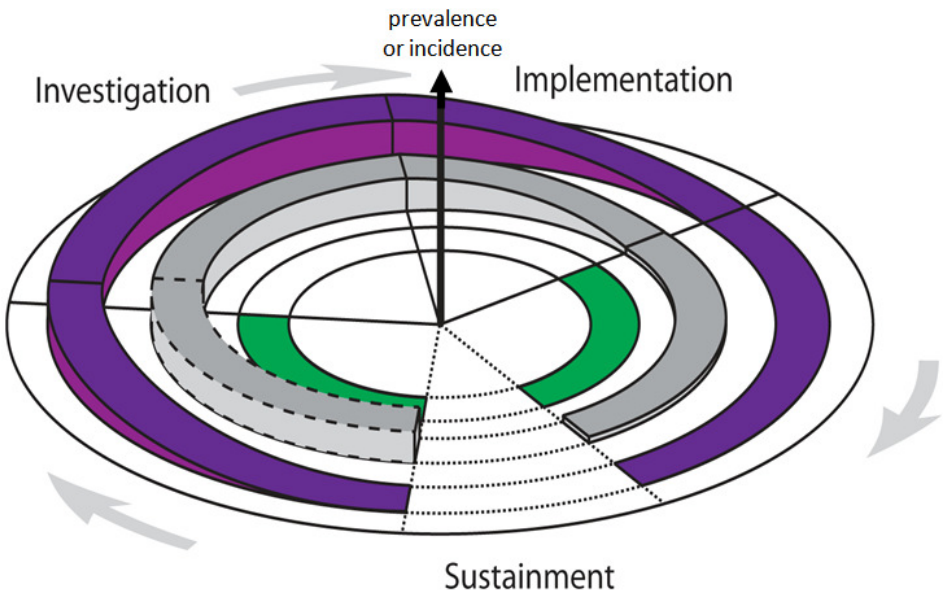


Figure 2-2: Schematic illustration of a classification system for surveillance based on a three stage mitigation system along a circular axis. (Re-)emerging or exotic epidemic hazard that is not controlled by response measures in the sustainment stage, continuous free status, endemic disease, dotted line: true value unknown.

Three examples to illustrate the proposed classification system are described in Appendix II.

2.3 Discussion

2.3.1 Implications for economic analysis

Taking into account the value of mitigation relative to its resource costs, there is in principle a best practice for hazard mitigation in each stage. Ideally, the aim is to extract the highest net benefits from mitigation resource use over time, thus optimising the long-term gain in net benefits to society.

The proposed concept facilitates understanding of the relationships between key elements of mitigation and their technical characteristics, an essential precursor to economic analysis. The effectiveness of mitigation is usually measured in terms of prevalence or incidence reduction. But prevalence and incidence are not in themselves of economic interest. They matter because the lower are prevalence or incidence rates the greater the value, or benefits, obtained as outputs from the resources committed to production.

Each of the three stages has been presented as a distinct phase in the sequential progression of a given hazard from its first appearance through to its eventual control. In practice, any given hazard typically will be observed at one specific stage at any given time.

For the initial sustainment stage to be a rational policy in economic terms, it must be based on an expectation that the future costs of failing to exclude a hazard, or to maintain it at an acceptable level, will exceed sustainment costs. Surveillance expenditures made now are to limit future resource expenditures on interventions to contain a hazard's adverse effects. It is thus expected that surveillance is by far the dominant mitigation activity, and the main source of costs. Intuitively, recurrent surveillance expenditures of this kind are expected to be lower than the accumulated costs of failing to maintain a situation of exclusion or acceptability with respect to a given hazard.

But if the first sustainment stage fails, it results in a switch to a different approach to mitigation. This involves changing the technical characteristics of surveillance in the light of investigation to provide information regarding resource expenditures for intervention. In that sense, the additional resources committed to surveillance in the investigation stage are a cost of failed sustainment. If the purpose of the investigation stage is to inform implementation, potentially it can be considered as a part of implementation, a fixed cost necessarily incurred. From another perspective, if investigation adds to knowledge about the hazard in such a way that the efficiency of mitigation is enhanced into the more distant future, it becomes a long-term investment with a pay-back in terms of additional avoided output losses, and fewer intervention resources expended.

In the implementation stage, both the quantity of resources allocated to surveillance, and their specific technical characteristics, inform the choice, timing, and scale of related interventions. They also document the progress of interventions in terms of impact on prevalence or incidence reduction and, by implication, output loss. Thus implementation again gives rise to two sources of mitigation costs, respectively the resources expended on surveillance and on intervention, but now with intervention expected to account for the greater proportion. Whether this is the case, is an empirical question.

Finally, after successful intervention the mitigation objective may again be the sustained absence of disease. However, this is unlikely to be identical to sustainment as first stage mitigation. The difference is that now more information is available about hazard effects, more having been learned as a result of investigation and implementation, and potentially more insight why earlier sustainment failed in the first place. In that sense, the productivity of mitigation resources has been enhanced by better knowledge, an unequivocal gain in economic efficiency.

2.3.2 Practical applications

The overriding implication of the above discussion is that understanding the technical relationships between surveillance, intervention and the consequent mitigation effect

(e.g. prevalence reduction) is the precursor to economic analysis to identify combinations that maximise social net benefit.

Because diseases are part of biological systems and therefore highly variable and complex, mitigation and thus surveillance need to be dynamic, adaptive and flexible over time, which is reflected in the approach presented. From the proposed classification system it is followed that mitigation for a defined hazard in a target population (e.g. the poultry population of a country or region) can only be attributed to one stage at a time. All surveillance programmes at one stage are likely to show similar characteristics, and so are expected to facilitate research and development of generic designs. Early warning systems in Stage I must be able to detect quickly the incursion of a (re-)emerging or exotic hazard and must therefore be highly sensitive, which is likely to result in considerable costs. Contrary to that, there is generally no need to act immediately on endemic diseases and more time can be spent to design surveillance programmes that provide fit-for-purpose data to prioritise and plan intervention activities. The situation is similar for documentation of freedom, where surveillance needs to detect the incidence or prevalence of a hazard for a defined level of confidence often stipulated in national or international legislation.

The classification system does not of itself provide any information about the most appropriate method of data collection, surveillance design, target pathogens or species. It reflects the real world setting within which decision makers need to operate, develop policies, and allocate their resources. The underlying assumption is that surveillance always informs mitigation. This helps to describe the goal of existing and putative mitigation targets clearly and outlines the need for surveillance to support that target. Hence, the classification system may also be useful for algorithms for decision-making processes or comprehensive evaluation tools for governmental surveillance.

CHAPTER 3

ECONOMIC PRINCIPLES OF RESOURCE ALLOCATION FOR DISEASE MITIGATION IN ANIMAL POPULATIONS

3.1 Introduction

This chapter investigates the implications of technical and economic relationships between magnitudes of lost production and the use of mitigation resources. The relevant principles are derived from basic microeconomics, best exemplified for present purposes in texts from Heady (1952) Doll and Orazem (1978), Heathfield and Wibe (1987), Bettie et al. (2009), and Rushton (2009).

Animal disease creates two categories of economic cost. First, mortality and morbidity directly impact on the quantity of goods and services produced thus reducing people's scope for consumption. Second, scarce resources with positive opportunity costs are allocated to mitigation. To these direct effects may be added wider impacts due to mitigation itself, including spill-over to other sectors (e.g. disruption to tourism), and impacts on downstream and upstream businesses (e.g. breeders, feed and drug producers, slaughterhouses). An inherent characteristic of many production losses is the possibility of measuring them in monetary units by multiplying physical losses such as reduction in litres of milk produced in dairy cows by price coefficients. In aggregate, the total monetary value of such losses is one measure of lost economic well-being to society. However, further economic costs accrue from non-monetary consequences such as human illness, animal welfare, consumer confidence, reputation, and impacts on the environment. Diminished animal welfare represents lost well-being to society, because of people's empathy with other sentient beings (McInerney, 2004). Translating these non-monetary losses into monetary values is problematical, but they are nevertheless real and must be taken into account when discussing values of animal health policy.

In principle, the objective as commonly understood is to reduce these economic costs in the form of benefits foregone. However, this can be achieved only by accruing costs in the form of mitigation expenditures. The overall objective, therefore, is to minimise the sum of benefits foregone and mitigation expenditures. In the present study, for simplicity, benefits foregone are mainly equated to conventional production losses.

3.2 The relationship between production losses and disease mitigation

3.2.1 Production losses with and without mitigation

The impact of disease and its mitigation on the total monetary value of production are investigated using two scenarios:

Scenario 1 relates to Stage I mitigation with epidemic or sporadic occurrence of a hazard, where incidence is the critical variable. New cases occurring over time have a cumulative effect on aggregate production losses. Maximum losses are reached once the epidemic is terminated and long term impacts such as breeding stock depletion are overcome.

Scenario 2 relates to endemic disease. By definition, endemic disease implies an ongoing disease state in an animal population, measured by its prevalence. Compared with a healthy population notionally free from a given disease, production losses are expected to be relatively constant over time.

3.2.1.1 Scenario 1: Epidemic or sporadic disease

Figure 3-1 summarises the implications of epidemic disease and its mitigation for production. The curve 'SD' is the economic counterpart of an epidemic curve (Thrusfield, 2005) without disease mitigation (labelled $(dL/dt)_{[-m]}$). Instead of plotting incidence over time, it represents the monetary value of all resulting production losses. For reasons of simplicity, a self-limiting epidemic curve is used in this example. Similar considerations apply for epidemics that are not self-limiting, but may result in endemicity.

Production losses are the aggregate of all current and future losses. Lost current production is attributable to mortality and morbidity, which may, for example, cause abortion or reduced milk, meat or wool yields. The value of all future production foregone because of breeding animal mortality and thus reduction in capital stock

must be added to estimates of lost current production. The magnitudes of the different effects and their time distribution depend on the specific disease and type of livestock. For example, adjustments take longer in cattle than in pigs or poultry because of the length of reproductive cycles and numbers of offspring.

As illustrated in Figure 3-1, the first cases of the epidemic are identified as occurring within period t1. New cases and associated losses accumulate until, at the end of t1, they add L1 to the monetary value of lost production. A similar interpretation applies to all other points along 'SD'. At the end of t2 for example, the epidemic is shown as already being past its peak, with L2 monetary losses contributed by the last increment of new cases in that period.

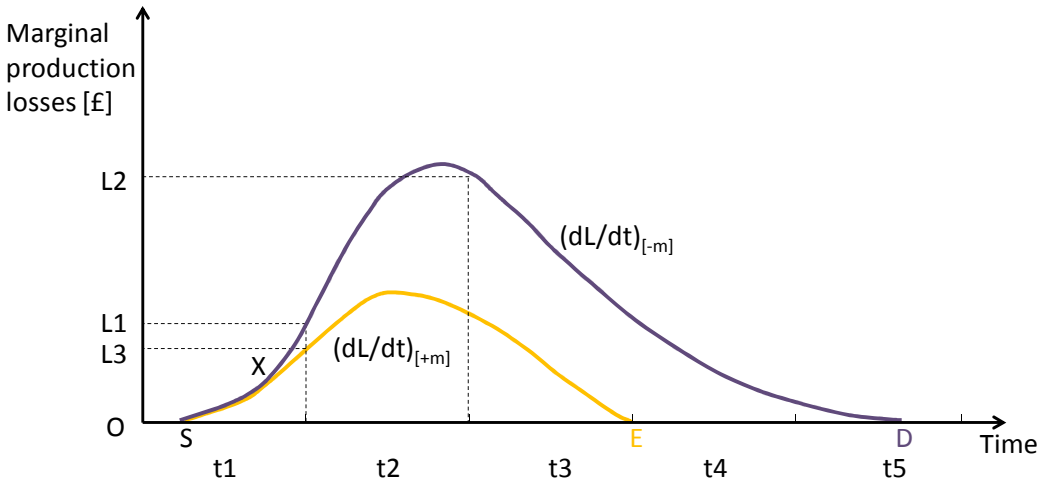


Figure 3-1: Marginal production losses of epidemic disease over time, with (+m, orange 'SE' curve) and without mitigation (-m, purple 'SD' curve). Explanations referring to the letters X, S, E and D can be found in the text.

Curve 'SD', labelled $(dL/dt)_{[-m]}$, thus represents the marginal production losses over time without any mitigation efforts. For economic appraisal of any national disease mitigation programme, it is indispensable to have knowledge of this baseline, i.e. an estimate of what would happen without mitigation action. Even for diseases already subject to mitigation, the best possible estimates of what may happen in its absence are indispensable. Epidemiological modelling makes a crucial contribution to economic analysis by providing estimates for the physical production losses expected from epidemics, which can then be translated into monetary values. The importance of

estimating curve 'SD' is that the total area under the curve, mathematically the integral of curve $(dL/dt)_{[-m]}$ over the range SD, measures the total monetary cost of all production irretrievably lost if a disease epidemic is left to run its natural course.

In contrast, curve 'SE' traces marginal production losses with mitigation. Its origin is also at S, the starting point of the epidemic, assuming that mitigation begins immediately when the first cases of a developing epidemic are seen. Up to point X the $(dL/dt)_{[-m]}$ and $(dL/dt)_{[+m]}$ mitigation curves are identical, indicating that because mitigation is a reaction to a disease outbreak there is inevitably a lag between implementation and seeing evidence of its first beneficial effects. Only to the right of X mitigation efforts begin to limit production losses. For example, at the end of t1, production losses at the margin are reduced from L1 without mitigation to L3 with mitigation. Curve 'SE' is also subject to epidemiological modelling, i.e. mathematical models are indispensable to simulate epidemics both with and without mitigation.

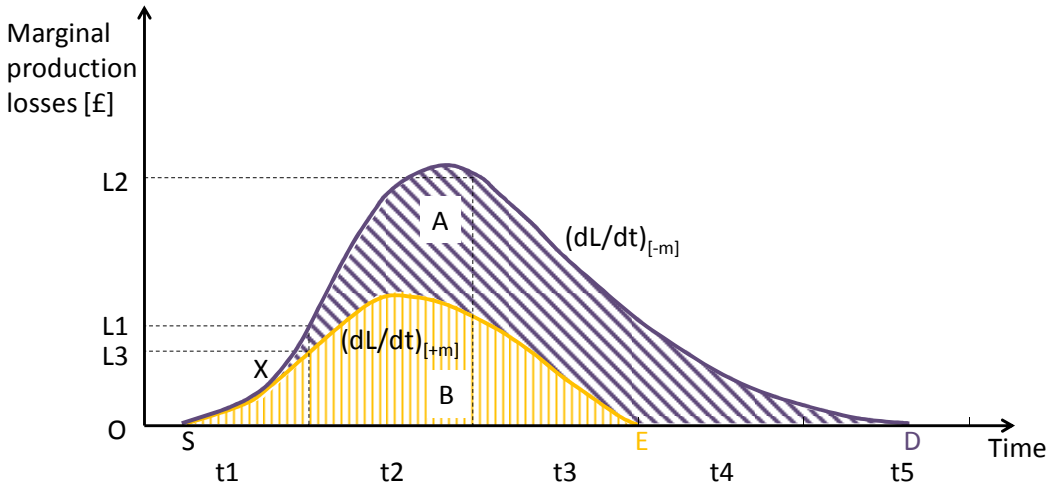


Figure 3-2: Maximum value of avoidable production losses resulting from mitigation (area 'A'). It represents the difference between the areas under the 'SD' and 'SE' curves.

Similar interpretations apply to all other points along 'SE'. Area B in Figure 3-2, mathematically the integral of curve $(dL/dt)_{[+m]}$ over the range SE, is the total monetary value of production losses with disease mitigation. Assuming that curve 'SE' maps the epidemic curve with the best possible technical approach to mitigation in place that currently exists, area A represents the maximum feasible value of avoidable production losses. Curve 'SE' is therefore a technical efficiency frontier.

3.2.1.2 Scenario II: Endemic disease

For endemic disease with stable prevalence over time, curves 'SD' and 'SE' in Figure 3-1 and Figure 3-2 in the long term show year-to-year fluctuations around approximately horizontal trends. This is because 'SD' represents a long-term equilibrium for disease prevalence without mitigation, and 'SE' a sustained lower prevalence level with mitigation, each exhibiting random variation around their respective means. As before, the vertical distance between 'SD' and 'SE' at any point in time measures the marginal benefit of disease mitigation in terms of the monetary value of future production losses avoided. Successful mitigation measures are expected to reduce prevalence over time, thereby avoiding production losses.

3.2.1.3 Discounting

Both in Scenarios I and II, monetary values of production losses that extend over a sufficiently long period into the future must be discounted to account for time preference, i.e. the principle that benefits from mitigation acquired now are preferred to prospective benefits in the more distant future. But while epidemics usually are curtailed after some months or perhaps a very few years, endemic disease normally endures over longer periods. Thus, compared to epidemic disease, discounting normally is expected to be of greater concern when measuring the consequences of endemic disease.

3.2.2 Optimal resource use for disease mitigation

The benefits from disease mitigation, illustrated as area A in Figure 3-2, are not obtained for free. Mitigation requires the expenditure of scarce resources with positive opportunity costs. Moreover, it is realistic to suppose that mitigation effort is subject to diminishing returns. In other words, the closer disease incidence or prevalence get to zero as a result of mitigation measures, the more difficult and therefore costly it may become further to reduce the residual. In some cases, it may not even be realistic to achieve zero incidence or prevalence due to the intrinsic nature of a hazard or its environment.

Diminishing returns, a widely observed phenomenon, reflect the characteristics of the actual world (Brue, 1993). According to a well-established criterion, optimal economic efficiency under diminishing returns is found where the marginal benefits from production losses avoided are just sufficient to cover the marginal mitigation costs required to obtain them. This is equivalent to maximising net benefits. The marginal mitigation costs are the mathematical product of quantities of real resources and their respective money prices. Similar logic applies to different kinds of physical products and their prices, so that

$$P_A \cdot dA = P_M \cdot dM \qquad [1]$$

where

P_A=the monetary value of a unit of physical production losses avoided
dA=increment of physical production losses avoided
P_M=monetary cost of providing an increment of mitigation resources
dM=increment of real resources for disease mitigation

Figure 3-3 illustrates the significance of this relationship. Given all technical options for disease mitigation, equation [1] represents the choice criterion for locating a specific curve between curves 'SD' and 'SE', so that the economic efficiency of mitigation is optimised. For simplicity, three discrete levels of mitigation curves, 'SE', 'SE1', and 'SE2' are shown. The total areas of avoidable production losses are, in ascending order of magnitude, Ai, (Ai + Aii), and (Ai + Aii + Aiii). They represent incremental reductions in production losses in monetary terms according to the equation $(P_A \cdot dA)j$, where (j=i, ii, iii ….n). In reality, the relationship is continuous and the objective in terms of the diagram is to compare the money value of Aj to a unit of expenditures for mitigation, i.e. $P_M \cdot dM$.

Assuming that the first unit of mitigation expenditures results in a more than proportionate marginal reduction of production losses, i.e. $Aj > P_M \cdot dM$, the additional benefits of mitigation exceeds their cost and mitigation resources should be increased. Adding another increment of A equals the additional benefit with the additional expenditure and thus satisfies the criterion for the economic optimum,

i.e. $Aj = P_M \cdot dM$. It is irrational to use more mitigation resources to avoid still more losses, because the marginal benefit will be smaller than the marginal expenditures and the total for net benefits overall will decline.

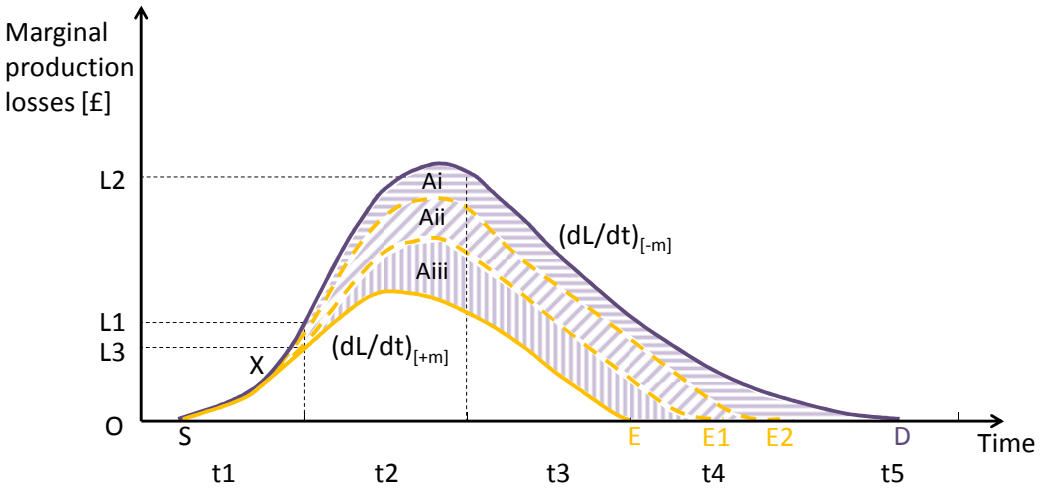


Figure 3-3: Total areas of avoidable production losses for three discrete mitigation curves 'SE', 'SE1', and 'SE2'.

Equation [1] can be re-arranged as:

$$P_A \cdot \frac{dA}{dM} = P_M \qquad [2]$$

The technical ratio dA/dM is defined as the marginal physical product of an increment of mitigation resources (e.g. the quantities of vaccines, veterinary personnel, and test equipment), in terms of physical production losses avoided (e.g. milk, eggs, meat). It is the gradient of the production function $A = f(M)$, where the output A, the production losses avoided, depend on variable M, the level of mitigation resources used. By multiplying dA/dM by P_A the value of the marginal physical product of mitigation in terms of avoided production losses is obtained. The net benefit is maximised, where the value of the marginal physical product of mitigation in terms of avoided production losses equals the price of a unit of mitigation resources, called the marginal factor cost.

Figure 3-4 expresses these relationships more conventionally in the form of a production function in value terms with mitigation resource expenditures on the x-axis

and total production losses avoided on the y-axis. The total production losses avoided correspond to the magnitudes of the Ai areas between curves 'SD' and 'SE' in Figure 3-3, and the origin O with zero losses and no mitigation. Optimal economic efficiency depends on the price ratio P_M/P_A, which is always positive. Hence, $\frac{dA}{dM}$ must also be positive. If expenditures are increased until the avoided losses are maximised, dA and consequently $\frac{dA}{dM}$ becomes zero and the technical optimum is reached. Note, however, that technical optimality coincides with economic optimality only if P_M/P_A tends to zero. In other words, for any positive value for production losses avoided, mitigation resources must effectively be free.

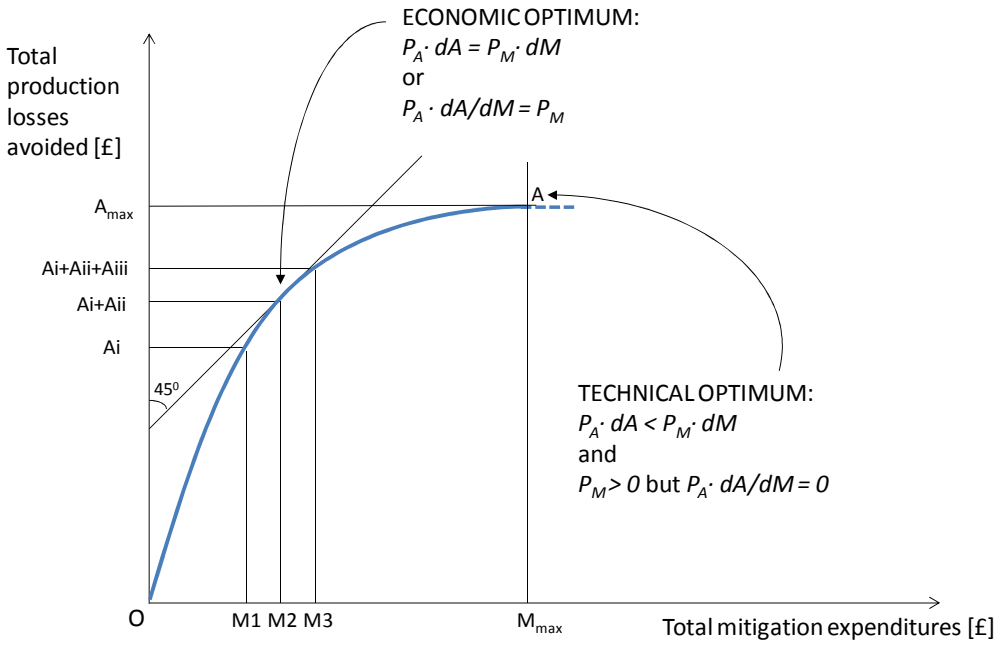


Figure 3-4: Production function illustrating the optimal technical and economic efficiency in disease mitigation.

Since both losses avoided, A, and mitigation expenditures, M, have the same units, a 45^{O} construction line identifies the economic optimum of avoided production losses and mitigation expenditures. Where it is tangential to the production function, a marginal unit in £ of mitigation expenditure equals the same marginal unit in £ of avoided losses. Below that point, the value of marginal avoided losses exceeds marginal mitigation expenditures, indicating that spending still more on mitigation will

add to total net benefits. Above that point, marginal mitigation expenditures exceed marginal losses avoided, thus reducing total net benefits.

3.2.3 Factors affecting the optimal level of mitigation

Two main factors affect the optimal level of mitigation:

1) Any technical changes in A or M with no price changes
2) The value of losses avoided relative to the costs of mitigation including priced production losses or un-priced losses, namely avoided negative externalities associated with animal disease.

Any technical improvements in mitigation methods will shift the production function upwards from the origin. Similarly, if P_A increases for unchanged P_M, curve OA in Figure 3-4 moves upwards from the origin indicating higher values of A for existing levels of M (Appendix Figure III-1).

The focus of this study is on conventional production losses, but where benefits from disease mitigation cannot be observed directly from prices in the conventional sense, they have to be valued using indirect estimation methods. The costs of zoonoses for human health, and therefore implicitly the value of avoiding human illness, can be measured by estimating disability-adjusted life years or quality-adjusted life years (Drummond, 1997). So can the value people place on the welfare of their companion and recreational animals from how much they spend on veterinary services and medicines. Freedom from fear of infection is more problematical to quantify, but is revealed by changes in people's normal consumption behaviour. In principle, the implication for disease mitigation policy is that P_A, the price of a unit of production, needs to be augmented by values for other sources of benefit, so that equation [1] becomes

$$[(P_A \cdot dA) + (V_E \cdot dE)] = P_M \cdot dM \qquad [3]$$

where V_E is the value per unit of a positive externality E.

In relation to Figure 3-4, the economic optimum on production function OA for any given P_M then gets closer to maximum avoided production losses as V_E increases. In the mathematical limit, with V_E sufficiently large, attaining the maximum is consistent with optimal economic efficiency because

$$\text{Lim } [P_M /(P_A + V_E)] \rightarrow 0 \text{ as } V_E \rightarrow \infty \qquad [4]$$

In economic terms, V_E therefore represents the value of unpriced other benefits, i.e. positive externalities, excluded from consideration when the only explicit policy objective is to mitigate production losses. If, in practice, disease mitigation expenditures exceed the measured benefits of a policy, the net cost could be interpreted as the minimum value of unmeasured benefits that must accrue to society from positive externality effects for the expenditures to be justified. And if policy-makers judge that the true value of these wider benefits does not match the imputed value required of them, the policy should be modified.

On the other hand, policy makers may feel intuitively that the true value of positive externalities actually exceeds their imputed monetary value. In that case, the optimal level of resource use cannot be defined according to equation [3] but, akin to the criterion of a benefit/cost ratio, which at least must be unity before deciding to invest, the conclusion is that the policy is worthwhile. The key point in relation to all the above situations is that economic analysis helps give empirical substance to the full implications of a policy decision, favourable or otherwise.

3.3 The relationship between mitigation, surveillance and intervention

The two main activities that comprise mitigation and their economic impact are surveillance (S) and intervention (I). If the above equations for defining optimal economic efficiency are to be satisfied, S and I must themselves be optimally combined. Surveillance is the technical process of generating information for decisions about interventions, also a technical activity, to mitigate disease. Though technically dissimilar activities that use mixes of different types of real resources such as

personnel, equipment and scientific expertise, to simplify exposition, S and I are defined such that the modified production function becomes:

$$A = f(M) = f(S, I) \quad [5]$$

It is crucial first to understand the relationships between S and I as a basis to make efficient resource use decisions.

3.3.1 Surveillance and intervention as technical complements

If $A = f(S{:}\, I)$, and S and I are always combined in a fixed proportion irrespective of the scale of resource use, they are perfect complements. It is thus impossible to evaluate their separate contributions to loss avoidance. They must be treated as a single resource in economic analyses, here M. For such cases, all criteria necessary for assessing economic efficiency have already been outlined. Perfect complementarity is technologically determined. It applies for any disease where mitigation requires a fixed proportion of S to I irrespective of the level of A. Examples of S and I as complements include mitigation strategies based on testing and culling or medication of animals identified by surveillance as eligible for treatment.

3.3.2 Surveillance and intervention as technical substitutes

In contrast, a given level of economic benefits may be obtained by using different combinations of S and I. For example, allocating more resources to surveillance should lead to better and more timely information about a disease threat. Interventions can then be tailored according to the surveillance outcome, allowing for targeted measures with fewer demands on intervention resource use. There is a trade-off between levels of surveillance effort and intervention to achieve a given mitigation objective or, in other words, S and I are economic substitutes. For example, the identification of high risk populations using surveillance allows focusing an intervention strategy, such as a vaccination programme, on affected animals only instead of applying the vaccine to all animals in a defined area or country. Intuitively, S and I are more likely to be substitutes than complements.

3.3.3 Iso-mitigation maps

The iso-mitigation maps in Figure 3-5 are particular examples of iso-quant maps, each plotting different combinations of S and I for increasing fixed levels of losses avoided. As implied above, their specific appearance depends on the technological relationship between the resources used and how they transform into the production losses avoided. Starting from the origin, A represent arbitrary levels for losses avoided for surveillance and intervention as complements (a) and substitutes (b) such that AIII > AII > AI and A3 > A2 > A1. Moreover, diminishing returns mean that moving towards the upper right corner from the origin causes A to increase in proportionately smaller amounts than the increments of S and I.

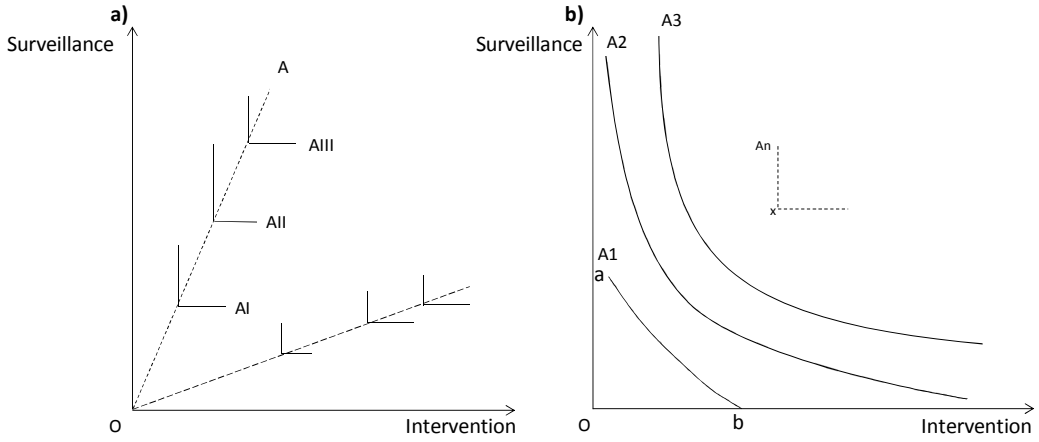


Figure 3-5: Possible configurations of iso-mitigation maps for animal disease when surveillance and intervention are a) complements (each ray depicts a different ratio for resource combinations) and b) substitutes. AI-AIII and A1-A3 are hypothetical discrete levels of production losses avoided.

Each ray in Figure 3-5 (a) represents an example of a particular ratio for combinations of S and I. The right angle intersection for each pair of straight lines is the only point where inputs can be combined efficiently. Increasing either S or I whilst keeping the other one fixed (illustrated by the vertical and horizontal lines starting from the kink), would be a waste of resources, because losses avoided remain the same.

Though mainly illustrating substitution between S and I, Figure 3-5 (b) incorporates an iso-mitigation 'curve' showing complementarity at An, a high level of avoided losses. It

represents the limit to curvature of iso-mitigation curves. The curves depicted illustrate a hypothesis about possible characteristics of the relationships between A, S and I. Specifically, substitution between S and I is shown as scale-dependent. Higher levels of loss avoidance lend less scope for reductions in the quantities of one resource being compensated by increases in the other until, for An avoided losses, there is none. Curvature observed at lower levels of A has here collapsed to a single point of complementarity. At the other extreme, curve A1 is shown as close to a straight line. The point 'a' is not an intercept on the vertical axis, but slightly to its right, indicating that S alone cannot contribute to avoided losses in the absence of at least some contribution from intervention. Moving from 'a' to 'b', reducing units of surveillance resource requires intervention resources to be increased in progressively greater amounts if avoided losses are to be maintained at A1. The slopes of curves A2 and A3 are more pronounced, indicating that as A increases offsetting increments of I for unit reductions in S become proportionately greater. The ease of substitution between S and I for iso-mitigation curves can be expressed as a single parameter, the Hicks elasticity of substitution, σ. It is defined as the proportional change in the ratio in which S and I resources are used relative to the proportional change in rate of technical substitution between I and S (Hicks, 1963). Its numerical value ranges from zero (perfect complements) to infinity for a straight line (perfect substitutability).

3.3.4 Optimal economic efficiency of disease mitigation

Two conditions must be satisfied for overall optimisation of economic efficiency in disease mitigation. First, S and I must be combined at least-cost. Second, the least-cost combination of S and I must produce the level of A that maximises total net benefit overall.

3.3.4.1 Least-cost surveillance and intervention

Formally, the slope of an iso-mitigation curve at any point is given by dS/dI, called the rate of technical substitution (or marginal rate of substitution) of I for S. The least-cost combination of S and I is found uniquely where $P_S \cdot dS = P_I \cdot dI$ for reasons analogous to the explanation of equation [1]. Any other outcome results in higher costs,

inequality indicating that the cheaper resource should be substituted for the more expensive one until their combined cost is minimised.

Rearranging terms,

$$\frac{dS}{dI} = \frac{P_I}{P_S} \qquad [6]$$

shows that the least-cost combination of S and I is found where their rate of technical substitution equals the ratio of their prices. Consistent with the interpretation of P_M above, P_S and P_I are respectively the monetary costs of providing a unit of surveillance or intervention resources. With respect to Figure 3-5, a line drawn tangential to any iso-mitigation curve with slope P_I/P_S identifies the least-cost combination of S and I for a given level of A. If the price ratio changes, so does the least-cost solution, unless S and I are complements. Then, by definition, the ratio in which S and I are used is always the same irrespective of changes in their relative prices. The significance of σ is that the higher its value the more sensitive the least-cost combination of S and I to changes in relative resource prices.

3.3.4.2 The overall economic optimum for disease mitigation

The overall economic optimum for disease mitigation requires that S and I combined at least-cost are used at levels maximising net benefits with respect to A.

From equation [2] we derive that for maximum net benefit, the value of the marginal physical product of mitigation in terms of avoided production losses equals the price of a unit of mitigation resources.

But M comprises S and I, so

$$\frac{dA}{dM} = \frac{\partial A}{\partial S} \cdot dS + \frac{\partial A}{\partial I} \cdot dI \qquad [7]$$

where $\partial A/\partial S$ and $\partial A/\partial I$ are the respective marginal physical products of S and I associated with increments of dS and dI. Thus following [2], we require that for given values of P_S and P_I

$$P_A \cdot \frac{\partial A}{\partial S} = P_S \quad [8a]$$

and

$$P_A \cdot \frac{\partial A}{\partial I} = P_I \quad [8b]$$

are solved simultaneously for S, I, and therefore A that maximises total net benefits of avoiding production losses. In terms of Figure 3-5, this is equivalent to searching across the iso-mitigation map until reaching the curve for A, and specific combination of S and I along it defined by the tangent in their price ratio, that satisfies the optimal criterion.

3.3.4.3 The practical significance of economic criteria

The 'expansion path' in Figure 3-6 is a particular example of an isocline, i.e. a locus of identical tangent points on iso-mitigation curves with the gradient corresponding to the price ratio for S and I. Each point of tangency defines the least-cost combination of S and I for the given $\mathrm{P_I}/\mathrm{P_S}$, calculated as $P_S \cdot S + P_I \cdot I$, for the level of A. If price data and knowledge about the loss avoidance production function are available, observations can be made about the evaluation of disease mitigation policy in the real world. In particular, it enables the optimal level of disease mitigation from society's point of view to be found.

In Figure 3-6 iso-cost lines represent all combinations of S and I summing up to the same total amount of mitigation expenditures. If policy makers allocate the same sum of money to disease mitigation, any such iso-cost line represents a 'budget line', which sets the limit to monetary expenditures on all combinations of S and I at their current prices. Other levels of A can be obtained for the same total expenditure, but are sub-optimal. Because iso-mitigation curves from a production function exhibiting diminishing returns are necessarily convex to the origin, all other combinations of S and I along a given budget line must yield lower values of A. So, for example, the optimal location on budget line BB' in Figure 3-6 is at H for A3 avoided losses, although H' is also feasible for lower A2 avoided losses. Yet without knowledge of the relationship between A, S and I, it cannot be known that a policy decision to allocate S and I to obtain H', given the budget, is actually an inferior outcome.

Depending on the animal disease under scrutiny, unpriced externalities may be critical. For example, if H is optimal with respect to avoided production losses but there are also positive externalities (e.g. reduced risk of human infection, beneficial effect on animal welfare), we require that $(P_A + V_E)$ replaces P_A in equations 8a and 8b. Budget line BB' is then insufficient to achieve optimal economic efficiency, and there is a case for increased funding. In terms of Figure 3-6, as a result of adding the positive externalities to the avoided losses the iso-mitigation curves shift north-easterly. For example, with the value of externalities added, A3 becomes A3+, and H is no longer optimal. A case can be made for mitigation resources to be increased to account for the positive externalities, climbing the expansion path to reach the optimum net benefits for society at point K on curve A3+.

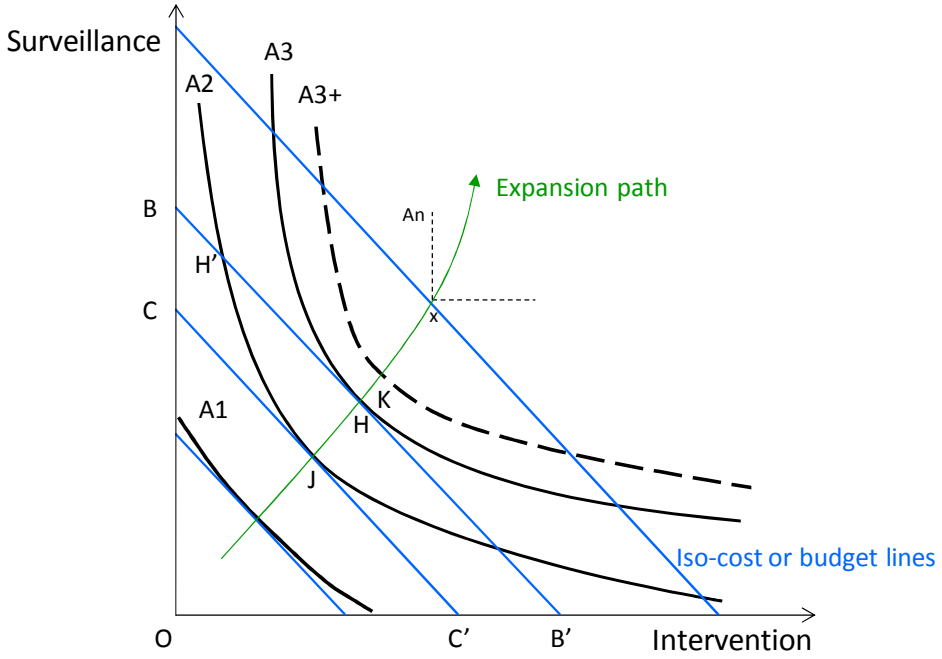


Figure 3-6: Economic interpretation of the iso-mitigation map. A1, A2, A3, A3+ and An are distinct levels of production losses avoided. J, H, K and x mark least-cost combinations of surveillance and intervention corresponding to distinct levels of loss avoidance. Explanations referring to the letters B, B', C, C', H and H' can be found in the text.

If A3 instead incorporates a negative externality, such as people's fears about zoonoses that turn out to have been exaggerated, then BB' funding was excessive. In that case, the budget costs of mitigation outweigh the real benefits to society, most or

all of which are found to derive from avoided production losses. For example, CC' budget expenditures for A2 avoided production losses may correspond to the true economic optimum, (B – C) budget expenditures having been the assumed economic worth of dissipating people's fears. In the face of prior uncertainty, however, what evidence may later show to be an excessive use of resources may be viewed as having been an insurance premium, willingly paid to protect society from potential negative disease effects.

If mitigation policy is to be guided by criteria for economic efficiency, such relationships underline the need for thorough empirical understanding of mitigation production functions for animal diseases.

3.3.5 The disease mitigation surface

The function $A = f(S, I)$ with surveillance and intervention as technical substitutes can be expressed as a three-dimensional figure with S on the x-axis, I on the y-axis and A on the z-axis. Analogous to a three-dimensional hill observed in a landscape, its topography can be portrayed in two dimensions by a contour map.

Because the technological possibilities and therefore the substitutability of S and I vary depending on the disease, there is no single mitigation surface valid for any disease and mitigation scenario. The potential for substitutability appears to be greatest for epidemic diseases where the time from introduction to detection of a hazard can be reduced, which is likely to lower the need for intervention resources. Figure 3-7 is a simplified diagram of a hypothetical disease mitigation surface for surveillance and intervention as substitutes for an incursion of an epidemic disease.

An observer located at X (outside the graph) sees the mitigation surface rising from left to right. Its curvature shows diminishing returns to variable intervention resources at every level of surveillance. Analogously, an observer located at Y sees the surface rising with diminishing returns to surveillance from right to left. Because surveillance alone cannot mitigate a hazard in the absence of some form of intervention, the loss avoidance without intervention is zero irrespective of the level of surveillance. At the other extreme, with a combination of high S and high I (given existing scientific know-

how and unlimited control resources), the maximum technically possible level of A is achieved. With zero or low levels of surveillance, an epidemic may go undetected for some time and even maximum levels of intervention will only achieve a fraction of the maximum possible loss avoidance. On the other hand, because high levels of surveillance detect an epidemic early, large loss avoidance can be achieved with lower levels of intervention resources. The levelling out of the surface for high S and I combinations indicates that $\partial A/\partial I$ for a given level of S approaches zero.

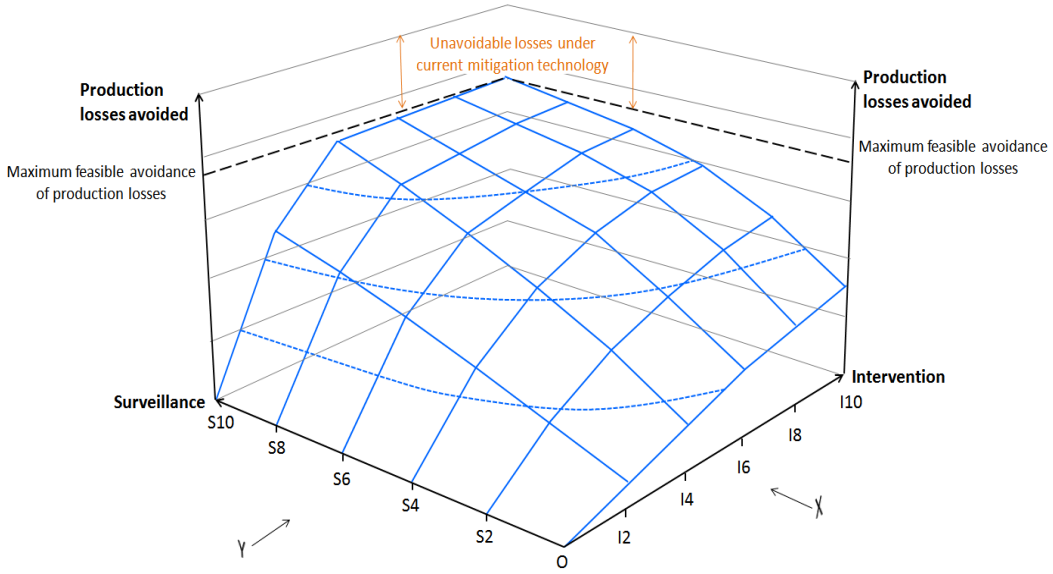


Figure 3-7: Three-dimensional representation of the relationships between avoidance of production losses and variable surveillance (S) and intervention (I) resources.

Given that the law of diminishing returns is very commonly observed in production, it is realistic to attribute diminishing returns to both I and S. However, in certain circumstances, increasing marginal returns seem possible. In principle, this could happen because greater surveillance effort improves understanding of how disease spreads through an infected animal population subject to intervention, and how to stop it. In practice, it is an empirical question whether this is a realistic scenario, for what specific diseases, and under what particular circumstances. The key point is that unless we have empirical knowledge of the mitigation surface it is impossible to make recommendations for overall economic efficiency of mitigation resource use.

Potentially, such a three-dimensional mitigation surface can be constructed from epidemiological models that investigate the impact of a wide range of combinations of surveillance and intervention on disease dynamics in the population. Alternatively, data about surveillance and intervention combinations and the respective outcomes for a particular disease could be gathered internationally, and used in conventional economic production function estimation.

In summary, to determine the optimal level of disease mitigation, we need to:

1. Estimate output loss avoidance curves with and without mitigation
2. Estimate technical relationships between loss avoidance and use of surveillance and intervention resources
3. Translate loss avoidance and resource use into (monetary) benefits and costs
4. Identify least cost combinations for surveillance and intervention
5. Identify least cost combination(s) consistent with the avoidance loss that maximises people's economic welfare

3.4 Discussion and conclusions

The scenarios discussed for epidemic and endemic diseases in farm livestock populations highlight the key variables to be taken into account. These are the impact of disease on lost current and future animal production, and resource expenditures aimed at curtailing losses by interventions to control and, ideally, eliminate the causative hazard. These are essentially the elements of social cost-benefit analysis (CBA), a technique very commonly applied to animal health problems. Having discounted future flows of benefits from reduced losses and corresponding flows of resource expenditures, a benefit-cost ratio of unity or greater is regarded as sufficient grounds for implementing a mitigation policy. But as can be deduced from the above discussion, a benefit-cost ratio is an acceptability criterion, not an optimising criterion. If unity or greater, it tells us only that in net terms society is better off from a particular policy, not whether there is a better alternative. In CBA a particular pair of co-ordinates for surveillance and intervention on the surface is identified, which enables quantification of the total resource costs in comparison to the loss avoidance. In cost-

effectiveness analysis (CEA), equally a pair of coordinates is determined, but without translating the technical parameter of loss avoidance into value terms.

In certain contexts animal disease has externality effects considered so detrimental by society that to focus uniquely on conventional production losses is inappropriate. For example, the fear of people contracting new-variant Creutzfeldt-Jacob disease from cattle has shifted the focus away from lost production due to bovine spongiform encephalopathy to the possibility of human illness and even death (Setbon et al., 2005). Since it is difficult, sometimes impossible, to quantify externalities using existing methods, there is a strong case for more research into finding novel ways to elicit and value people's preferences. Also in relation to externalities, empirical results that throw up apparently net costs of mitigation should not automatically lead to the conclusion that a policy is ill-advised. Instead, in the absence of any better means of estimation, it should be asked if non-priced benefits not taken into account could conceivably match the net costs. Though based on a subjective judgement, it makes such benefits an integral element of the decision-making.

The choice of discount rate should also be carefully reviewed. It is well known from CBA that the choice of discount rate can be contentious, but that there has to be one. The frequent solution is to use the discount rate applied in appraising government investment projects. However, where there is a strong social time preference for an early solution to a disease problem, investigating the impact of applying different discount rates on economic outcomes can assess people's attitudes towards mitigation. Broadly, the higher the discount rate applicable, the greater is the urgency with which society views the need for problem solution.

Epidemiological models have an indispensable role in helping to quantify both the biological and other technical relationships for scenarios that incorporate different approaches to surveillance and intervention, all translatable into quantities of products and resources used. Epidemiological modelling is able to capture disease dynamics in a population considering a variety of inputs. It also investigates the impact of mitigation strategies on for example prevalence or incidence in a population. Therefore, it has the potential to model the characteristics of mitigation surfaces for any disease, and offers an alternative to econometric production function estimation.

By investigating the mitigation production function, A=f(S, I), in detail it is apparent that it is impossible to answer questions about the economic value of surveillance without investigating its technical role and economic worth in the context of intervention. Hence, a thorough understanding of the technical and economic relationships between surveillance, intervention and output loss avoidance are critical for informed decision-making. The conceptual framework presented builds on well-established economic principles to explore such relationships, thereby building a sound foundation for problem formulation and empirical research.

CHAPTER 4

APPLICATION

OF ECONOMIC PRINCIPLES

TO FOUR CASE STUDIES

4.1 Introduction

Economic assessments of four surveillance programmes were conducted with regard to the general theoretical framework described in Chapter 3 in accordance with FVO requirements. The economic principles guided the interpretation and analysis of each programme, which vary in technical complexity. The surveillance programmes for BTV-8, BVDV, AI and salmonella in laying hens were selected in collaboration with key participants from the FVO. They were chosen among all surveillance programmes from the national control plan based on the criteria of relevance, topicality and representativeness. For each surveillance programme, at least one FVO contact person was identified to support the analysis by providing data, information and clarifications as well as feedback.

For all case studies, an overview of the surveillance programme and relevant data were obtained as follows. First, the surveillance objective, as well as the organisation, activities and structure of the surveillance programme needed to be understood and how the programme is embedded within the legal, technical, institutional and political context. To consolidate this information, programme coordinators, scientific literature and unpublished information such as reports or governmental manuals were consulted. Using this information, surveillance programmes were described in detail and classified according to the system presented in Chapter 2. Next, the analytical question, economic criteria and data requirements were outlined for each programme taking into account the economic principles in Chapter 3, FVO requirements, the context of the programme and legal or other obligations. Meetings with representatives from the FVO and related institutions were held to compile data about surveillance and intervention expenditures, and surveillance information, such as prevalence or incidence, in the population. Further, mathematical modellers were met to discuss the availability of epidemiological modelling outcomes for the economic analyses and the possibility of assessing the impact of surveillance and intervention strategies on disease dynamics in the population. Finally, the economic analyses were performed as described below.

4.2 General approach

The economic assessments required technical information about surveillance and intervention activities, epidemiological models to simulate disease transmission dynamics in the population under different mitigation scenarios, and market values, prices and wage rates to calculate costs and benefits. The next sections describe the general structure of the calculations performed and input data used.

4.2.1 Surveillance and intervention costs

For each surveillance programme, detailed activities were listed following nine main steps: 1) planning, 2) preparation, 3) supervision, 4) sampling, 5) laboratory testing, 6) data collection, transfer and administration, 7) data analysis and interpretation, 8) dissemination and communication of results, and 9) revision and adaptation of the running programmes. For each intervention programme, detailed activities were listed as for surveillance, apart from steps 4) and 5) that were replaced by 'implementation of the intervention programme'. When activities of a programme were not well differentiated, steps were merged (e.g. inclusion of step 9 into step 1).

Each surveillance or intervention activity was either classified as labour or operations and expenses. The total surveillance cost (SC) and intervention cost (IC) of a programme was calculated as follows:

$$SC = \sum_i \sum_j LB_{i,j} + OE_{i,j}$$

$$IC = \sum_h LB_h + OE_h$$

where *LB* is the labour cost and *OE* the cost for operations and expenses in the context of two distinct surveillance system components *i* and *j* (e.g. entomological and serological surveillance), and an intervention programme *h*.

The labour cost was:

$$LB_{i,j} = h_{X_{i,j}} \cdot w_z$$

$$LB_h = h_{Y_h} \cdot w_z$$

Where h is the number of working hours spent per surveillance activity $X_{i,j}$ or intervention activity Y_h and w_Z the wage rate per job position Z. Each job position at the FVO (e.g. researcher, communication staff) was assigned a specific wage rate per productive hour that was calculated based on actual salary classes and an annual productive working time of 1,781 hours. The cantonal veterinary service (CVS) wage rates were obtained from the CVS Geneva. The wage rate for agricultural employees was derived from monthly published agricultural statistics (Swiss Farmers' Union, 2009). The numbers of working hours per job position were indicated by the persons performing the described tasks or by their supervisors using whenever possible data from the official time recording system.

The cost for operations and expenses was:

$$OE_{i,j} = U_{X_{i,j}} \cdot p_U$$

$$OE_h = U_{Y_h} \cdot p_U$$

Where U is the number of units per surveillance activity $X_{i,j}$ (e.g. blood sampling, postage, enzyme linked immunosorbent assay, ELISA) or intervention activity Y_h (e.g. disposal of dead animals, cleaning and disinfection, electronic registration of vaccinated animals) and p_U the price per unit (e.g. price of laboratory test). The input data for operations and expenses were either requested from the respective institutions or businesses that delivered the service (e.g. laboratories, private veterinarians) or indicated by FVO or CVS staff involved in the surveillance and intervention programme.

4.2.2 Estimation of avoidable disease costs

The aggregate value of disease avoided was estimated as the sum of benefits from lower output loss, reduced expenditures and fewer negative externalities, such as human illness.

4.2.2.1 Production losses

Production losses accrue for example from mortality, premature culling, reproductive disorders, reduction in wool, milk, meat, or eggs and trade bans due to disease. The type of production loss varies according to the pathogen, species, age, or physiological status (e.g. pregnancy) of the animal. The general equation used to calculate production losses (PL) is:

$$PL = \sum_{e} \sum_{f} NoA_{e,f} \cdot LPP_{e,f} \cdot p_{e,f}$$

Where *NoA* represents the number of animals of the type *e* (e.g. dairy cows) suffering from disease impact *f* (e.g. reduction in milk yield), *LPP* the lost physical production coefficient (e.g. rate of reduced milk yield in dairy cows) and *p* the price coefficient related to the disease impact (e.g. production price per litre cow milk).

To calculate production losses related to a programme, a list of all disease impacts per animal type was made. Lost physical production coefficients were quantified based on Swiss data, scientific literature and/or expert opinion. Data regarding the study population (e.g. number of animals per species and age per holding) were derived from the Swiss national agricultural census data, which were provided by the FVO. Animal values (e.g. market value, slaughter value), production data (e.g. milk or wool yield) and prices (e.g. production price milk) were derived from Swiss statistics. Where data were missing or inconsistent, values from the scientific literature and expert opinion were used.

4.2.2.2 Expenditures

Expenditures due to disease itself or related mitigation measures accrue for example from palliative treatment of clinical symptoms, additional testing for export, and other measures such as insecticide treatment or vector control. Any expenditure was calculated by multiplying the number of units used (e.g. number of animals treated) by the price per unit (e.g. price per treatment per animal).

4.2.2.3 Externalities

The most important externality in the context of animal disease is its impact on human health. Zoonotic diseases may be transmitted by direct contact with infected animals or by consumption of infected food produce and cause human illness and in the worst case human death. Other externalities include spill-over to other sectors of the economy (e.g. tourism, leisure activities) as well as upstream and down-stream effects on businesses along the production chain (e.g. breeders, feed producers, abattoirs, retailers). Depending on the viewpoint of the analysis, such externalities may be classified as production losses.

Because of the nature of the diseases investigated and/or the analytical approaches chosen in accordance with economic principles and the practical context, none of the case studies required estimation of externalities.

4.2.3 Epidemiological input

Epidemiological models are a key source to provide important input for the economic assessment of disease mitigation. Epidemiological outcomes, which can be used as inputs in economic assessments, depend on disease characteristics and the specific requirements of the analytical approach selected. Outcome measures are, for example, the number of animals showing clinical signs, number of animals dying, or number of animals being culled per time unit. If such detailed outcomes are not available, proxies may be used such as incidence or prevalence at animal or holding level.

Epidemiological models were available at the FVO for Case Studies 1 and 2, but not for Case Studies 3 and 4.

4.2.4 Other information

The case studies were performed between March 2009 and October 2010. Stochastic spreadsheet models for the economic analyses were developed using @Risk software for Excel version 5.0 (Palisade Corporation, Newfield, NY, USA). All uncertain data values were integrated as distributions and the models were run with 10,000-20,000 iterations over the given time period. Mathematical descriptions of the probability distributions used can be found in Appendix IV.1. The impact of uncertain input values on the outputs was assessed using the in-built sensitivity analysis tool, which performed multivariate stepwise regression for values sampled from the defined distributions. The resulting beta regression coefficients indicated the sensitivity of the simulation output to the distributions of the input parameters. All monetary values were expressed in Swiss francs (CHF) (1 CHF=0.56-0.65 £ at the time of analyses).

All future costs and benefits needed to be translated into present values by multiplying the costs or benefits by the discount factor $1/(1 + r)^t$, where r=3.5% is the selected discount rate and t the time in years.

Disease specific expert teams were formed to elicit expert opinion whenever needed. They included scientists, FVO and CVS staff members as well as veterinary practitioners.

4.3 Case study 1: Surveillance and intervention programme for bluetongue virus serotype 8 (Stage III mitigation programme)

4.3.1 Introduction

In 2006, BTV-8 was reported for the first time in the Netherlands with subsequent spread in north western Europe (Wilson and Mellor, 2008), reaching Switzerland in

October 2007 (Hofmann et al., 2008). Shortly after the first outbreaks were detected, Switzerland declared the whole country as one 'restriction zone' to avoid trade restrictions on national level. As more cases were confirmed, the FVO implemented a compulsory BTV-8 mass vaccination campaign in 2008 for all cattle, sheep and goats over three months old. In 2009, all cattle and sheep over three months old were vaccinated while the vaccination of goats was voluntary.

The vaccination programme aimed to avoid and reduce disease and infection in the population, while serological surveillance activities aimed to check if the vaccination programme yielded the expected results. Further, entomological surveillance was used to monitor the vector dynamics.

According to the FVO's needs, a retrospective and prospective economic assessment of the BTV-8 surveillance and intervention programme was conducted. The objectives were 1) to assess if the implementation of the surveillance and intervention programme to contain the disease in 2008 and 2009 was economically efficient and 2) to evaluate if continuation of the implemented programme during 2010 – 2012 would be justified.

4.3.2 Methodology

4.3.2.1 General overview and scenarios

For 2008-09, the surveillance and intervention programme implemented (called the retrospective comparative scenario, RCS), was compared to a retrospective baseline scenario (RBS), a hypothesised alternative. For 2010-12, the implemented surveillance and intervention scenario was assumed to continue, now called the prospective comparative scenario (PCS), and compared to two different prospective baseline scenarios 1 and 2 (PBS1 and PBS2). Details of the scenarios are provided in Table 4-1.

Entomological surveillance was performed in 16 regions in accordance with EU Regulation 1266/2007. In line with the requirements of this Regulation, entomological surveillance in Switzerland was envisaged to be abandoned by the end of 2010.

Table 4-1: Time frame and scenarios for the economic analyses of bluetongue virus serotype 8 surveillance and intervention activities in Switzerland.

	2008 and 2009 Retrospective analysis		2010 to 2012 Prospective analysis		
Scenario	Baseline scenario	Comparative scenario	Baseline scenario 1	Baseline scenario 2	Comparative scenario
Serological surveillance					
Monthly seroconversion	2%	2%	20%	2%	2%
Confidence	99%	99%	95%	99%	99%
Entomological surveillance	Yes	Yes	In 2010 only	In 2010 only	In 2010 only
Vaccination coverage	35%	90%	0%	35%	90%

4.3.2.2 Analytical framework

The analytical objective was to estimate whether the benefit resulting from mitigation was bigger than or equal to the surveillance and intervention costs. Benefits and costs were estimated by comparing corresponding baseline and comparative scenarios for the respective time period. The total benefit (TB) resulting from the programme was the disease costs avoided. Subtracting the difference in intervention costs resulted in the margin over intervention (MI). Crucially, this margin represents the maximum additional expenditures potentially available for surveillance without the net benefits from mitigation overall becoming zero. Subtracting the difference in surveillance cost from the MI provided the net value (NV, i.e. net benefit or net cost) of the programme:

$$TB = Disease\ costs_{BS} - disease\ costs_{CS}$$

$$MI = TB - (Intervention\ cost_{CS} - intervention\ cost_{BS})$$

$$NV = MI - (Surveillance\ cost_{CS} - \ surveillance\ cost_{BS})$$

where BS denotes the baseline scenario (e.g. RBS) and CS the corresponding comparative scenario (e.g. RCS).

4.3.2.3 Epidemiological model

In an independent project, a deterministic compartmental model with susceptible, infected, recovered, vaccinated and protected holdings was developed to simulate the effect of different vaccination strategies on the BTV-8 disease dynamics in the Swiss

cattle, sheep and goat population (Di Labio et al., 2009). It was built and run with the modelling software Vensim© Professional, Version 5.5c (Ventana Systems, Inc., Harvard, USA) and applied on single clusters of holdings that were considered to form an epidemiological unit for spread.

For the simulation of the retrospective scenarios, the starting population was fully susceptible, while for the prospective scenarios the starting population was partly protected due to the compulsory vaccination campaign in 2008 and 2009. The epidemiologic output "number of BTV-8 infected holdings" per year and scenario was used as input parameter in the economic model. The epidemiological model predicted the number of infected holdings in a zone with a 25 km radius and a starting population of 3,100 susceptible holdings. The epidemiological modelling output "number of BTV-8 infected holdings" was used to calculate the national number of infected holdings per year and scenario. First, the proportion of BTV-8 infected holdings of the 3,100 susceptible holdings was calculated. Assuming homogenous mixing, the national number of infected holdings per scenario and year was calculated by multiplying this proportion by the total number of holdings.

4.3.2.4 Study population

The study population included 53,290 holdings that kept cattle, sheep and/or goats as recorded in the 2008 national agricultural census (census data provided by FVO). Animal categories defined in the agricultural census were allocated to 13 specific categories according to species and age (e.g. dairy heifers). These categories were further allocated to animal groups, namely adult cattle, adult sheep, lambs, calves and goats. Next, the respective number of infected holdings per scenario was randomly selected from all holdings listed in the national agricultural census database. By summing up all animals per category the aggregate number of bovine, caprine and ovine animals in infected holdings was calculated. These two steps were repeated a 1,000 times per scenario to produce a set of estimates characterising the total number of animals per category on infected holdings. The 1,000 datasets per scenario were then exported into @Risk for Excel, where the integrated distribution fitting feature

was used to fit probability distributions to the simulated data. All distributions were either normal or lognormal.

4.3.2.5 Surveillance and intervention cost

Surveillance and intervention cost accrued from the activities listed in Appendix Tables IV-2, IV-3 and IV-4 and were calculated as described in section 4.2.1, apart from the surveillance cost in 2008. From July 2007 to May 2008, 200 holdings with 5,400 dairy cattle were surveyed monthly for anti-BTV antibodies using bulk milk samples and ELISA testing (Schwermer et al., 2008). The surveillance cost for the bulk milk surveillance in 2008 was included as a lump sum of 50,000 CHF as listed in the FVO's financial budget. In 2009 bulk milk surveillance was replaced by blood sampling and ELISA testing of individual animals. Polymerase chain reaction (PCR) was used to re-test and serotype all animals that were ELISA positive. In 2009, 8.7% of all samples were seropositive (Schwermer, 2009). The prospective proportion of seropositive samples was estimated to be a Pert distribution with a minimum value of 0.08, a most likely value of 0.087 and a maximum value of 0.094. For the entomological surveillance of the vector, 19 traps were installed in Switzerland and Lichtenstein and midges were collected and counted weekly during 34 weeks (Zaugg et al., 2008).

In the comparative scenarios, the call-out fee was included with the intervention costs, because the vaccinating veterinarians took blood samples at the time of vaccination to exploit synergies. For the RBS and PBS2, the call-out fee in CHF for the serological surveillance was set to a uniform distribution with a minimum of 20 and a maximum of 25, which reflected the call-out fee officially recommended by the FVO during the bluetongue campaign, while all other inputs stayed the same. For the PBS1, serological surveillance activities were expected to comply with the minimal requirements stipulated in EU Regulation 1266/2007, which would reduce the total serological surveillance costs by a factor of 10 (personal communication H. Schwermer, FVO).

In 2008, all cattle were vaccinated twice, while sheep and goats were only vaccinated once. In 2009, cattle that had not been vaccinated previously needed to be vaccinated twice, which reflected the proportion of young animals in the population (10%), as

derived from the national agricultural census data. All other animals of the bovine and ovine species needed to be only vaccinated once as stipulated in the Swiss ordinance regarding the vaccination against bluetongue (SR[2] 916.401.348.2). The calculation of the total number of holdings visited for vaccination and the number of vaccines given is explained in detail in Appendix IV.2.2.

No data were available for the workload, operations and expenses for intervention activities in the RBS and prospective scenarios. Consequently, FVO staff members were asked to make qualitative estimates for these, and for lump sum expenditures in relation to the RCS. Then the qualitative estimates were transformed into quantitative values by applying the following weights to the observed RCS values: much less (0.4), less (0.7), the same (1.0), more (1.3), and much more (1.6).

4.3.2.6 Monetary benefits

The monetary benefits were estimated as the difference in disease costs between the comparative scenario and the corresponding baseline scenario. Disease costs were the sum of production losses and expenditures for export, palliative treatment and cantonal response measures for suspect and confirmed cases. Detailed calculations and parameterisation can be found in Appendix IV.2.3. Production losses included losses due to mortality, abortion, prolonged calving interval, premature culling, reduced milk yield, wool reduction, reduced weight gain, and export. Their estimation was based on Velthuis et al. (2009) who calculated the financial costs of the BTV-8 epidemic in the Netherlands. Because Switzerland declared itself as one restriction zone, no losses occurred due to movement bans within the country. The bluetongue expert team determined that the BTV-8 incursion in Switzerland as well as vaccination did not affect the consumption of beef and dairy products.

From reference to Swiss trade statistics for the years 2007 to 2009, we concluded that the number of export cattle in the comparative scenarios was not perceptibly affected by bluetongue disease and related mitigation measures. However, for the baseline

[2] SR denotes the official compilation of all Swiss federal laws and ordinances (http://www.admin.ch/ch/e/rs/rs.html)

scenarios it was assumed that fewer animals would be exported due to BTV-8. The number of cattle destined for export that could not be exported was estimated from the number of movement ban days for confirmed and suspect cases. This figure was then multiplied by the expected loss per animal not exported.

Export of cattle caused expenditures for vaccinating or blood sampling and testing of animals that were not already vaccinated. The call-out fee for a veterinarian, the price of vaccination (including labour, vaccine and material) or sample taking (including labour and material) and the price for laboratory testing were accounted for.

Cantonal response expenditures for suspect and confirmed cases accrued from labour for epidemiological investigations, implementing and lifting the movement ban, as well as sample taking, laboratory testing, and measures to control midges. In case of a clinically suspect case, the CVS implements an animal movement ban on the holding, and orders blood sampling of suspect animals (maximum five per holding) and an epidemiological investigation. The samples from suspect animals are tested for all BT serotypes using PCR. Sick animals receive palliative treatment and are treated with insecticides. If the holding is virus positive, all non-vaccinated animals have to be blood sampled and tested. Once the holding fulfils the requirements for termination of an outbreak as stipulated in the Swiss Animal Health Ordinance (SR 916.401), the CVS lifts the movement ban.

4.3.3 Results

4.3.3.1 Surveillance and intervention costs

Table 4-2 lists the serological surveillance costs for the RBS and RCS in 2009 and the entomological surveillance cost for all scenarios. Serological surveillance cost mainly accrued from the costs of laboratory testing (43% and 45%, respectively), sampling (18% and 15%, respectively) and planning of the surveillance programme (14%).

The mean undiscounted prospective serological surveillance cost for the PBS2 and PCS were the same as for the RBS_{2009} and RCS_{2009}, respectively, while the PBS1 was 1/10 of

the RCS_{2009} value. Discounted surveillance cost for the 2010-12 are listed in Appendix Table IV-7.

Sensitivity analyses showed that the price for PCR testing of samples that tested positive in the ELISA test had the strongest positive impact on the total surveillance cost for all prospective scenarios with regression coefficients ≥0.93. The other regression coefficients for the prospective scenarios were 0.28 for the number of animals sampled, 0.20 for the proportion of seropositive samples, and <0.20 for the number of holdings visited and the call-out fee.

Table 4-2: Mean serological and entomological surveillance cost (SC) for bluetongue virus serotype 8 (90% central range) calculated for Switzerland [in Swiss francs]. RBS=retrospective baseline scenario, RCS=retrospective comparative scenario.

	Serological SC		Entomo-logical SC
	RBS_{2009}	RCS_{2009}	Any scenario
1) Planning	22,000	22,000	2,200
2) Preparation	8,428	8,428	1,908
3) Monitoring and controlling	2,200	2,200	895
4) Sampling	29,657 (29,094; 30,219)	24,032	3,925
5) Laboratory testing	69,873 (61,683; 78,026)	69,873 (61,683; 78,026)	20,000
6) Data collection, transfer and administration	8800	8800	--
7) Analysis and interpretation of data	6600	6600	3,300
8) Dissemination & communication of results	9258	9258	1,937
9) Improvement & adaptation of project	4400	4400	1,100
Total	**161,216 (153,024; 169,421)**	**155,591 (147,400; 163,780)**	**35,265**

Appendix Table IV-8 lists the detailed intervention cost for all scenarios. The mean totals of intervention cost for the RCS were 17.52 m CHF in 2008 and 10.67 m CHF in 2009. The mean totals of intervention cost for the RBS were 9.22 m CHF in 2008 and 5.72 m CHF in 2009. The intervention cost for the retrospective scenarios mainly accrued from implementation costs (91-94%) and to a much lesser extent from planning (1-2%), preparation (3%), and dissemination and communication (1-5%). The mean total discounted intervention cost was highest for the PCS with 9.54-10.23 m

CHF. The intervention cost for the PBS2 was about half the cost for the PCS. The PBS1 yielded the lowest intervention cost of 0.33-0.35 m CHF. The intervention cost for the PCS and PBS2 accrued mainly from implementation costs (92-94%) and to a lesser extent from preparation (3%), dissemination and communication (2-4%), and planning (1%). The intervention cost for PBS1 stemmed mainly from dissemination and communication efforts (52%), planning (30%), and preparation work (17%).

4.3.3.2 Total disease costs

Table 4-3 lists the total disease costs for all scenarios. Detailed disease costs are listed in Appendix Table IV-9. The mean total disease costs were 0.86-5.62 m CHF for the comparative scenarios, 3.97-18.48 m CHF for the RBS and PBS2 and 7.14-9.95 m CHF for the PBS1. For the RCS in 2008 and 2009, disease costs mainly accrued from the cantonal response measures (55%), mortality (20% and 19%, respectively), and veterinary treatment expenditures (11%). For the RBS in 2008 and 2009, the disease costs mainly accrued from losses due to mortality (38% and 35%, respectively), cantonal response measures (26% and 25%, respectively) and palliative treatment expenditures (21% and 20%, respectively).

Table 4-3: Total bluetongue virus serotype 8 related disease costs calculated for Switzerland for the years 2008-12 in million CHF. RBS=retrospective baseline scenario, RCS=retrospective comparative scenario, PBS1=prospective baseline scenario 1, PBS2=prospective baseline scenario 2, PCS=prospective comparative scenario.

		2008	2009			2010	2011	2012
RBS	mean	18.48	5.45	**PBS1**	mean	9.95	7.37	7.14
	5th percentile	15.01	4.46		5th percentile	8.03	5.96	5.77
	95th percentile	22.03	6.47		95th percentile	11.89	8.80	8.51
RCS	mean	5.62	0.86	**PBS2**	mean	5.82	4.03	3.97
	5th percentile	3.56	0.55		5th percentile	4.74	3.30	3.25
	95th percentile	7.74	1.18		95th percentile	6.91	4.78	4.70
				PCS	mean	1.23	3.14	3.03
					5th percentile	0.78	1.93	1.86
					95th percentile	1.70	4.39	4.24

For the PCS in 2010-12, the total disease costs mainly accrued from losses due to the cantonal response measures (56-59%), mortality (20-21%), and palliative treatment

expenditures (11%). For the PBS1 and PBS2, the total disease costs mainly accrued from losses due to mortality (35%), cantonal response measures (25-27%), and palliative treatment expenditures (20%).

In all scenarios, losses due to premature culling, reduced wool production, reduced weight gain and export contributed least to the total disease costs.

Sensitivity analysis produced very similar results for the retrospective and prospective scenarios. For all scenarios, the proportion of confirmed cases per total number of infected holdings had the strongest positive impact on total disease costs (regression coefficient ≥0.93). The relative reduction in milk yield in morbid cows, morbidity in adult cattle, the price of veterinary treatment for adult cattle and mortality in adult cattle showed regression coefficients between 0.10-0.17 for all baseline scenarios. The number of working hours for the epidemiological investigation showed a regression coefficient of 0.11 for all comparative scenarios. All other input parameters had regression coefficients <0.1.

4.3.3.3 Total benefit, margin over intervention cost and net value

The total benefit, difference in intervention cost, margin over intervention cost, difference in surveillance cost and net values resulting from the retrospective and prospective comparison of the baseline and comparative scenarios are illustrated in Figures 4-1 and 4-2 and/or detailed in Appendix Table IV-10. All figures in the text below are mean values. For the retrospective analysis (Figure 4-1), the total benefit was 12.86 m CHF in 2008, 4.60 m in 2009, and, in aggregate, 17.46 m CHF for the two years together. The net value was 4.56 m CHF in 2008, -0.35 m CHF in 2009 and, in aggregate, 4.21 m CHF for the two years together.

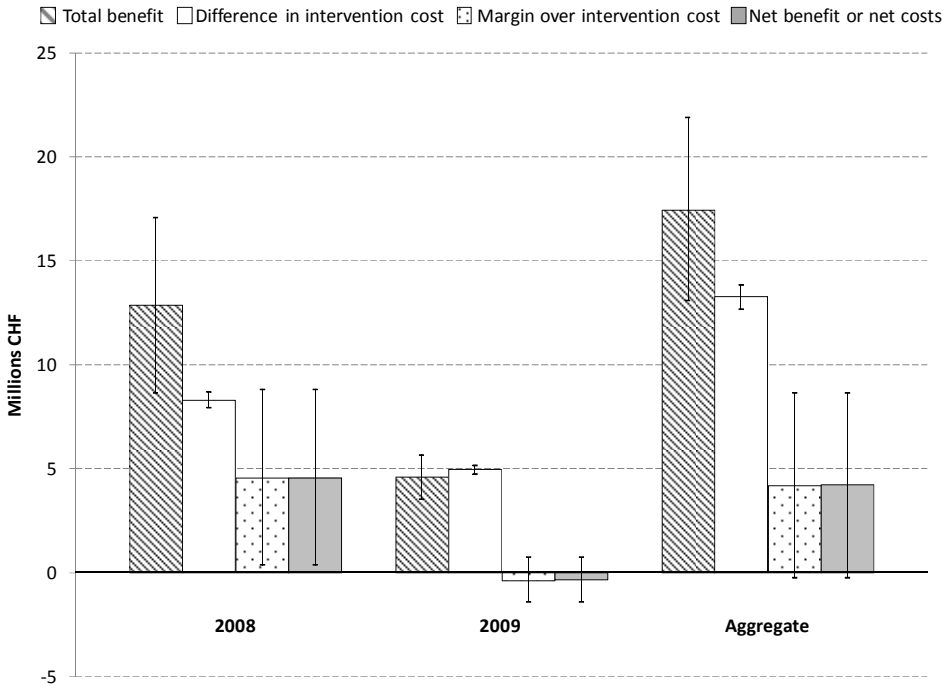


Figure 4-1: Total benefit, difference in intervention cost, margin over intervention cost, and net benefit or net costs resulting from the comparison of the retrospective baseline scenario and retrospective comparative scenario.

The discounted total benefit resulting from the comparison between the PCS and PBS1 (Figure 4-2 A) was 4.13-8.75 m CHF for the years 2010-12 and 17.15 m CHF for the three years together. The difference in discounted intervention cost was larger than the benefit, which resulted in a negative margin over intervention cost for all years. The difference in surveillance cost was 0.13-0.14 m CHF for 2010-12 and 0.39 m CHF for the three years together. The net values were between -5.40 and -1.26 m CHF for 2010-12 and -11.86 m CHF overall.

The discounted total benefit resulting from the comparison between the PCS and PBS2 (Figure 4-2 B) was between 0.93 and 4.58 m CHF for the years 2010-12 and 6.41 m CHF for the three years together. The difference in discounted intervention cost was larger than the benefit, which resulted in a negative margin over intervention. The difference in discounted surveillance cost was near zero m CHF. The net values were between -3.73 and -0.20 m CHF for the years 2010-12 and -7.46 m CHF for the three years together.

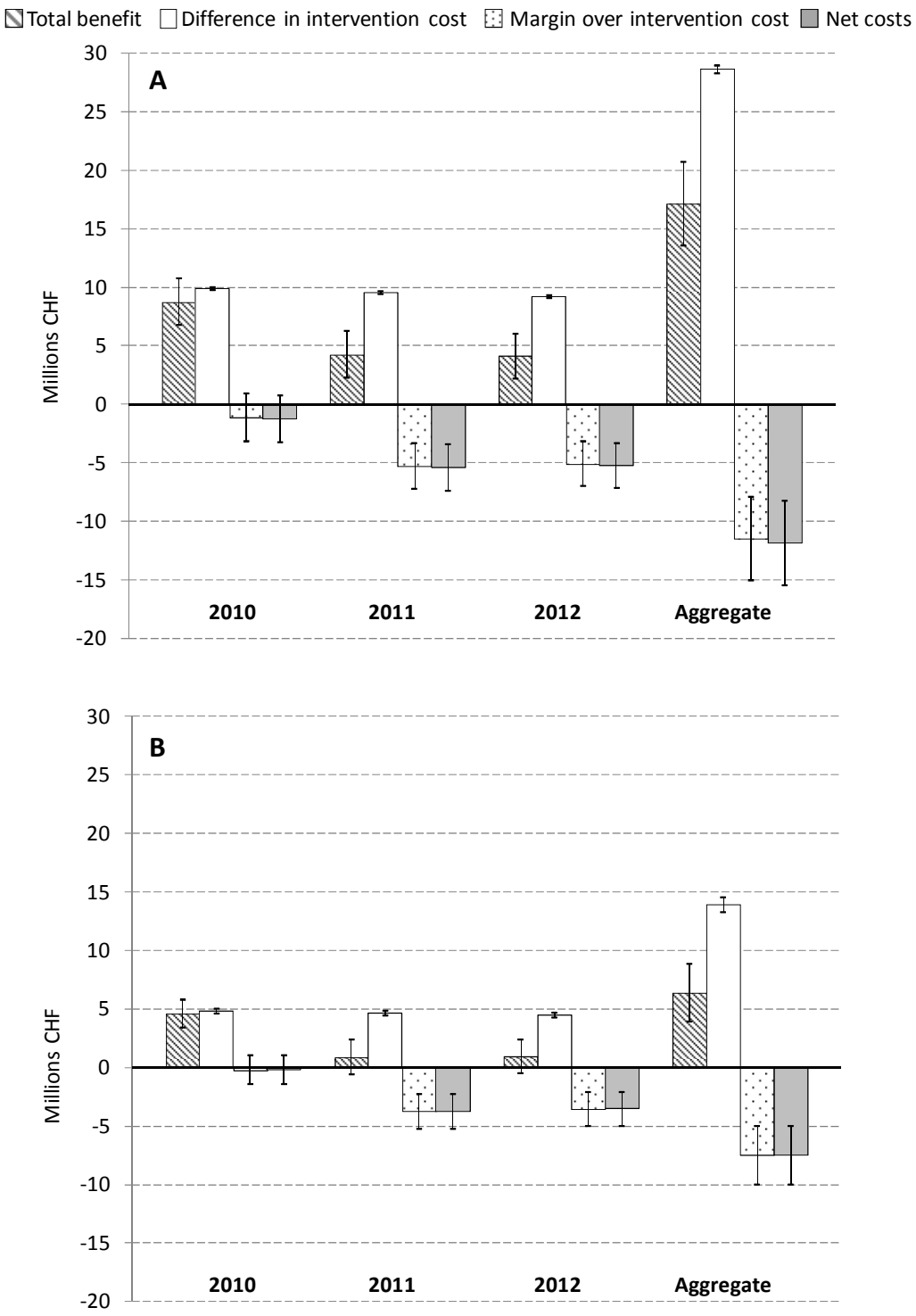


Figure 4-2: Total benefit, difference in intervention cost, margin over intervention, and net costs resulting from the comparison of A) the prospective baseline scenario 1 and prospective comparative scenario, and B) the prospective baseline scenario 2 and the prospective comparative scenario.

4.3.4 Discussion

The retrospective analyses demonstrated that the surveillance and intervention programme to contain the disease implemented in 2008 and 2009 produced a mean net benefit of 4.21 m CHF for the two years together. Yet the estimates for 2009 already signal changes that become more apparent from the prospective analyses. These show that the continuation of the surveillance and intervention programme in the same form would produce mean net costs of 7.46 m CHF for the period 2010-12 when compared to the most likely alternative scenario. This loss is due to intervention cost remaining constant at a level of approximately 10 m CHF per year while the total benefit in a fully vaccinated population, i.e. the avoidable disease costs, are expected to be comparatively small (1-5 m CHF between 2010-12). It was shown that the margin over intervention cost for surveillance was negative for all years except 2008. Overall, surveillance cost was only a fraction of the intervention cost. Moreover, the surveillance approaches differed little between the scenarios, which highlighted their secondary role. Hypothesising that surveillance and intervention are economic substitutes, an increase in surveillance resources could produce more and better information, which in turn would allow more targeted and potentially less resource-intensive intervention.

At the time of analysis (2009), the surveillance information gained was mainly used to evaluate the success of the vaccination programme and to adapt the strategy if evidence showed unsatisfactory progress, which was not deemed necessary. In 2010, the FVO decided to change its strategy and offered farmers the possibility to apply for an exemption from compulsory vaccination for cattle and sheep. In total, 14% of farmers decided to abandon the national vaccination programme (Anonymous, 2010a). In 2011, the FVO decided to discontinue the national vaccination programme (Anonymous, 2010b).

For similar questions in the future, it is recommended to consider a range of combinations of surveillance and intervention approaches to potentially identify a combination with a net benefit, which would make such a programme economically justifiable.

4.4 Case study 2: Surveillance and intervention programme for bovine viral diarrhoea virus (Stage III and Stage I mitigation)

4.4.1 Introduction

Economic costs due to BVDV accrue from reduced conception rates, abortions and stillbirths, reduced milk yield, premature culling, reduced weight gain, and increased veterinary treatment costs (Bennett, 1998). Moreover, animal welfare may be affected by stress and pain caused by mucosal disease (Lindberg et al., 2006) and consumer welfare by increased commodity prices (Gunn et al., 2005). However, it is difficult to calculate these disease costs exactly, because of the variable infection dynamics in a cattle population and the often vague clinical signs (Sandvik, 2004). Despite such complications, a wide range of studies have estimated the magnitude of economic costs accruing from BVDV (Houe, 2003). In 2001, BVDV disease costs in the Swiss cattle population were estimated to be 8.8 m CHF per year (95% CI: 5.5-12.9 m CHF) (personal communication P. Schaller).

In 2008, the FVO initiated a compulsory national eradication programme for BVDV based on individual identification and elimination of persistently infected (PI) animals in the Swiss cattle population. In the initial phase, the whole Swiss cattle herd was tested for virus detection within a year. Tissue samples were taken using special ear tags and tested in certified laboratories using either PCR or ELISA to detect virus-positive animals. When required, confirmatory tests were performed using blood samples (Presi and Heim, 2010). Persistently infected animals were slaughtered and new infections avoided by animal movement restrictions. Since October 2008, all newborn calves have been subject to antigen testing to identify and slaughter PI animals (called “calf phase”). The eradication programme will cease at the end of 2011 and a surveillance programme will be implemented to document disease freedom and to detect infected animals early enabling rapid response, i.e. the programme will move from Stage III to Stage I. The projected duration of the mitigation programme is 2008 to 2017. As of February 2011, 3.28 million cattle have been tested and 19,500 PI

animals were found and slaughtered, thereby reducing the prevalence of newborn PI calves from an initial 1.47% (95% CI: 1.44-1.50%) to 0.16% (95% CI: 0.14-0.17%).

Given that the decision to allocate resources to BVDV eradication had already been taken and the technical characteristics of the programme had been defined, the analytical question focused on the relationship between the value of the eradication programme and subsequent future surveillance to document freedom from disease after eradication. The objectives were 1) to calculate the costs and benefits of the eradication programme to determine its break-even point and the margin over eradication cost, 2) to estimate the cost of putative surveillance strategies to confirm disease freedom following BVDV eradication, and 3) to assess the overall economic value of the mitigation programme.

4.4.2 Methodology

4.4.2.1 General overview

With the resource allocation decision to eradicate BVDV from the Swiss cattle population taken, the question was if the eradication programme produced a positive margin when comparing the cumulative eradication costs and benefits. Importantly, this margin represents the maximum additional expenditures potentially available for surveillance to document freedom from disease without the net benefits from mitigation overall becoming zero. Comparing putative surveillance costs to the margin over eradication provides the net value of the mitigation programme.

In part 1 of this case study, the eradication cost and benefit were calculated to determine the break-even point of the programme and the margin over eradication cost. The total benefit of the eradication programme was calculated as the disease costs avoided when comparing with a baseline scenario. Because the results of a BVDV survey conducted ten years ago (Rüfenacht et al., 2000) and the data from the initial phase (Presi and Heim, 2010) showed very similar PI prevalences of 0.64 and 0.80%, respectively, the baseline chosen was a situation of endemic equilibrium.

In part 2, costs of putative alternative surveillance scenarios were calculated to assess their economic value and identify the least-cost option. Four antibody surveillance scenarios with equal sensitivity were proposed by decision-makers:

Annual antibody testing in

- Scenario 1): blood of all calves 6 to 18 months old
- Scenario 2): milk from all first lactating cows
- Scenario 3): blood of calves 6-18 months old on 50% of farms and milk from first lactating cows on the other 50% of farms
- Scenario 4): milk and blood simultaneously on 50% of farms.

For practicality, first lactating beef cows were to be blood instead of milk sampled. For all scenarios, it was defined that the whole herd would be tested for antigen if more than 40% of all samples per farm were seropositive.

4.4.2.2 Epidemiological model and study population

In an independent project, a stochastic compartmental model was developed to study BVDV spread between farms at country level (Presi et al., 2009). In this model, animals on a farm are allocated to compartments according to their age and health status, the model unit being a combination of age and health status. After each time step, the number of animals in a specific compartment is updated according to demographic and infection parameters. The model had a time step of 14 days, the minimal time period to follow the presence of transiently infected (TI) animals. The model's outputs regarding the health situation were the number of PIs, TIs and the number of seropositive animals in each age group at farm level. The effect of mitigation strategies could be evaluated observing the evolution of those numbers.

The study population included 43,267 farms that kept cattle as recorded in the 2008 national agricultural census. Animal categories used were based on the epidemiological model and included calves, heifers and cows. The number of PI calves, heifers and cows, as well as TI calves, heifers and cows was either derived from data

gathered during the eradication phase of the programme or from epidemiological modelling predictions.

4.4.2.3 Part 1: Estimation of the break-even point of the eradication programme and margin over eradication cost

Subtraction of the cumulative eradication cost from the cumulative eradication benefit over a ten year time period yielded the margin over eradication cost.

The monetary benefit was calculated as the difference in disease costs between the eradication programme and the baseline. Disease costs comprised avoidable production losses due to mortality, premature culling, abortion, and reduced milk yield, and expenditures for palliative treatment and laboratory testing and were calculated as described in section 4.2.1. Detailed calculations and input data used can be found in Appendix IV.3.1.

The monetary eradication cost comprised variable expenditures for labour and operations and expenses for epidemiological modelling, establishment and maintenance of an electronic registration system, sampling, laboratory testing, implementation of movement bans, data analysis, and communication. The number of laboratory tests performed, animals tested, and PIs detected until October 2010 were actual figures from the ongoing programme provided by the FVO. For the time after October 2010, epidemiological modelling output was used to estimate costs and benefits. Input data used to calculate the eradication cost are listed in Appendix Table IV-11.

In the initial phase, 1,553,526 tests were performed on 1,520,859 cattle on 43,267 farms. All farms were visited once for the initial sampling. An additional visit by the veterinarian became necessary when farmers required a confirmatory test (n=8,267 animals). Further, an additional visit was accounted for each ear tag tissue sample that arrived empty at the laboratory, which happened on 13,681 occasions. For all animals that needed to be re-sampled, the call-out fee, blood sampling, postage and confirmatory antigen testing were accounted for. A total of 12,125 PIs were detected, of which 65% were calves, 20% were heifers and 15% cows. For farms with PIs,

movement restrictions applied which were implemented by the cantonal veterinary services as stipulated by the Swiss Animal Health Ordinance (SR 916.401). All PIs were slaughtered and the value loss accounted for.

In the calf phase until 31st October 2010, 1,481,836 tests were performed on 1,465,078 new born calves. A total of 6,933 calves were PI that needed to be removed from the population. Further, 832 farms were re-visited to re-test the mothers of the PI calves detected and 46,660 calves needed to be re-sampled because the ear tag tissue samples had arrived empty in the laboratory. For each PI the loss in value was added to the eradication cost. Further, for each farm with a PI calf, the cost for implementing the movement ban was calculated.

Based on the data available, it was estimated that 832,558 tests on 823,143 newborn calves would be performed from 1st November 2010 to 31st December 2011. According to epidemiological modelling predictions, in these 14 months 50 PI calves would be born and slaughtered.

All farms and cantonal veterinary services received special ear tag pliers that cost 14 CHF/piece. Further, lump sums for epidemiological modelling and data analysis (=0.78 m CHF), establishment and maintenance of an electronic registration system (=0.55 m CHF), communication efforts (=0.17 m CHF), and reference laboratory service (=0.32 m CHF) were added to the eradication cost.

4.4.2.4 Part 2: Estimation of surveillance cost to document disease freedom after eradication

Surveillance cost per scenario for the period 2012-17 included expenses for labour, operations and materials. The cost for primary testing included the call-out fee, sample taking including material, postage (0.4 CHF/sample), and laboratory analysis (=Uniform(2.8,3.2) CHF). The call-out fee was 30 CHF for a veterinarian and zero for a milk quality consultant, because the samples would be taken during regular visits for milk quality control. The cost for sample taking was the number of blood and/or milk samples to be taken multiplied by the price for blood sampling (=7.5 CHF) or milk sampling (=Pert(0.5,1.25, 2) CHF). If more than 40% of the samples per farm tested

positive, all cattle were to be blood sampled by a veterinarian and tested for antigen in the laboratory. For this follow-up testing of the whole herd, cost accrued from the farm visit, sample taking, postage and laboratory testing as described above. All prices were the same, apart from the price for antigen testing, which was Pert(10,15,20) CHF per sample. Further, lump sums for information technology (=20,000 CHF/y), communication (=20,000 CHF/y) and reference laboratory (=60,000 CHF/y) efforts were added to the surveillance cost.

The number of farms visited, number of samples taken as well as the number of farms that needed to be re-visited and the number of animals sampled and tested in the follow-up were derived from epidemiological modelling predictions (Appendix Table IV-13). Because there would not be any PI animals left in the population after successful eradication, response costs (e.g. epidemiological investigation, removal of positive animals) were not accounted for.

4.4.3 Results

4.4.3.1 Disease costs

The mean disease costs for the baseline scenario were 16.04 m CHF (90% central range (CR): 14.71-17.39 m CHF) in 2008 and 14.89 m CHF (90% CR: 13.72-16.08 m CHF) in 2009. The total disease costs in 2008 and 2009 mainly accrued from losses due to mortality (62 and 65%, respectively) and to a lesser extent from losses due to reduced milk yield (23 and 20%, respectively), losses due to premature culling (9 and 8%, respectively), expenditures for palliative treatment (7%), expenditures for laboratory testing (0.3%) and abortion losses (0.05%). Sensitivity analyses showed that in 2008 and 2009, the premature culling rates of TI heifers and TI cows had the largest impact on disease costs (regression coefficients 0.73 and 0.66, respectively). The other regression coefficients with respect to disease costs were between 0.42 and 0.57 for the mortality rates for TIs and PIs, and 0.15 and 0.14, respectively, for the rate of reduced milk yield in 2008 and 2009. All other regression coefficients were <0.1.

The mean disease costs with the implemented programme decreased from a maximum 2.85 m CHF (90% CR: 2.69-3.02 m CHF) in 2009 to zero from 2012 onwards.

4.4.3.2 Eradication cost, benefit and margin over eradication cost

In aggregate, the mean total eradication cost was calculated to be 68.35 m CHF (90% CR: 67.93 – 68.78 m CHF), of which 50% were attributable to the initial phase, 34% to the calf phase until 31 October 2010 and 16% to the calf phase from November 2010 to December 2011. Table 4-4 lists the detailed eradication cost per eradication phase.

Table 4-4: Detailed eradication cost for bovine viral diarrhoea estimated for Switzerland in million CHF (mean and 90% central range where applicable).

	Initial phase	**Calf phase until 31st October 2010**	**Calf phase November 2010 to December 2011**
Cost primary sampling	11.93	3.96	2.22
Cost laboratory analysis	12.43	11.85	6.66
Cost re-sampling and re-testing and movement ban	2.07	3.95	1.89
Loss in animal value	6.98 (6.76; 7.21)	2.86 (2.67; 3.06)	0.02 (0.02; 0.02)
Lump sums[1]	0.64	0.92	0.27
Total	**34.05** **(33.82; 34.28)**	**23.55** **(23.35; 23.74)**	**11.07** **(11.07; 11.07)**

[1] Includes epidemiological modelling, data analysis, information technology and reference laboratory function

In aggregate, the mean total discounted benefit over 10 years was estimated to be 131 m CHF (90% CR: 124-138 m CHF). The break-even point of the programme is reached in 2012 (Figure 4-3). The margin over eradication cost representing additional expenditures potentially available for surveillance to document freedom from disease in 2012-17 without the overall net benefits from mitigation becoming zero was estimated to be 63.15 m CHF (90% CR: 53.72-72.82 m CHF).

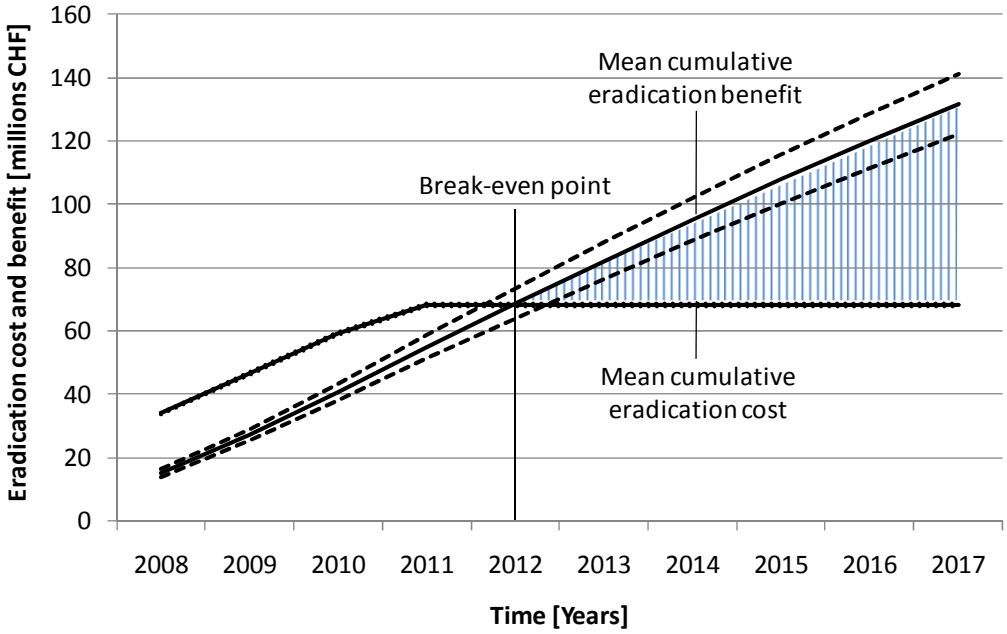


Figure 4-3: Mean cumulative eradication cost and benefit with 90% central ranges (dotted lines) and break-even point of the bovine viral diarrhoea eradication programme implemented in Switzerland. The hatched area marks the margin over eradication cost representing the maximum additional expenditures potentially available for surveillance to document freedom from disease without the net benefits from mitigation overall becoming zero.

4.4.3.3 Surveillance cost to document disease freedom and net benefit

The cost for the four surveillance scenarios to document freedom from BVDV are summarised in Table 4-5. The mean discounted surveillance costs for scenarios 1 to 4 were calculated to be between 21.70 and 23.95 m CHF. In S1, primary sampling cost contributed most to the surveillance cost (77%). In S2, follow-up sampling and testing contributed most to surveillance cost (80%). In S3 and S4, both primary sampling cost and follow-up sampling and testing contributed most to the total surveillance cost (40-44%).

The discounted mean net benefit of the mitigation programme was found to be 41.44 m CHF using Scenario 1 (90% CR: 31.87-51.21 m CHF), 39.20 m CHF using Scenario 2 (90% CR: 29.30-49.30 m CHF), 40.81 m CHF using Scenario 3 (90% CR: 31.22-50.67 m CHF), and 40.66 m CHF using Scenario 4 (90% CR: 31.09-50.51 m CHF).

Table 4-5: Discounted surveillance cost to demonstrate freedom from bovine viral diarrhoea calculated for Switzerland for the years 2012-17 in million CHF (mean and 90% central range where applicable). IT=information technology.

Cost	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Sampling	16.79	2.15	8.99	9.25 (9.11; 9.38)
Laboratory analysis	3.83 (3.60; 4.05)	2.03 (1.92; 2.13)	2.93 (2.79; 3.06)	2.93 (2.79; 3.06)
Follow-up sampling and testing	0.57 (0.50; 0.64)	19.26 (16.75; 21.77)	9.90 (8.61; 11.20)	9.80 (8.52; 11.07)
Communication, IT, reference laboratory	0.52	0.52	0.52	0.52
Total	**21.70 (21.46; 21.95)**	**23.95 (21.44; 26.46)**	**22.34 (21.04; 23.63)**	**22.49 (21.21; 23.78)**

4.4.4 Discussion

Results showed that the eradication programme will reach the break-even point in 2012, leaving a margin over eradication cost of 63.15 m CHF (90% CR: 53.72-72.82 m CHF). This margin represents the maximum additional expenditures potentially available for surveillance to document freedom from disease without the net benefits from mitigation overall becoming zero. The estimation of surveillance cost of four putative surveillance strategies to document freedom from BVDV showed that surveillance cost of all scenarios were smaller than this margin. Hence, the mitigation programme is expected to produce a net economic benefit using any of the surveillance strategies suggested. By adopting the least-cost of equal surveillance options, the highest net benefit can be achieved.

Surveillance to document freedom from disease after eradication is expected to operate at a high level of alert in the first years of the programme to early detect any BVDV recurrence. The surveillance strategies proposed comprise testing of all farms in the population every year (scenarios 1-3) or 50% of the farms every other year until the end of the mitigation programme. In aggregate, the mean discounted surveillance costs were between 22-24 m CHF for all scenarios. Scenario 2 was the most costly, because of high cost of follow-up sampling and testing, which contributed 80% to

surveillance cost. A decrease in the number of animals and/or farms to be sampled and tested would reduce aggregate surveillance costs. After the first few years of surveillance to document disease freedom, policy makers may want to reduce the number of farms and/or animals to be sampled. Risk assessment methods were shown to be useful if repeated surveys are conducted to document disease freedom (Hadorn et al., 2002; Knopf et al., 2007) and may be considered in this process. When the mitigation programme comes to its end in December 2017, the question may be raised about whether to continue with active surveillance or not. Future surveillance activities will be economically justifiable if the benefit (avoidable disease costs) resulting from the comparison of a situation with surveillance and without surveillance will at least cover surveillance costs. Such calculations will need to take into account the risk of possible introductions of BVDV, the magnitude of an outbreak and related disease costs with and without surveillance.

4.5 Case study 3: Avian influenza surveillance (Stage I mitigation)

4.5.1 Introduction

Avian influenza virus (AIV) surveillance in Switzerland aims to document the free status and to provide early warning of an increase in incidence and thereby enable rapid response. Active surveillance in wild birds consists of i) reporting birds found dead by members of the public (no active patrolling), followed by collection and testing of birds if deemed necessary; and ii) sentinel surveillance of a flock of Mallards kept on Lake Constance in the nature reserve Rhine delta in Austria. Detection of a case of highly pathogenic avian influenza virus (HPAIV) may trigger the implementation of preventive measures to reduce the probability of transmission from wild birds to poultry. Active surveillance in poultry aims at detecting low pathogenic avian influenza virus (LPAIV) infection. Detection of LPAIV in poultry triggers stamping-out measures as stipulated in the Swiss Animal Health Ordinance (SR 916.401) that impede the spread of LPAIV and are thus expected to reduce the probability of mutation of LPAIV into HPAIV in poultry.

As explained in Chapter 3, for early warning surveillance to be rational in economic terms, potential disease costs avoided must at least cover surveillance expenditures. However, if decision-makers believe that non-monetary benefits (e.g. the avoidance of human illness, consumer confidence) resulting from mitigation are very large relative to the costs, the implementation of a mitigation programme is considered to be worthwhile. The economic analysis is then reduced to identifying the technical procedures for surveillance and determining their costs.

In the case of AIV, there is a perceived risk in society of an HPAIV outbreak in poultry and the fear of potential transmission to humans with fatal consequences. Therefore, the potential benefits are expected to be very high, even though not all of their elements are easily measured in monetary units. Thus, surveillance expenditures can be justified by non-monetary benefits such as freedom from fear or zoonosis.

This case study aimed to assess the technical procedures for rapid detection and response should an outbreak occur and their costs. The objectives were 1) to assess the effectiveness of AIV surveillance to give an early warning to enhance early response and prevent spread within the poultry population, and 2) to calculate a cost-effectiveness ratio to determine the cost increase relative to the change in effectiveness.

4.5.2 Methodology

4.5.2.1 General overview and risk questions

The aim of AIV surveillance is to detect disease or infection early and thereby enable rapid response. To assess the effectiveness of the current AIV surveillance system, a qualitative risk assessment approach was used to estimate the probability of primary and secondary AIV outbreaks in Switzerland with and without surveillance in place. Risk assessments are a widely used technique to support decision-making, particularly in a data-scarce environment. They allow understanding transmission and spread of infectious pathogens and the potential impact of mitigation strategies.

The primary and secondary outbreaks could either stem from an introduction of LPAIV and subsequent mutation into HPAIV or the transmission of HPAIV via wild birds or illegal trade. Unless otherwise specified, LPAIV refers to the subtypes H5 or H7 and HPAIV to subtype H5N1. Figure 4-4 gives an overview of AIV surveillance activities in Switzerland in relation to pathways of AIV introduction by illegal trade and wild birds and subsequent transmission to poultry holdings and outbreak response measures.

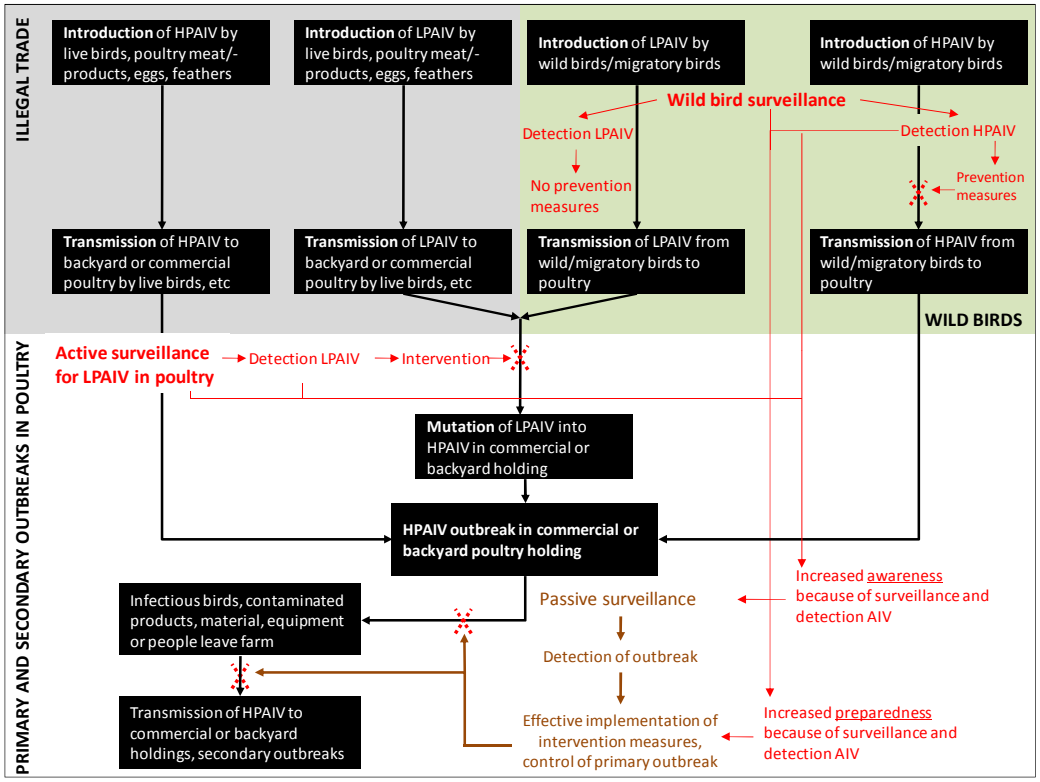


Figure 4-4: Overview of avian influenza virus (AIV) surveillance activities in Switzerland in relation to pathways of AIV introduction by illegal trade and wild birds and subsequent transmission to poultry holdings. HPAIV=highly pathogenic AIV, LPAIV=low pathogenic AIV.

To assess the effectiveness of surveillance, the probability of introduction of the pathogen (release assessment) and probability of exposure of poultry on other farms following a primary outbreak (exposure assessment) with and without wild bird and poultry surveillance were estimated. The detailed risk questions were the following:

- **Wild bird surveillance:** As both LPAIV and HPAIV have been found in the wild bird population in Switzerland (Baumer et al., 2010), a release assessment on country level was deemed redundant. Therefore, a modified release

assessment describing the biological pathways necessary to release AIV into a particular environment was used:

- *Release assessment:* What is the probability of transmission of HPAIV from wild birds/migratory birds to poultry on commercial or backyard farms in Switzerland with and without wild bird surveillance and preventive measures in place?
- *Exposure assessment:* What is the probability of transmission of HPAIV from commercial or backyard farms to other poultry farms with and without wild bird surveillance in place?

- **Active poultry surveillance:**
  - *Release assessment:* What is the probability that LPAIV which was introduced and transmitted via wild birds/migratory birds or illegal trade to poultry mutates into HPAIV on commercial farms or backyard farms with and without active surveillance in poultry in place?
  - *Exposure assessment:* What is the probability of transmission of HPAIV from commercial or backyard farms to other poultry farms with and without active surveillance in poultry in place?

4.5.2.2 Risk pathways and mitigation measures

Figure 4-5, 4-6 and 4-7 illustrate pathways for the transmission and spread of AIV. Moreover, surveillance, prevention and intervention measures and their impact on transmission are illustrated (boxes in red and orange). All pathways compared a scenario 'without surveillance' with a scenario 'with surveillance' and were the same for both commercial and backyard holdings. All boxes outlined in blue may give a different estimate for the two scenarios.

Figure 4-5 describes the pathway to determine the probability of HPAIV transmission from wild birds to commercial and backyard poultry holdings with and without wild bird surveillance.

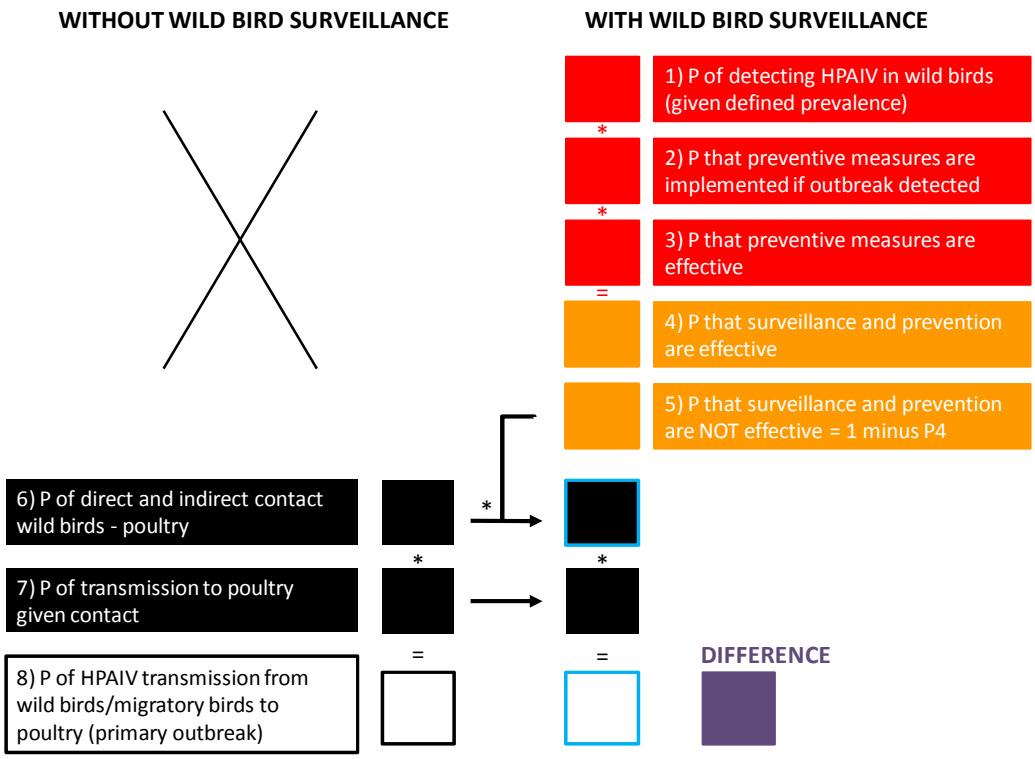


Figure 4-5: Pathway to determine the probability of highly pathogenic avian influenza virus (HPAIV) transmission from wild birds to commercial and backyard poultry holdings without and with wild bird surveillance in place. P=Probability.

Figure 4-6 describes the chain of events to determine the probability that LPAIV introduced by wild birds or illegal trade and transmitted to poultry holdings mutates into HPAIV. The starting point for LPAIV in poultry was a combination of the probabilities of a primary outbreak in commercial and backyard holdings found through illegal trade or wild birds. The probabilities for introduction by illegal trade were derived from Läubli (2010) and those for introduction by wild birds from the release assessment described above. Because more than one factor contribute to the probability estimate of the starting point (additive effect), the highest probability was considered.

Figure 4-6: Pathway to determine the probability that low pathogenic avian influenza virus (LPAIV) which was introduced via wild birds or illegal trade and transmitted to poultry holdings mutates into highly pathogenic avian influenza virus (HPAIV) without and with active surveillance in poultry in place. P=Probability.

Figure 4-7 describes the chain of events to determine the probability of a secondary outbreak without and with wild bird or poultry surveillance considering a possible change in awareness due to mitigation activities.

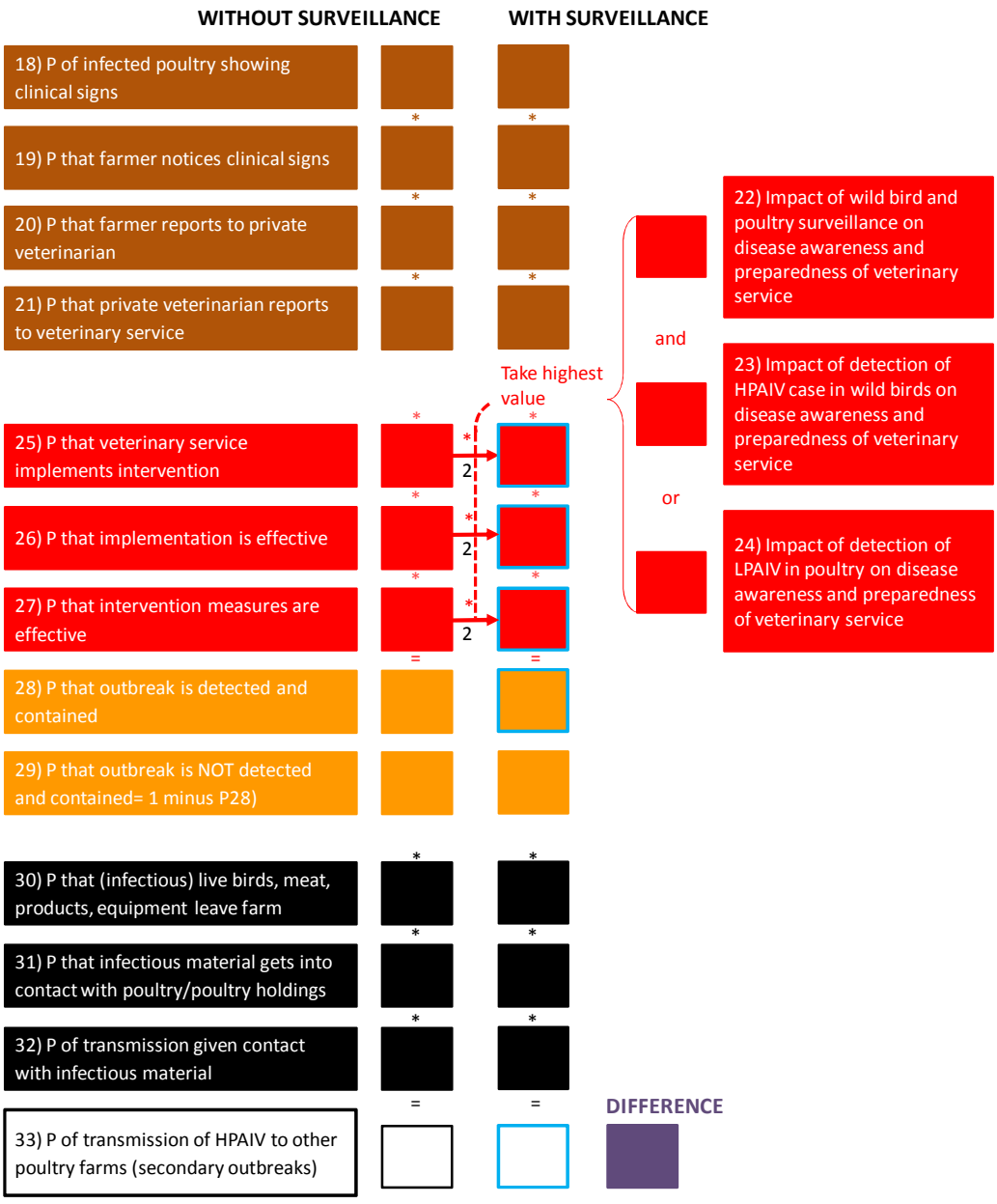


Figure 4-7: Pathway to determine the probability of secondary outbreaks of highly pathogenic avian influenza virus without and with surveillance in place. For the steps labelled with '2' matrix 2 was used (Table 4-7). P=Probability.

4.5.2.3 Estimation of probabilities

A workshop was held with four Swiss AIV experts to discuss all steps of the pathways and estimate probabilities and uncertainties using data from the scientific literature whenever possible.

Four probability categories were included in the risk assessment, namely negligible (N, event is so rare that it does not merit to be considered), low (L, event is rare but does occur), medium (M, event occurs regularly), and high (H, event occurs very often). For each probability, the uncertainty of the estimate was also given (High, Medium, Low). Where quantitative estimates were available, these were translated into qualitative estimates as follows: <0.1%=negligible; ≥0.1% to 20%=low; >20-50%=medium; and >50%=high.

For all situations where events were dependent on the previous step and therefore represented an hierarchical chain of events, a combination matrix based on an approach suggested by Beckett (2007) was used. With this matrix an increase of probability along the pathway is not possible (Table 4-6).

Table 4-6: Matrix 1 is used for a hierarchical chain of events where the probability along the pathway cannot be increased.

Event 2 / Event 1	**Negligible**	**Low**	**Medium**	**High**
Negligible	Negligible	Negligible	Negligible	Negligible
Low	Negligible	Low	Low	Low
Medium	Low	Low	Medium	Medium
High	Low	Medium	Medium	High

Where the probabilities of implementation and effectiveness of intervention were enhanced by raised awareness and preparedness caused either by surveillance itself or detection of AIV (called 'impact'), matrix 2 was used (Table 4-7). With this matrix, the probabilities of implementation and effectiveness of intervention can be increased, but not decreased. In case of several factors contributing to the probability of increased disease awareness and preparedness (Figure 4-7), the highest estimate was used.

Table 4-7: Matrix 2 is used for scenarios where the probability of intervention implementation and effectiveness can be increased by the impact of surveillance or detection on awareness and preparedness.

Impact of surveillance or detection Event 1	Negligible	Low	Medium	High
Negligible	Negligible	Low	Low	Medium
Low	Low	Low	Medium	Medium
Medium	Medium	Medium	Medium	High
High	High	High	High	High

Disease mitigation measures were expected to be effective in reducing the probability of disease transmission and spread. The impact of surveillance, prevention and intervention measures on transmission and spread of AIV was integrated as the 'probability of non-effectiveness', which was calculated as 1 minus the probability of effectiveness of disease mitigation measures: 1 – H=L; 1 – M=M; 1 – L=H; 1 - N=H, as suggested by Wieland et al. (2011).

For example in Figure 4-5, the probability of HPAIV transmission from wild birds/migratory birds to poultry without surveillance is the vertical multiplication of probabilities 6 and 7 using matrix 1. With surveillance, probability 6 changes its value because of the mitigation measures implemented. First, probabilities 1, 2 and 3 are multiplied vertically using matrix 1. Next, 1 minus the estimated probability gives the probability of non-effectiveness. By multiplying probability 6 by this non-effectiveness measure using matrix 1, probability 6 *with surveillance* is determined.

4.5.2.4 Surveillance costs and cost-effectiveness ratio

The surveillance costs were derived from a previous study (Sauter, 2008) and included the costs for organisation, material, sample taking, laboratory analysis and labour. The average cost-effectiveness ratio (ACER) was the difference in costs without and with surveillance (ΔC) divided by the difference in probability without and with surveillance (ΔP).

4.5.3 Results

Table 4-8 summarises the outcome of the AIV risk assessment to determine the effectiveness of surveillance in wild birds and poultry. The results show that surveillance does not reduce any of the probabilities addressed in the risk questions. Estimated probabilities, uncertainties, and the rationale for the estimates as well as combinations are described in Appendix Table IV-14.

Table 4-8: Outcome of a qualitative risk assessment to estimate the probability of primary and secondary avian influenza virus (AIV) outbreaks in commercial and backyard holdings without (w/o) and with surveillance (S) in place. HPAIV=highly pathogenic AIV, LPAIV=low pathogenic AIV, L=Low, H=High, ∆=Difference.

Outcome		Commercial			Backyard		
		w/o S	with S	∆	w/o S	with S	∆
Wild birds S	Probability of HPAIV transmission from wild birds to poultry (primary outbreak)	L	L	0	L	L	0
	Probability of transmission of HPAIV to other poultry farms (secondary outbreak)	L	L	0	H	H	0
Poultry S	Probability of mutation from LPAIV into HPAIV in poultry (primary outbreak)	L	L	0	L	L	0
	Probability of transmission of HPAIV to other poultry farms (secondary outbreak)	L	L	0	H	H	0

The expert group concluded that surveillance activities would have a low impact on increased disease awareness and preparedness of staff working for the Swiss veterinary service. A case of HPAIV in wild birds was defined to have a medium impact and a case of LPAIV in poultry a high impact on disease awareness and preparedness of the veterinary service. However, the expert team concluded that the public and farmers would not be affected by having in place active surveillance programmes or by detecting a case in either wild birds or poultry. The probabilities of backyard holders noticing clinical signs and reporting to a private veterinarian were estimated to be low, which resulted in a high probability of secondary outbreaks.

The annual surveillance costs were estimated to be 27,400 CHF for wild bird and 14,900 CHF for poultry surveillance. Because the difference in probabilities was zero, it was not possible to calculate cost-effectiveness ratios.

4.5.4 Discussion

Surveillance in both wild birds and poultry did not change the estimated probabilities of primary and secondary outbreaks of AIV in Switzerland. Possibly, four probability categories were not enough to detect small differences. However, the use of six categories is not recommended due to considerable uncertainty and lack of data.

Moreover, the experts agreed that surveillance activities and detection of HPAIV in wild birds or LPAIV in poultry would increase disease awareness and preparedness of the veterinary service, but not poultry holders or the general public. As the quality of the veterinary service and the effectiveness of implementation and interventions are already at their maximum level (high), they cannot be enhanced by active surveillance. The situation may be different in countries that do not have the technical and financial capacity to implement effective interventions. The probabilities of backyard holders noticing clinical signs and reporting to a private veterinarian were estimated to be low, resulting in a high probability of secondary outbreaks. This finding suggests that measures aimed at increasing disease awareness among backyard poultry holders may reduce the probability of secondary outbreaks given a primary outbreak in backyard holdings.

The surveillance costs were estimated to be 42,300 CHF per year. This is a relatively low figure if compared, for example, with the approximately 160,000 CHF spent annually on salmonella surveillance in poultry. Given the findings of this study, this figure can only reflect the value policy makers implicitly attribute to externalities such as peace of mind or freedom from fear. The approach is based on the assumption that there is a perceived risk of potential spread of HPAIV to humans with potentially fatal consequences, which was the most likely scenario at the time of analysis (October 2009-March 2010). The situation would be different if the risk of HPAIV outbreaks in poultry and transmission to humans was negligible and recognised as such. If this were

the case, the economic value of surveillance would be reflected in its ability to give an early warning that would potentially reduce the number or magnitude of outbreaks by enabling rapid response and thereby avoid production losses. Future assessments may compare the mitigation costs to the production losses avoided as described in Chapter 3.

4.6 Case study 4: Salmonella surveillance and intervention in laying hens (Stage III mitigation)

4.6.1 Introduction

This case study aimed to perform a cost-effectiveness analysis of the surveillance and intervention programme for salmonella in laying hens. The rationale for having a surveillance and intervention programme in layers is to avoid human illness, a potent positive externality of disease mitigation at farm level. Poultry can become carriers of paratyphoid *Salmonella* spp., the motile serovars such as *S.* Enteritidis and *S.* Typhimurium (Saif, 2003). The carrier state is usually asymptomatic. The consumption of eggs is the major source of human salmonellosis in Europe (Pires et al., 2010). The reduction of salmonella in the layer population has been shown to be correlated to a lower incidence of human foodborne salmonellosis cases (Kornschober et al., 2009; Korsgaard et al., 2009).

The positive externality effects in humans from mitigation in laying hens are believed to be large enough to outweigh the mitigation cost, which is reflected in national and international legislation that dictates targets for the reduction of salmonella in laying hens. Therefore, the economic assessment reduces to the question what technical procedures achieve the desired effect at least cost.

In 1993, Switzerland implemented a surveillance and intervention scheme to control *S.* Enteritidis in laying hens. In 2003, the EU laid the foundation for enhancing food safety by obliging member states to run national control programmes to reduce salmonella in poultry and pigs. The EU Commission Regulation 1168/2006 stipulates the sampling frame, frequency and status of sampling, the sampling protocol and examination

method for the serotypes *S.* Enteritidis, *S.* Typhimurium, *S.* Hadar*, S.* Infantis*, and S.* Virchow in laying flocks*.* Because of harmonisation with EU law, Switzerland adapted its domestic salmonella surveillance and intervention strategy to include the relevant serotypes (Bruhn, 2008). The surveillance and intervention programme for salmonella aims to reduce prevalence in commercial layer flocks that have at least 1,000 birds. Surveillance is used to identify infected flocks and to verify achievement of the community target. The technical guidelines regarding the sample taking for salmonella in poultry stipulate the sampling plan for laying hens. Domestic legislation currently lays down a higher average sampling frequency than the minimal EU requirements (Appendix Tables IV-15 and IV-16). Every time an infected flock is detected, the hens will be culled and the holding cleaned and disinfected as laid down in the Animal Health Ordinance (SR 916.401).

The objectives in this case study were 1) to conduct a cost-effectiveness analysis of three scenarios with variable surveillance and fixed intervention measures, and 2) to examine the correlation between the effectiveness measure and the final outcome, i.e. reduction of human illness.

4.6.2 Methodology

4.6.2.1 General overview

A two-step approach was adopted. In step 1, ACERs were calculated for three surveillance and intervention scenarios. In step 2, a source attribution model that partitions the human disease burden of foodborne infections to specific sources was used to examine the relationship between the intermediate outcome measure (prevalence reduction in layers) and the final outcome (avoidance of human salmonella cases).

The three surveillance scenarios assessed were:

- Scenario 1): implemented programme that stipulates testing every three months
- Scenario 2): adoption of the minimal EU requirements, which foresee testing every four months
- Scenario 3): no surveillance

The effectiveness measure was the annual prevalence reduction in the Swiss commercial laying hen population over a time period of three years, which follows the time frame used in EU Regulation 1168/2006. An epidemiological model simulating the disease dynamics in this population was created to measure the annual prevalence reduction. The ACER was calculated as follows:

$$ACER = \frac{Annual\ costs\ of\ surveillance\ and\ intervention}{Annual\ reduction\ in\ Salmonella\ prevalence\ in\ national\ layer\ flock}$$

4.6.2.2 Surveillance and intervention costs

Surveillance and intervention costs accruing from regular surveillance and culling of positive flocks upon detection were calculated as outlined in section 4.2.1. Detailed input data are listed in Appendix Tables IV-17 and IV-18. For each scenario, the surveillance cost was calculated based on the frequency of testing stipulated by legislation and the number of commercial layer holdings with at least 1,000 birds (n=390). The outcome 'number of detected holdings' was used to calculate the total intervention cost per scenario by multiplying this number by the intervention cost per positive case.

4.6.2.3 The epidemiological model

A stochastic susceptible-infected compartmental model was developed to simulate the prevalence in the commercial Swiss laying hen population in monthly time steps for the years 2010 to 2012 (Figure 4-8). Detailed equations are listed in Appendix IV.5.3. The model units were commercial laying hen holdings with at least 1,000 birds according to the sampling protocol laid down in Swiss technical guidelines, and a

standard production cycle of 14 months. The model was developed in collaboration with a visiting veterinary medicine undergraduate student who did a one-month internship at the Royal Veterinary College (see acknowledgments).

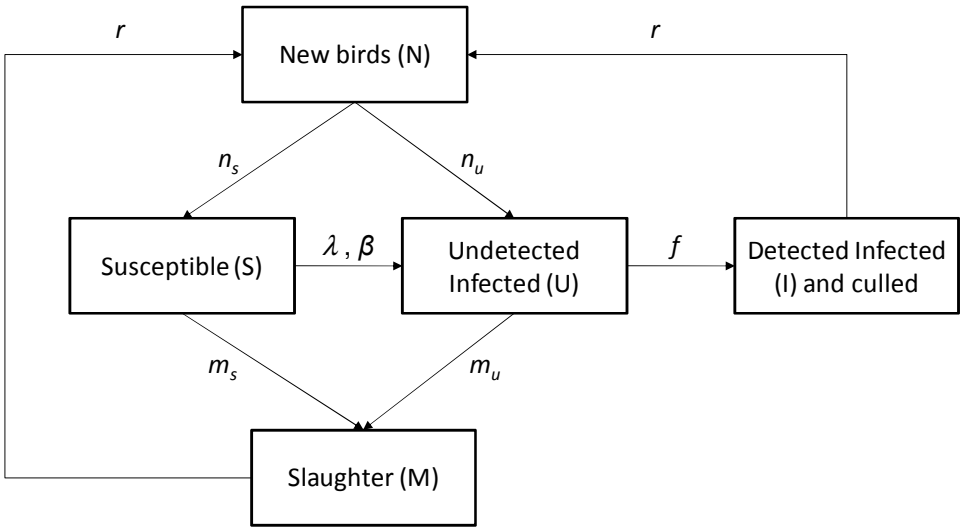


Figure 4-8: Structure of the epidemiological compartmental model used to simulate the salmonella transmission dynamics in the Swiss laying hen population. Parameters used are explained in the text.

The number of new birds being introduced in the population at time t reflected the re-stocking of laying hens from the breeding population. They could either be susceptible (from negative breeding flocks) or infected (from positive breeding flocks). Susceptible layer flocks could stay susceptible throughout and be slaughtered at the end of the production cycle (m_s=rate at which birds from susceptible holdings are sent to slaughter) or become infected. The rate of infection depended on a horizontal transmission rate (λ=Uniform(0.00075,0.00125)/month), which reflected the outdoor exposure to salmonella, cleaning procedures after slaughter, and contact with rodents, as well as the contact rate (β=Uniform(0.0025,0.0042)/month), which reflected the between farm movement of people in a commercial setting. The infection flow from susceptible to infected holdings was calculated as follows:

$$Infection\ flow = S(t) \cdot [\lambda + \beta \cdot \lambda \cdot U(t)]$$

Where *S* is the number of susceptible holdings and *U* the number of undetected infected holdings per time step.

Birds on infected holdings either remained undetected and were slaughtered at the end of the standard production cycle (m_u=rate at which birds on undetected infected holdings are sent to slaughter) or were detected at the rate *f* which reflected the overall sensitivity of the sampling protocol, the sampling frequency and laboratory testing. The sensitivity of one sampling session was defined as Uniform(0.30,0.40) based on Carrique-Mas et al. (2008) and Arnold et al. (2010). All detected infected flocks were removed from the population. After slaughtering or culling of the birds, the holding was restocked which was reflected by the restocking rate (*r*=rate at which empty holdings are restocked).

Scenario 1 was run with the settings described above. For Scenario 2, the frequency of sampling was changed from three to four months and for Scenario 3, the frequency of sampling was zero. All other parameters stayed the same. The integral of the infection flow was the total number of infected holdings per time period. This figure was used to calculate the annual prevalence for the three scenarios for the years 2010-2012. The integral of the detection flow was the total number of detected holdings per time period.

4.6.2.4 The source attribution model

The relationship between the intermediate and final output was assessed in collaboration with Sara Monteiro Pires from the National Food Institute in Denmark who has applied a Bayesian source attribution model that partitions the human disease burden of foodborne infections to specific sources (Pires et al., 2009; Pires and Hald, 2010). The model estimates the number of human sporadic cases that can be attributed to food-animal sources *(λ_{tji})* as a function of the prevalence in the food source according to the following equation:

$$\lambda_{tji} = p_{tij} \cdot m_{tj} \cdot a_{tj} \cdot q_i$$

where p_{tij} is the salmonella prevalence in the major animal-food sources per year, m_{tj} the amount of food source available for consumption each year, a_{tj} a food-source-dependent factor and q_i a subtype-dependent factor. The multi-parameter priors constituted by q_i and a_{tj} were defined as uninformative prior distributions (uniform

distributions). The subtype-dependent factor describes the differences in the ability of the various *Salmonella* spp. subtypes to cause human disease, accounting for differences in the subtypes' survivability along the food chain and potential differences in pathogenicity. The food-source-dependent factor (a_{tj}) was assumed to vary over the years, accounting for yearly differences in epidemiological sensitivity of the surveillance programmes, variability of the sampling schemes and changes in consumption patterns not captured by m_{tj}. This factor may also include general variations between sources like the pathogen load/concentration in the food, and processing, handling or preparation practices.

Swiss data were provided for the number of isolates in humans, pigs, broilers, layers and imported poultry meat for the years 2006 to 2009 (Appendix Table IV-20). The total number of reported human cases was provided by the National Centre for Enteropathogenic Bacteria of the University of Zürich. The number of outbreak related human cases was provided by the Federal Office of Public Health. The FVO delivered data for the number of isolates in the different animal populations and 'Proviande', the umbrella organisation of the Swiss meat industry, detailed statistics for meat consumption in Switzerland.

Next, prevalence *p* for layers in the model equation was replaced by the simulated prevalence from the epidemiological model, thus to estimate the number of cases attributable to the source with a changed prevalence.

4.6.3 Results

4.6.3.1 Costs and effectiveness

For Scenario 1, the mean undiscounted annual surveillance cost was 163,876 CHF (90% CR: 150,018-176,564 CHF) and the mean undiscounted annual intervention cost was 178,985 CHF (90% CR: 84,523-398,804 CHF). For Scenario 2, the mean undiscounted surveillance cost was 102,670 CHF (90% CR: 85,350-118,401 CHF) and the median undiscounted intervention cost was between 114,539 CHF (90% CR: 69,034-32,261

CHF) and 123,267 (90% CR: 75,358-361,206 CHF). For scenario 3, both surveillance and intervention cost were zero.

Table 4-9 illustrates the simulated annual prevalence for the years 2010 to 2012 and the total number of holdings tested positive. The mean prevalence was stable for Scenarios 1 and 2, but increased slightly for Scenario 3 from 1.18 to 1.26% over three years. Because there was no reduction in prevalence, cost-effectiveness ratios could not be calculated.

Table 4-9: Predicted salmonella prevalence in the Swiss laying hen population and number of detected holdings positive for salmonella in 2010 to 2012 for the three surveillance scenarios.

	Scenario 1			Scenario 2			Scenario 3		
	2010	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
Prevalence in %									
Mean	1.15	1.15	1.15	1.15	1.16	1.16	1.18	1.23	1.26
5th percentile	0.87	0.86	0.86	0.87	0.87	0.87	0.89	0.91	0.92
95th percentile	1.44	1.45	1.45	1.45	1.47	1.47	1.50	1.59	1.63
Total number of detected holdings									
Mean	2.78	2.78	2.78	2.30	2.46	2.49	0	0	0
5th percentile	2.25	2.08	2.06	1.85	1.84	1.84	0	0	0
95th percentile	3.33	3.52	3.54	2.77	3.15	3.19	0	0	0

4.6.3.2 Source attribution model

The source attribution model did not converge using the data provided and no outcome was obtained from step 2.

4.6.4 Discussion

The Swiss mitigation programme for salmonella in laying hens has been successful in reducing the number of detected flocks from about 30 cases per year in the early 90s to three cases in 2010 (www.infosm.bvet.admin.ch). At the same time, the number of human salmonellosis decreased from 114 cases/100,000 inhabitants in 1992 to about 30 cases/100,000 inhabitants in the past years (Bruhn, 2008).

Due to legal obligations, the surveillance and intervention programme must be continued for the time being. However, the results of this study show that the current programme does not reduce prevalence further. This is corroborated by the fact that the annual number of detected cases in laying flocks has remained stable at around three over the past five years (www.infosm.bvet.admin.ch). Only a substantial increase in the sensitivity of surveillance or frequency of sampling would allow a further reduction in prevalence. However, the involvement of an environmental source that may be difficult to control means that prevalence anyway cannot be reduced to zero even with perfect surveillance (data not shown). Moreover, there is no evidence that a further reduction of salmonella in the laying hen population will avoid sufficient human cases to justify continuous surveillance and intervention cost.

Because of the very low number of human and animal isolates detected, the Bayesian source attribution model did not converge. Finding ways of demonstrating a link between very small reductions in prevalence in layers and avoided human cases is technically challenging and time consuming. Decision-makers are advised to consider moving from Stage III to Stage I mitigation and to identify least-cost surveillance and response protocols that allow keeping prevalence stable at an acceptable level. However, a change in national mitigation strategy will be possible only if EU regulations are modified accordingly. As long as there is no change in EU law, it is recommended to adopt the sampling frequency suggested by the EU, because it is cheaper and equally effective.

4.7 Conclusions

The economic assessment of the four programmes produced outcomes that allow recommendations to decision-makers regarding the allocation of scarce resources for disease mitigation. However, due to data and practical limitations, the approach outlined in Chapter 3 to determine the economic optimal level of disease mitigation could only be partially implemented for the following reasons.

The most pervasive limitation was that for all programmes decisions had already been taken regarding the level of prevalence or incidence to be achieved, or the scale of

surveillance and intervention activities to be used. These decisions were either made at national (e.g. decision to eradicate BVDV) or international level (e.g. EU decision to reduce salmonella prevalence in poultry by a certain percentage). Further, international regulations dictate the implementation of surveillance and/or intervention activities for BTV-8, AI and salmonella and sometimes specify detailed surveillance protocols. With no possibility of comprehensively following the approach outlined in Chapter 3, each analytical question was nevertheless formulated to take into account the theoretical principles described. In that way, the needs of decision-makers are addressed while drawing attention to the wider perspectives on the economics of mitigation.

Furthermore, to simulate loss avoidance curves under a range of surveillance and intervention combinations, epidemiological models are indispensable. But typically, they are not constructed from the outset to take into account the economic dimensions of resource allocation decisions (Howe, 1988). Still, they capture the biological dynamics and complexity of disease in animal populations, and therefore are an important source of data for economic analyses (Perry and Randolph, 2004). For the BTV-8 and BVDV case studies, epidemiological models to simulate disease dynamics were available. However, they were not set up in a way fully compatible with the requirements of economic assessment of surveillance. Consequently, certain epidemiological outputs could not be directly included into economic models, but were used to calculate inputs that were then used in the economic analysis. For example, the epidemiological model for BTV-8 provided the output 'number of infected holdings', from which the number of infected animals had to be derived to be able to estimate BTV-8 production losses. Moreover, available epidemiological models had been developed to investigate the implemented strategy and so did not include combinations of surveillance and intervention that would have allowed testing the hypothesis of substitutability between those different aspects of mitigation. Owing to time and personnel restrictions, it was not possible to extend the epidemiological models available.

Epidemiological approaches also provide important information regarding the effectiveness of a mitigation programme for CEA, which has been extensively used,

discussed and refined in health economics over the past decades. However, in the veterinary field it has only been sporadically applied to analyse intervention programmes, diagnostics tests and preventive measures, as for example done by De Vos et al. (2005) and Knight-Jones et al. (2010). The appropriate measure of effectiveness for surveillance is key in that process and needs to be selected according to the surveillance objective. A "CEA is only as valid as its underlying measures of effectiveness and cost" (Weintraub and Cohen, 2009), but unlike in health economics, where attempts have been made to harmonise CEA methodologies and encourage comparability of studies (Murray et al., 2000), there are no specific guidelines available yet for its application in animal health. A compartmental model was developed to assess the impact of mitigation strategies on the salmonella prevalence in the population in accordance with reduction targets defined by national and international legislation. For the AI case study where the incidence in the poultry population is zero and fear of a pandemic dictates the implementation of surveillance, a modified risk assessment approach was developed to assess the effectiveness of the current surveillance programme. This approach explicitly addressed the impact of mitigation strategies on the probabilities of introduction and spread of AIV in the poultry population.

Benefits such as consumer confidence or reputation are perceived values that are generally not converted to monetary values by the price system of the market. Therefore, indirect methods of valuation such as willingness-to-pay approaches need to be adopted. Because there were no values for non-monetary benefits and costs readily available and their measurement was beyond the scope of this thesis, they could not be quantified. Given the results for AI surveillance, it was concluded that the 42,300 CHF was the minimum implicit value that decision makers must attribute to non-priced benefits for the policy to be worthwhile. Additional perceived benefits or costs in other programmes may have stemmed from animal welfare impact, expertise gained in setting up a registration system for vaccination purposes in ruminants, impact on national and international reputation, consumer and industry confidence and trust.

The translation of mitigation units used and disease costs avoidance in monetary costs and benefits was accomplished using Swiss statistics, scientific literature and expert opinion. Calculation of surveillance and intervention costs was straightforward, because of the availability of detailed market values, prices and time recording systems for labour. However, estimation of disease costs needed to make allowance for considerable uncertainty because reliable data regarding lost physical production coefficients was lacking.

Each case study provides valuable practical information regarding the economic assessment of such programmes and adds to understanding of the relationships between surveillance, intervention and mitigation outcomes. Single point estimates and values for acceptability rather than optimality could be determined. However, a three dimensional mitigation surface could not be produced for any of the case studies because of lack of technical information regarding loss avoidance curves for different combinations of surveillance and intervention. The BTV-8 study showed that the implemented programme was efficient in the first two years of operation, but produced a net cost afterwards. It is important to remember that the value of a programme may change over time and that a re-evaluation may become necessary after a certain time. The BVDV study showed that the programme overall was beneficial in economic terms and that the margin over eradication cost is large enough to accommodate any of the surveillance programmes currently envisaged. However, it is the least-cost surveillance option that should be adopted, because it produces the largest net benefit of the mitigation programme for the options investigated. This case study demonstrated how an economic assessment can link two mitigation stages. The AIV study showed that the surveillance programme can only be regarded as efficient if the perceived value of the programme is at least as big as the surveillance cost. Further, it demonstrated that the perceived risk of HPAIV outbreaks in poultry and transmission to humans is critical in assessing the economic value of the surveillance programme. The salmonella case study is an example of the relevance of CEA given legislative constraints that cannot be changed. It highlights the critical importance of appraising Stage III mitigation programmes that have been in place for a prolonged time period.

In conclusion, the constraints and practicalities faced in everyday decision-making processes at governmental level, time restrictions and the limitations of epidemiological models available prevent comprehensive application of the economic principles presented in Chapter 3. To do so, it is necessary to conduct an economic assessment at the planning stage in the decision-making process, and to create epidemiological models capable of exploring different combinations of surveillance and intervention activities and related output loss avoidance levels. By planning epidemiological and economic analyses together from the start, they can be developed in an interdisciplinary, fully compatible way that provides decision-makers with the comprehensive technical and economic information they require.

CHAPTER 5

A PRACTICAL GUIDE FOR THE ECONOMIC ASSESSMENT OF VETERINARY SURVEILLANCE AT NATIONAL LEVEL

5.1 Introduction

When considering the start, end or change of a surveillance programme, policy makers need to know if and how much surveillance is worth it. Therefore, we developed a practical guide to enhance decision-makers' understanding of suitable approaches, data requirements and relevant principles for the economic assessment of surveillance. This will help them to plan, design, and conduct or commission economic assessments of current and future surveillance programmes. The guide is set up in a user-friendly format in Microsoft Power Point making use of visual aids (flow charts, colours, fonts, shapes) as well as interactive buttons and hyperlinks that allow movement between slides and retrieval of additional information whenever required. In this chapter, the structure and content of the guide are described.

The guide has been tailored to the needs of decision-makers at the FVO who wished to have a scientifically valid and user-friendly tool to facilitate the economic assessment of national surveillance programmes. Findings from the theoretical work and practical issues encountered in the case studies have been used to define and summarise essential features that impact on the economic assessment of surveillance.

The classification system in Chapter 2 facilitates the understanding of the technical relationship between mitigation as a source of economic value, and surveillance and intervention, as sources of economic cost. It lays the foundation on which to conduct the economic assessment of surveillance and the related mitigation. The economic principles outlined in Chapter 3 allow recommendations to be made about how to achieve economic efficiency with a future policy (*ex ante* appraisal). However, the reality faced in the empirical work in Chapter 4 demonstrated that the assessment of implemented mitigation programmes always means looking back at a decision already taken. Further, the case studies highlighted the limitations stemming from the assessment of just one mitigation option, i.e. the implemented one, and the unavailability of suitable epidemiological models. Consequently, *ex post* appraisals of single mitigation programmes that are part of the national control plan can only determine if the implemented strategy is acceptable, but not if it is optimal. Until the

integration of economic and epidemiological models for *ex ante* economic assessments to determine the optimal level of disease mitigation are possible, economic assessments are inevitably confined to CBA and CEA. Therefore, taking into account the current institutional reality and the limitations described in Chapter 4, the practical guide focuses on approaches that allow determining acceptability and cost minimisation criteria. Questions asked and comments made by decision-makers as well as constraints faced in the empirical analyses were used to formulate a list with factors that may impact on the selection and implementation of CBA and CEA of surveillance programmes. Because the economic expertise at the FVO is sparse and there are no permanent economic advisers to assist decision-makers in economic questions, there is no systematic approach for the economic appraisal of mitigation programmes in place. Therefore, the guide explicitly addresses constraints that may impact on the economic assessment of surveillance, data needed for the economic analysis as well as key economic concepts.

5.2 The practical guide

5.2.1 Overview

Figure 5-1 illustrates the basic structure of the guide. In a first step, decision-makers are advised to describe the viewpoint of the analysis, the rationale for selecting the surveillance option(s) to be assessed, and the time frame and relevant factors that impact on the implementation of surveillance.

Next, the guide helps select the appropriate method for the economic assessment of the surveillance options in relation to the question posed. The starting point is the consideration of constraints decision-makers face and the assessment of their implications for economic analysis. They include any legal, political or other obligations that limit the surveillance options and consequently the scope for basing decisions solely on economic criteria. If it is perceived that surveillance must be done because of such obligations, economic analysis reduces to the question of what technical procedures for surveillance minimise costs. In that case, the CEA pathway is applicable. If there are no such constraints, the CBA pathway is applicable. In this pathway, the

classification system is used to define both the stage of mitigation and the surveillance and intervention objectives. Because each stage requires a different mitigation practice, three sub-pathways are presented that take account of these differences. At the beginning of each pathway, the basic economic framework underpinning the analysis, economic criteria and data requirements are presented. Flowcharts then lead decision makers step-by-step through a set of questions to ensure that all necessary elements to conduct the economic analysis are available.

Where essential elements, such as the technical procedures for intervention, are not given (marked with 'X' in Figure 5-1), the guide asks if resources are available to develop these within a time frame acceptable to decision-makers. If the answer is no, interpretations and recommendations about how to proceed are given (see following sections). Finally, a set of instructions at the end of each pathway outlines the key steps of the economic analysis. In the appendices, explanations regarding relevant economic concepts and techniques are provided.

Preparation: Describe the viewpoint of the analysis, the rationale for selecting the surveillance options to be assessed, the time frame and relevant factors that impact on the implementation of surveillance.

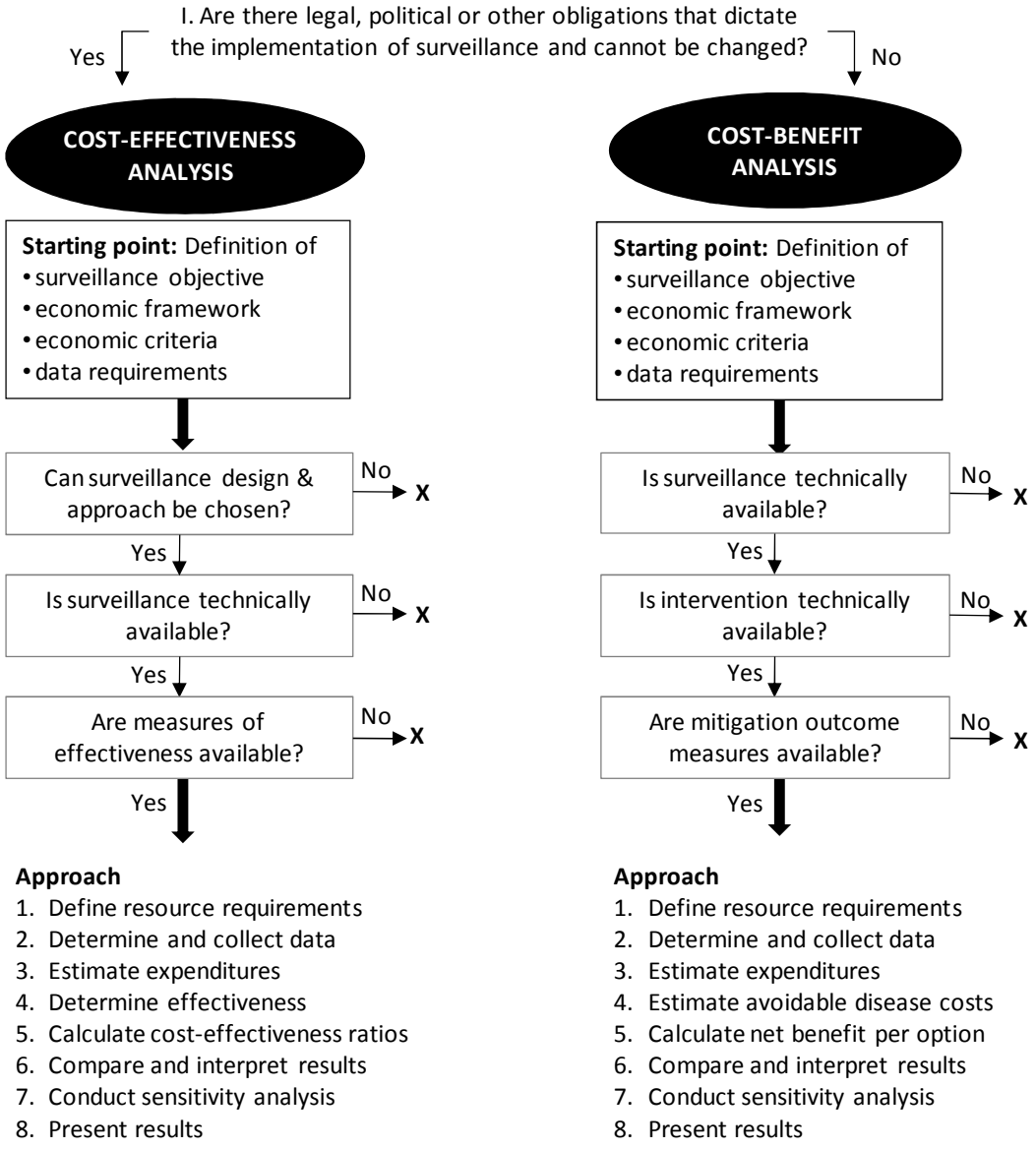


Figure 5-1: Scheme of a practical guide for the economic assessment of surveillance. 'X' leads to another set of questions and/or recommendations for decision-makers

5.2.2 Cost-effectiveness analysis pathway

Figure 5-2 summarises the CEA pathway for the economic assessment of surveillance.

Often, national and international legislation and official guidelines stipulate surveillance requirements. They either dictate the outcome of a surveillance programme (e.g. the surveillance programme must demonstrate with a certain confidence that the prevalence in the population is lower than a specified value) and/or the design of the programme (e.g. frequency of sampling and number of samples to be taken). Further, decision-makers need to implement surveillance because of social scares that could potentially cause a collapse of demand for certain food products or when the political agenda envisages tackling a certain hazard. Some hazards have the potential to cause such large economic losses that their mitigation is believed to be beneficial in any case (e.g. avian influenza).

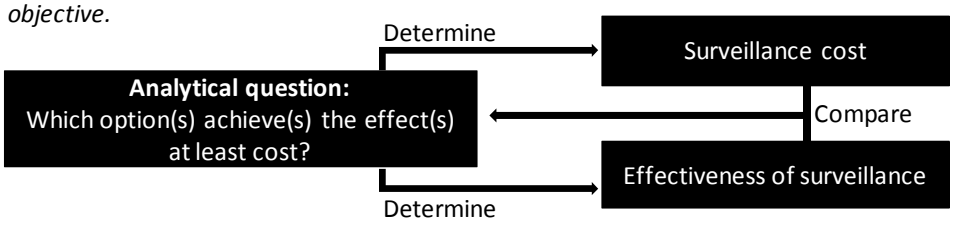
The unifying feature of all these examples is that there are strong constraints that preclude mitigation options in advance of the economic analysis. In other words, a decision regarding the implementation of surveillance has already been taken and technical targets have been formulated that curtail choices. The question then is what the technical procedures are for surveillance and which option minimises cost. Cost-effectiveness analysis is a widely used technique that allows the comparison of the effects and costs of different strategies. Commonly the results of a CEA are expressed in the form of a ratio that expresses the price per effectiveness unit. In fact, the effectiveness measure is a technical proxy for an economic benefit.

Surveillance options can either be strategies to be implemented in the future or a novel strategy that is compared to existing practice. If surveillance must be done and there is only one strategy available, economic assessment becomes redundant as there is no choice to be made. However, an economic assessment may still be conducted to investigate if a given strategy is efficient.

STEP 1: DEFINE AND DESCRIBE SURVEILLANCE OBJECTIVE

STEP 2: CONSIDER ECONOMIC FRAMEWORK

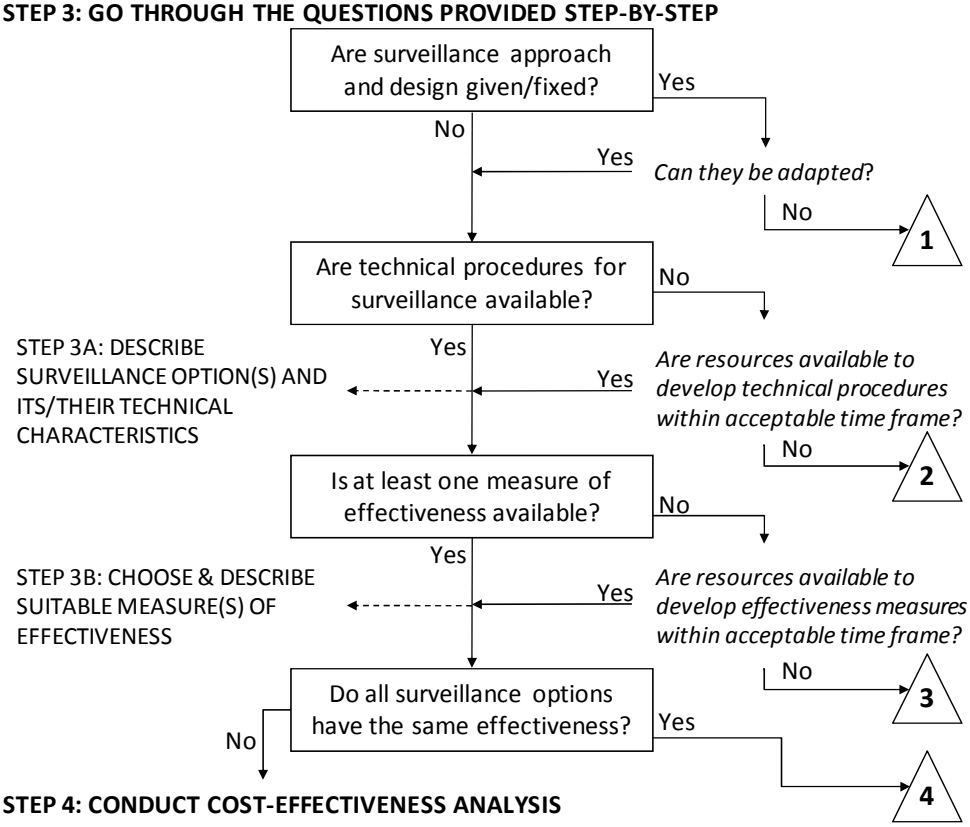
Economic criteria: The constraints cannot or shall not be changed. Therefore, the economic analyses reduce to the question what the *technical procedures* are for surveillance and to decide *which option minimises costs in relation to the surveillance objective*.



Will require: Data to

- Calculate costs for labour, material, and operations for all surveillance activities
- Determine appropriate measures of effectiveness

STEP 3: GO THROUGH THE QUESTIONS PROVIDED STEP-BY-STEP



STEP 4: CONDUCT COST-EFFECTIVENESS ANALYSIS

1. Define resource requirements of surveillance activities
2. Define data required to determine measure(s) of effectiveness
3. Conduct data collection
4. Estimate the monetary expenditures associated with each option
5. Determine effectiveness
6. Calculate cost-effectiveness ratios of all surveillance options
7. Compare and interpret the cost-effectiveness ratios
8. Conduct sensitivity analysis
9. Present results

Figure 5-2: Summarised pathway to conduct cost-effectiveness analysis of surveillance. The numbers 1-4 in triangles refer to recommendations described in Table 5-1.

Table 5-1: Recommendations for scenarios where cost-effectiveness analysis (CEA) is not feasible (see Figure 5-2).

Number	Recommendation
1	No scope to perform CEA at the current stage, because the programme is fixed and there are no options to compare. Minimise cost of programme by comparing prices of suppliers of services (e.g. laboratories) and materials. Another option to minimise cost is to use synergies by linking the surveillance programme to other activities.
2	No scope to perform CEA of surveillance at the current stage, consider investing in research to create the necessary technical procedures for surveillance.
3	No scope to perform CEA at the current stage, consider investing in research to create the necessary measures of effectiveness. Determine cost of surveillance.
4	No scope to perform CEA, because all surveillance options have the same effectiveness. Estimate the costs of the surveillance options and identify the cheapest one.

Effectiveness measures the ability of achieving a defined objective (Appendix V.1). Thus, decision-makers need to ask themselves what the surveillance objective is, what measures of effectiveness reflect this objective and how effectiveness can be best assessed. Measures of effectiveness for example are the time of introduction of disease until its detection, the probability of detecting an outbreak, the ability to document disease freedom for a certain hazard with a specified probability, the number of cases detected or sensitivity of the surveillance system. Obtaining measures of effectiveness is primarily an epidemiological issue. Therefore to determine the effectiveness of surveillance options it is essential to select and quantify appropriate measures of effectiveness using epidemiological approaches.

If the technical procedures for surveillance are not yet available or pre-determined (for example by legislation), or if there are no measures of effectiveness available or if the effectiveness of the surveillance options is known to be equal, then 1-4 in Table 5-1 apply.

If all the necessary elements to conduct CEA are available, data collection can be organised and cost-effectiveness ratios (CER) calculated. It measures the cost of surveillance divided by the resulting effectiveness in non-monetary units. There are two types of CER: The average CER is calculated for independent programmes that are evaluated against a baseline (e.g. no programme), while the incremental CER is

generally used to compare a new programme to the best alternative available (Cohen and Reynolds, 2008), i.e. it compares mutually exclusive programmes (Appendix V.2).

5.2.3 Cost-benefit analysis pathway

For scenarios where decision-makers have the choice whether or not to implement surveillance or if they want to assess the economic value of surveillance under strong constraints, the CBA pathway applies (Figures 5-3 and 5-4). Cost-benefit analysis is an approach that compares estimations of the costs and benefits of a strategy in monetary terms over a period of years. Costs and benefits may be of economic, environmental, biological and medical nature and are often difficult to quantify (Rushton et al., 1999).

Critical for the CBA of surveillance is the concept of avoidable disease costs advocated by McInerney (1996) that reflects what can be done about a disease by integrating disease dynamics, technical procedures of surveillance and intervention, feasibility, and time (Appendix V.3). Disease costs include losses that are caused by disease (e.g. mortality, abortions, reduced milk yield) and expenditures, which are extra resources used as a consequence of the disease (e.g. vaccines, veterinary services, drugs). The disease costs avoided by a mitigation strategy are the benefits of that strategy. To estimate the benefits generated from veterinary service mitigation measures, it is necessary to have a baseline, i.e. an estimate of what would happen without government action. Depending on the perspective of the analysis, certain expenditures can be avoided and are therefore part of the benefit. For instance, if the magnitude of an outbreak is smaller because of rapid response enabled by surveillance, outbreak response expenditures are likely to be smaller than without surveillance, i.e. intervention costs can be avoided. To account for all benefits, a detailed list of all elements that comprise disease costs for the baseline and comparative scenarios should be made. They may include production losses, trade losses, spill-over to other sectors of the economy (e.g. tourism), and impacts on downstream and upstream businesses (e.g. breeders, feed producers, slaughterhouses). Consequently, changes in market prices may be observed, which impact on consumer and producer surpluses. Further, non-monetary consequences such as human illness, animal welfare, consumer

confidence, reputation, and impacts on the environment may be considered. There are a range of techniques available to value non-monetary benefits, such as contingent valuation or Quality-Adjusted Life Years (Appendix V.4). The policy objective and the practical feasibility determine the level of detail and boundaries of the economic analysis.

At first, the mitigation stage as well as surveillance and intervention objectives need to be defined using the proposed classification system (Chapter 2). For each mitigation stage and related surveillance objective, a distinct sub-pathway applies.

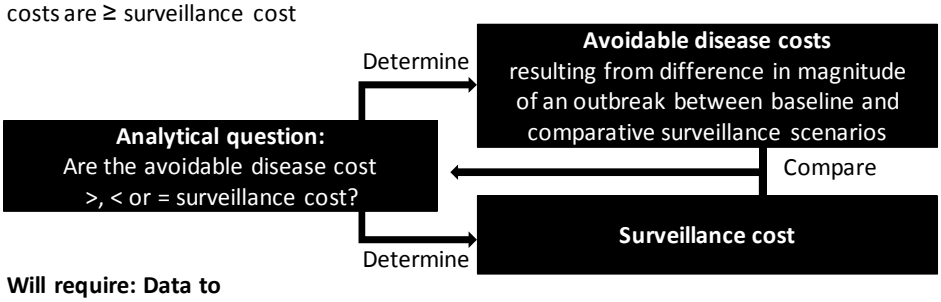
In the pathway for Stage I mitigation, the surveillance objective is to document the free status and detect a hazard early when it occurs thereby enabling rapid response (Figure 5-3). Disease costs accruing from efforts to restore a free status include response expenditures (e.g. outbreak control measures) and production losses (e.g. reduced wool production, mortality of animals). With a surveillance programme in place, the time from introduction of disease to its detection is expected to be shorter enabling rapid response, which may reduce the magnitude and duration of an outbreak. For a surveillance strategy to be justifiable, the avoidable disease costs (=benefit) must be greater than or equal to surveillance costs. If decision-makers are willing to allow for a shift to Stage II and III mitigation and the failure of sustainment is directly attributable to insufficient surveillance, disease costs not only include response expenditures and production losses in Stage I, but also mitigation expenditures and production losses in Stages II and III (Appendix Figure V-1).

STEP 1: CLASSIFICATION – STAGE I SURVEILLANCE

Mitigation to sustain acceptable or free status. Surveillance to document that hazard is not present or only at acceptable level and to give early warning signal if incidence increases.

STEP 2: CONSIDER ECONOMIC FRAMEWORK

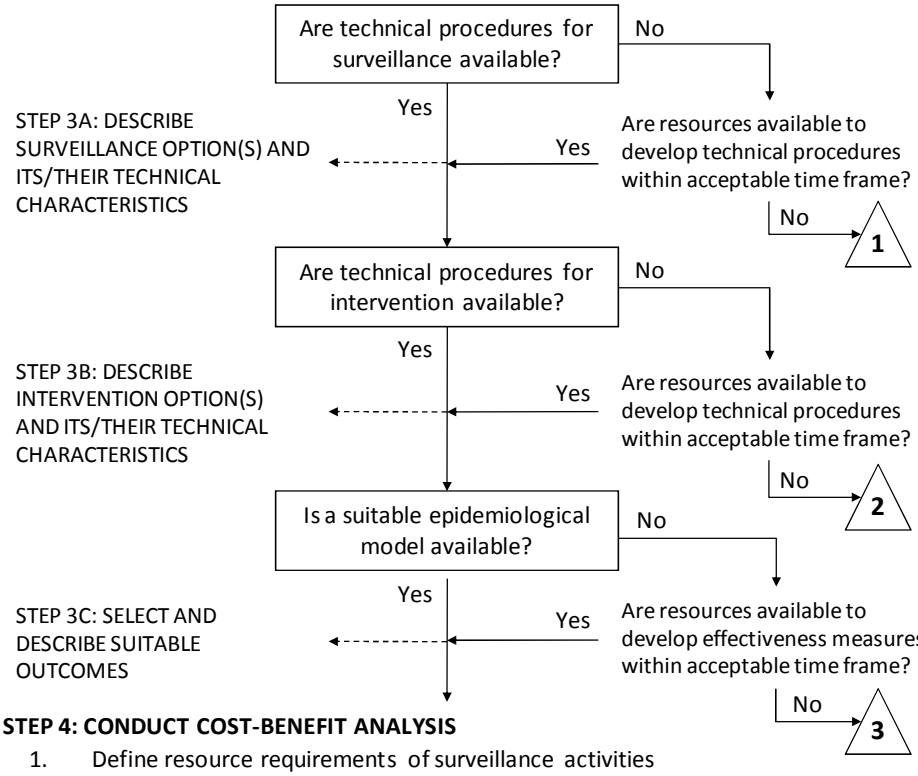
Economic criteria: Surveillance economically justifiable if future avoidable disease costs are ≥ surveillance cost



Will require: Data to

- Estimate magnitude of outbreak and related disease costs
- Calculate costs for labour, material, and operations for all surveillance activities

STEP 3: GO THROUGH THE QUESTIONS PROVIDED STEP-BY-STEP



STEP 4: CONDUCT COST-BENEFIT ANALYSIS

1. Define resource requirements of surveillance activities
2. Define resource requirements of intervention activities
3. Define data required to determine disease costs
4. Conduct data collection
5. Estimate the monetary expenditures associated with each option
6. Estimate disease costs associated with each option
7. Calculate benefit (=avoidable disease costs)
8. Compare costs and benefits
9. Conduct sensitivity analysis
10. Present results

Figure 5-3: Summarised pathway to conduct cost-benefit analysis of Stage I mitigation. The numbers 1-3 in triangles refer to recommendations described in Table 5-2.

Table 5-2: Recommendations for scenarios where cost-benefit analysis (CBA) is not feasible (see Figure 5-3).

Number	Recommendation
1	No scope for CBA of surveillance at the current stage, consider investing in research to create the necessary technical procedures for surveillance
2	Surveillance is used to detect a hazard when it occurs, but intervention measures cannot be implemented, because they are not available (yet). Therefore, surveillance costs shall not be bigger than the non-monetary benefit resulting from knowing if hazard is present or absent (e.g. 'peace of mind', feelings of safety). Consider investing in research to create the necessary procedures for intervention.
3	Consider alternative ways of gathering outcome measures to perform CBA (e.g. data or epidemiological models from other countries, expert elicitation) and/or alternative evaluation strategies (e.g. cost-effectiveness analysis)

In the pathway for Stage II mitigation, the surveillance objective is to re-assess the situation. Surveillance is used to obtain epidemiological indicators such as prevalence or incidence, morbidity, mortality, geographical distribution, and frequency of risk or preventive factors to inform the selection of future intervention programmes. Surveillance in Stage II is economically justifiable if the surveillance costs of investigation (Stage II) plus implementation (Stage III) are equal or smaller than avoidable disease costs resulting from implementation. In such a case, Stage II surveillance is to be integrated into Stage III calculations. If it is decided that implementation is currently inadvisable for economic, technical, or political reasons, the benefit obtained from investigation is non-monetary, experienced as feelings of safety or contentment. In that case, the expenditures made for investigation surveillance can be interpreted as the minimum implicit value of non-monetary benefits that must accrue for the surveillance expenditures to be justified.

In Stage III mitigation, surveillance is used to identify animals or herds eligible for intervention, monitor the progress and effectiveness of intervention measures (mid-term evaluation) and to ultimately verify their success (final evaluation), while intervention measures are implemented to reduce or eradicate a hazard in the population. Surveillance is no longer used to document a free status and give an early warning signal or to measure epidemiological indicators, but to combat a widespread

hazard. The impact of surveillance cannot be measured directly, as surveillance alone will not reduce prevalence in the population. Thus, it must be assessed in combination with intervention. What is measurable is the benefit resulting from the combination of surveillance and intervention, reflected by prevalence reduction in the population. The combined expenditures for surveillance and intervention must not be bigger than the benefit resulting from surveillance and intervention efforts (Figure 5-4).

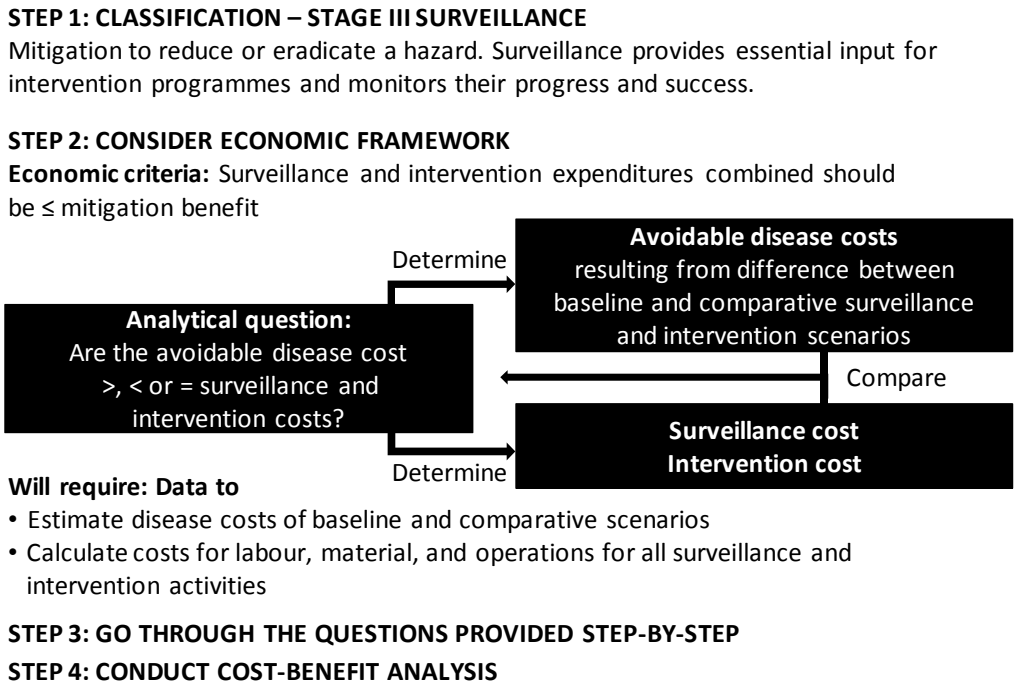


Figure 5-4: Summarised pathway to conduct cost-benefit analysis of Stage III mitigation. The questions in Step 3 and instructions in Step 4 are exactly the same as in Figure 5-3.

For scenarios where CBA is not feasible, the same recommendations apply as for Stage I mitigation (Table 5-2), with the exception of recommendation number 2, which changes to "Surveillance is used to inform the intervention process. Without intervention, the economic assessment of surveillance in Stage III becomes redundant. Consider investing in research to create the necessary procedures for intervention".

Ideally, a range of distinct surveillance, intervention and mitigation combinations is compared to identify justifiable surveillance options. In Stage I, response measures are often clearly defined and stipulated in national legislation. Hence, their technical characteristics are given and their implementation is triggered by the detection of cases in the animal population. However, surveillance can be varied and compared to

the mitigation outcome (e.g. magnitude of an outbreak), which reflects the disease costs. In Stage III, both surveillance and intervention options can be varied and different combinations be compared to the mitigation outcome (e.g. prevalence reduction), which reflects the disease costs.

Epidemiological models allow capturing the impact of technical mitigation procedures on the disease dynamics in the population and provide predictions for epidemiological indicators, such as prevalence or incidence over time, in relation to the mitigation strategies assessed (Appendix V.5). There is no universally applicable outcome measure, but it must be defined for each hazard in relation to the surveillance (and intervention) objective. The economic framework and data requirements outlined at the beginning of each pathway help decision-makers to think about relevant epidemiological outcome measures. A set of questions specifically refers to the availability of epidemiological models. The summarised question in Figure 5-3 *"Is a suitable epidemiological model available?*"contains the following sub-set of questions (Figure 5-5):

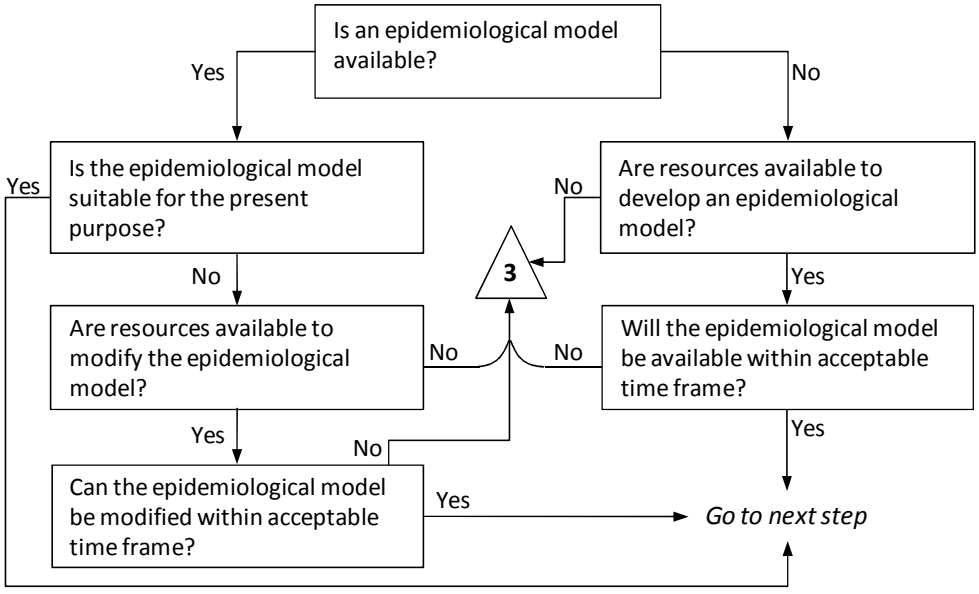


Figure 5-5: Flowchart to ensure the availability of epidemiological outcomes for the economic assessment of surveillance. The number 3 refers to recommendations described in Table 5-2.

If costs and benefits extend over a sufficiently long period into the future, their monetary values must be discounted to account for time preference (Appendix V.6)

before calculating measures of economic efficiency in the CBA (Appendix V.7). It is recommended to use sensitivity analysis to measure how outputs of the economic model vary when values of input parameters are changed (Appendix V.8).

5.3 Discussion

This guide has been tailored to the needs of decision-makers at the FVO who desired a practical, scientifically valid, and user-friendly tool for the economic assessment of surveillance. However, the generic nature of the proposed guide makes it not only useful for the FVO, but for any veterinary service interested in the economic assessment of surveillance programmes. Even though the guide is tailored to the needs of a developed country, conceptually it is also valid for developing countries.

The guide enhances decision-makers' understanding of important relationships, concepts and elements that need to be considered when making an economic assessment of surveillance. It stimulates reflection about relevant questions, embeds surveillance in the wider context of decision-making and facilitates the dialogue with veterinary scientists, epidemiologists and economists. Thereby, it helps to bridge the gap between disciplines and to promote interdisciplinary research. However, the guide is not a substitute for seeking advice from an economist in all steps of the policy cycle, i.e. from specification of the rationale and objectives, to identification, formulation and assessment of options, decision-making, and implementation of the preferred option.

To be able to assess the disease dynamics in a population under a range of mitigation scenarios, the availability of epidemiological models is indispensable. Epidemiological models study the behaviour of a disease in a population under variable conditions of animal species, transmission pathways, climate, as well as mitigation strategies. Because economic questions drive the information needs, bringing together both economists and epidemiologists in the planning stage ensures that economic and epidemiological modules are developed in a fully compatible way.

The identification of constraints at the beginning provides an important pre-selection that categorises surveillance programmes into two broad groups that constitute two distinct types of economic questions. Often, veterinary services have to comply with

national and international legislation and guidelines and political and social pressures that dictate the implementation of a surveillance programme and cannot be changed for the time being. In such cases, a decision has already been made and the surveillance objective is given. For this type of analysis, CEA is recommended, because it allows assessment of the technical procedures for surveillance in relation to their costs. It does not measure the benefit related to the technical target, but demonstrates which level of effectiveness can be achieved in relation to the cost. Important drawbacks are that it can only compare programmes that use the same measures of effectiveness and that it does not quantify the benefit of the programme.

If there are no such constraints that dictate the implementation of a surveillance programme or if there is an interest in assessing if a planned or implemented surveillance programme is worthwhile despite strong constraints, decision-makers may want to conduct a CBA. For example, CBA could be used to demonstrate if an ongoing programme is worthwhile and to collect evidence to promote a change in legislation if the programme is not efficient. Cost-benefit analysis is the recommended technique because it offers a rigorous approach to capture a wide range of costs and benefits for mitigation options in different time periods, is widely accepted and intuitively understandable. Because it attempts to quantify all costs and benefits related to a programme, it provides a comprehensive picture of the consequences of suggested strategies. The quantification of these consequences, especially those of non-monetary costs and benefits is not straightforward and require using special economic techniques. The guide provides relevant additional information about valuation approaches. Other techniques that could be integrated in the analyses, but would require advanced analytical skills, include economic surplus, mathematical programming and systems analysis methods (Rushton et al., 1999).

The results from both the CEA and CBA have to be interpreted bearing in mind the surveillance objective and influencing factors, such as the institutional and social setting which may impact on the effectiveness of implementation. The rationale for selecting the surveillance options, the time horizon, discount rates, full disclosure of input data and their sources, and sensitivity analyses are important to get a comprehensive picture.

Taking into account practical limitations of empirical analysis and the decision-making context at the FVO, in its current form, the practical guide provides acceptability and cost minimisation criteria only. It includes relevant economic principles and allows assessing surveillance programmes of the national control plan that have already been implemented as well as future programmes. Further, it provides a foundation for the economic analysis of various combinations of surveillance and intervention options for different mitigation stages, an essential step towards the estimation of optimisation criteria. Any additional information to take account of optimisation criteria can be easily added to the guide. It is recommended to consider the economic principles outlined in Chapter 3 to determine the economic optimum of disease mitigation in the longer term policy making and research agenda.

CHAPTER 6

SUMMARY,

GENERAL DISCUSSION AND

FUTURE DIRECTIONS

In this final chapter, the main findings of the thesis, their significance and limitations are discussed. Finally, the project's contribution to existing knowledge and possibilities for further research are outlined.

6.1 Summary

The aim of this thesis was to develop a user-friendly, practical tool for the economic assessment of surveillance programmes that are part of the national control plan of Switzerland, based on rigorous economic principles. Having specified a detailed classification system for surveillance programmes, the economic principles of resource allocation for disease mitigation were described. Most importantly, surveillance and intervention must be considered as integrated components of disease mitigation. The economic principles of resource allocation for disease mitigation were applied empirically to four case studies. Lessons learned from the conceptual and empirical work were used to inform the development of a practical guide to assist decision-makers in the economic assessment of surveillance. This guide provides a solution for robust and standardised assessments of surveillance programmes.

Figure 6-1 summarises the key technical and economic relationships between surveillance, intervention and loss avoidance and economic criteria established in this project.

Crucially, three levels of criteria for economic efficiency result from the theoretical and empirical investigation of these relationships: The leading criterion is optimisation, which defines how the net benefit accruing to society from allocating scarce resources to disease mitigation is maximised. Next, the acceptability criterion concerns whether the benefits stemming from a mitigation policy at least cover its costs, thus making a strategy justifiable. Finally, the cost-minimisation criterion applies when achieving a technical target for mitigation without quantification of the benefit is the policy objective.

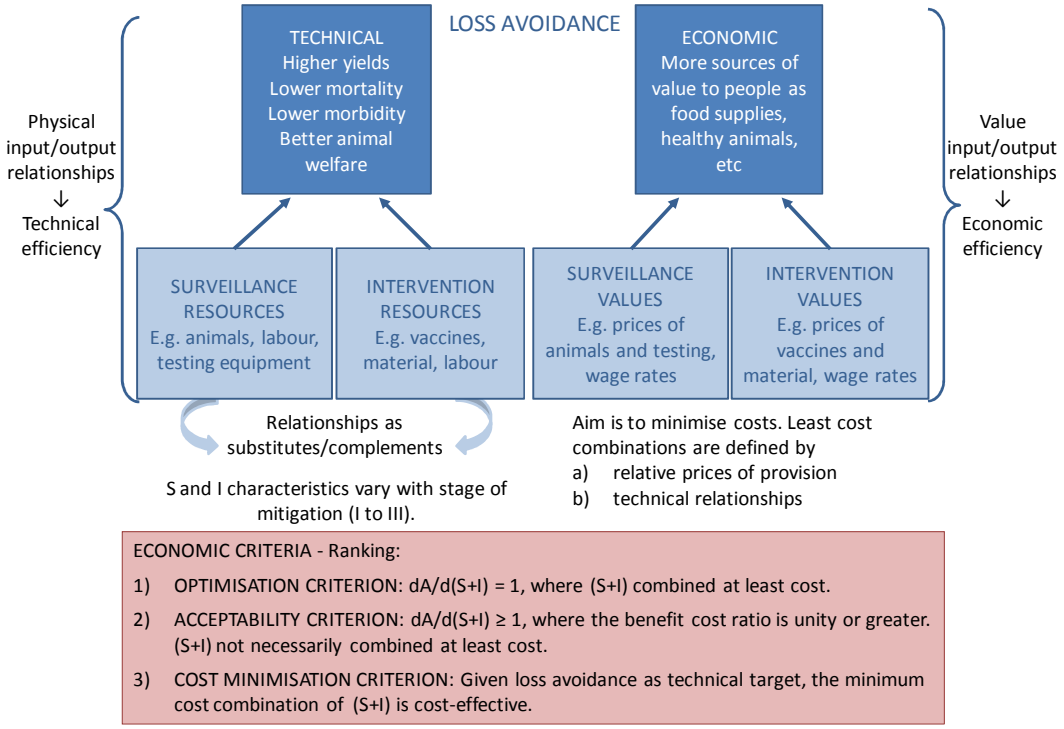


Figure 6-1: Technical and economic relationships of disease mitigation and ranked economic criteria. A=loss avoidance, S=surveillance, I=intervention.

There is no simple answer to the question how much surveillance is worth, but the economically optimal or acceptable level must be determined from case to case taking into account disease specific factors that impact on production losses, externalities, and the type and quantity of resource use in mitigation.

6.2 General discussion

6.2.1 Surveillance and economics in the decision-making context

Surveillance is inextricably linked to intervention and so the assessment of its economic value is meaningful only 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, as for example done by Kompas et al. (2006), Moran and Fofana (2007) and Carrasco et al. (2010).

Building on that finding, a classification system for surveillance to inform economic analysis was developed. By looking at the mitigation objective and the related surveillance and intervention from a policy perspective, decision-makers' understanding of the technical relationships between surveillance, intervention and mitigation is enhanced. This is an essential pre-requisite for framing appropriate questions for economic analysis, depending on the existing or putative stage of mitigation. Thereby it creates a foundation upon which to apply the economic principles outlined in Chapter 3.

The animal health decision-making process is closely linked to the political economy that defines investments in animal health and drives factors impacting on mitigation programmes, such as social and cultural acceptability (Rushton et al., 2007). For example, the EU's animal health strategy for 2007-2013 focuses on reducing serious threats to human health and the rural economy to a negligible level, and advocates the use of CBA and CEA to allocate limited resources efficiently. Such political strategies and cultural aspects often impact on the formulation of technical targets of disease mitigation, sometimes independent of economic criteria. Consequently, the keys to optimisation of mitigation programmes are in the hands of policy makers. Any economic assessment of surveillance thus needs explicitly to take into account the wider decision-making context and the boundaries set by political and cultural realities.

While epidemiological criteria have a central place in veterinary decision-making, economic analysis is rarely a key point of mitigation policy designs, or else tends to be used informally in an implicit way or retrospectively to justify decisions already 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). While there is an abundance of textbooks on general economics and agricultural economics, such material is limited for the application of economics to problems in animal health. Consequently, animal health professionals are generally poorly equipped to understand the role of economics in decision-making. These limitations were prominently kept in mind during the research for this thesis, and the

outcomes are presented in a way that facilitates communication between decision-makers, economists and epidemiologists.

6.2.2 The economic framework and its application

The framework of economic principles demonstrates how established concepts and relationships from microeconomics can help decision-makers better understand complex interactions between the elements of disease mitigation and their implications for resource allocation. For example, it provides criteria for the optimal level of disease mitigation for surveillance and intervention according to whether they are economic complements or substitutes. Further, it highlights the impact of externalities and explains the practical significance for the application of economic criteria. The framework builds on previous research by McInerney et al. (1992) and McInerney (1996). The microeconomic principles of production stem from observations about the nature of the real world, supplemented by criteria to help people make rational choices if their well-being is to be maximised in the face of scarce resources. They provide a rigorous and well-established foundation to inform policy decisions about disease mitigation. Importantly, the framework highlights that what is achievable technically is not necessarily best from an economic perspective. Only the economic optimum is based on criteria for maximising people's welfare, the best outcome from disease mitigation for society as a whole.

The framework demonstrates that the key variables in assessing disease mitigation are: 1) the time path of disease effects on lost current and future production and their magnitude with respect to time, and 2) resource expenditures aimed at curtailing losses. It makes explicit reference to the efficiency of combining the two main mitigation resources, surveillance and intervention, and therefore takes the analysis an essential step further than conventional CBA. By conceptualising disease mitigation as a production function it was confirmed that it is impossible to answer questions about the economic value of surveillance without investigating its technical role and economic worth in relation to intervention. For example, if surveillance and intervention are economic complements separating out their individual effects is impossible and they must be treated as one single input. However, if they are

substitutes, there are potentially many options for combinations, whereby the least-cost option will be determined by the relative prices and the elasticity of substitution.

Economic criteria have a crucial role in helping to inform the research agenda for disease mitigation. For example, if empirical analysis demonstrates that production losses avoided are insufficient to justify mitigation expenditures under a given policy, the value of economic benefits that must accrue from positive externalities for net benefits to become positive (e.g. improved animal welfare, freedom from zoonoses) must be evaluated.

The economic principles show where empirical knowledge is essential, before efficient choices about mitigation resource allocation can be made. Due to decision-making practicalities, time restrictions and limited suitable epidemiological data, the empirical research here was not able to explore fully the theoretical concepts described. This precluded construction of a three-dimensional disease mitigation surface (see next section) for the case examples. Therefore, this points to directions for further research. To discover the properties of any such surface for the mitigation of animal disease, economic analysis should be made an integral component of the policy planning and evaluation cycle in the veterinary service.

However, there is no simple way for dissemination of economics among animal health professionals in the short term. This will require a structured approach to promote the application of economics to animal health. Mlangwa and Kisauzi (1993) stated that universities, government and the private sector should enhance the teaching and training of animal health economists. Strategies to create links between economics and animal health professions include the integration of economics in undergraduate and postgraduate animal health curricula, the provision of continuing professional development courses, as well as networking and collaboration between economists and animal health professionals. The need for an increased effort in teaching and training to promote the use of economic concepts and principles was confirmed in 2010 in an international workshop of world leading experts who discussed the use of economics in animal health decision making (Rushton, 2010). An initiative based on the outcomes of this meeting aims to create a network to enhance the use of economics in animal health education, research and policy making.

6.2.3 Empirical analyses

Three important pre-requisites are needed to determine the economic optimum for disease mitigation using the economic principles described in Chapter 3: 1) *ex ante* assessment to inform a decision regarding the future implementation or continuation of a disease mitigation programme, 2) availability of economic and epidemiological expertise to apply the relevant principles and techniques and integrate respective models, and 3) availability of data required for the economic and epidemiological models.

While *ex ante* economic assessments are conducted in the planning stage of a project to provide information for decision-makers regarding the selection of a suitable mitigation option, *ex post* assessments are performed after full or partial completion of a project. The latter show if an implemented strategy has been justified from an economic point of view. If not, corrective measures may be taken to improve the existing programmes. Further, the outputs from the *ex post* assessment provide important information for the *ex ante* assessments of future programmes, i.e. it enhances the institutional understanding of factors relevant to the economic assessment of mitigation programmes. However, economic assessments of this type never fully inform a resource allocation decision, because they only look back at decisions already taken.

In the case studies, the most important limitation was that decisions regarding the desirable level of disease had already been taken mainly based on non-economic criteria. *Ex post* economic assessments were used to investigate if the implemented programme was justified and, where appropriate, *ex ante* assessments were conducted to inform the future direction of a programme. Significantly, the approaches found to be feasible given the decisions already taken and with the data available were the familiar CBA and CEA perspectives. This underlines the current limited scope for economics to become a more comprehensive framework that helps inform resource allocation decisions for disease mitigation.

Cost-benefit analysis has been widely used to assess disease mitigation strategies, despite some economists repeatedly pointing out its limitations. The main criticisms

are that the sole use of CBA neglects the wide array of economic principles and approaches better suited to illuminate the nature of decisions for disease mitigation problems, and that sometimes benefit-cost ratios as choice criteria are misleading (Grindle, 1985; McInerney, 1991; McInerney et al., 1992; Howe and Christiansen, 2004). The structured framework of CBA is intuitively appealing because decision-making generally involves balancing the positive and negative consequences of a particular choice, and because costs and benefits are quantified in a systematic way in one common unit (usually money) to enable comparisons to be made (Ramsay et al., 1999).

In the case studies conducted, surveillance and intervention were assessed as two separate cost-elements, providing information about the relationship of surveillance to intervention and their roles in the mitigation process. In the BTV-8 and BVDV case studies, both Stage III mitigation programmes, the impact of surveillance could not be measured directly, as surveillance alone would not reduce prevalence in the population. Therefore, it was only possible to quantify the benefit resulting from the combination of surveillance and intervention and to compare it to the expenditures for surveillance and intervention. The BTV-8 case study indicated the secondary role attributed to surveillance compared to intervention and the potential of using more surveillance to design more effective intervention based on the information provided. The economic assessment demonstrated that the implementation of the programme was worthwhile for the years 2008 and 2009, but that the continuation of the programme in the same form would produce a net cost in future years. Hence, economic analysis confirmed that the decision to implement a compulsory vaccination programme in 2008 was justified. At the same time, it clearly showed that the economic value of a mitigation programme changes over time and that regular assessments of an existing policy are essential. The BVDV case study highlighted the relationship between the benefit from eradication efforts and subsequent surveillance to demonstrate disease freedom, i.e. it provided an example of linking two mitigation stages. Estimation of the net value of the programme showed that it is expected to gain an overall net benefit.

Cost-effectiveness analysis, commonly used to assess human health interventions, has rarely been applied to animal health decision-making problems. The empirical assessment of the AIV and salmonella in layers surveillance programmes clearly demonstrated its usefulness for application to surveillance programmes under technical constraints. Cost-effectiveness analysis aims to assess the effect of a programme 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 objective can be measured in various technical terms, for example reduction of CO_2 emissions or detection of cases of disease. The common presumption of all types of CEA is that the objective or effect of the programme is pre-determined. This may be due to the perception or fact that the aggregate monetary and/or non-monetary benefits resulting from a project are known to be high enough to outweigh its costs (Mishan and Quah, 2007). Thus, this approach lends itself to the analysis of veterinary surveillance programmes that are dictated by legal, social, political and/or other obligations. In all these cases, the surveillance options are curtailed in advance of the economic analysis, which limits scope for making fully informed economic choices. The effectiveness measure may reflect the benefit resulting from the mitigation programme, but only its explicit quantification in relation to the cost would give a comprehensive picture of its economic value.

The selection of the appropriate effectiveness measure based on the surveillance objective is critical in conducting CEA. For the AIV case study, a Stage I mitigation programme, the effectiveness of surveillance was selected as the reduction of the probability of primary and secondary outbreaks in poultry. The use of a modified risk assessment approach to determine the effectiveness of surveillance for CEA has two important advantages. It is based on the well-established risk assessment framework suggested by the OIE, and it allows investigating the relationship between transmission pathways and mitigation measures. Thereby it provides information about the effectiveness of surveillance and, at the same time, highlights critical points in the transmission-mitigation interaction. The results showed that the AIV surveillance system was ineffective. Therefore, for the policy to be worthwhile, the implicit value of non-monetary benefits that accrue from the programme must be at least sufficient to cover the surveillance cost.

Because the mitigation programme for salmonella in layers aims to reduce prevalence in the population, the effectiveness measure chosen was the annual reduction in prevalence. While the programme has been effective in the past, it does not appear to be reducing prevalence any further. Unless non-monetary benefits equal the surveillance and intervention cost, the programme must be considered inefficient. But because the reduction target has been stipulated in EU legislation, it cannot be changed in the short term. Therefore, as long as there is no indication of changes in EU and domestic law, it is recommended to reduce the surveillance programme to the minimum defined by the EU and to save costs by, for example, exploiting synergies with other surveillance programmes. In the medium to long term, it is advised to open the debate about the current salmonella policy and to consider moving from Stage III mitigation to Stage I mitigation. There are two ways forward: either increase resources to further reduce salmonella prevalence in the national layer flock, or else define an acceptable level and find the cheapest way to sustain it.

6.2.4 Transition between mitigation stages

For Stage I mitigation programmes to be justifiable, the surveillance cost should not exceed the cumulative avoidable disease costs over time. The avoidable disease costs are determined by the biological and physiological characteristics of the disease, the probability of an outbreak occurring, and the related response. Because the likelihood of (re-)emergence or introduction of an exotic disease and structural characteristics of the production system (e.g. livestock sector, veterinary service) may change over time, economic and epidemiological models should be regularly updated. For example, shortly after successful disease eradication, mitigation activities are directed at sustaining the status quo and avoiding disease recurrence. Over time, with the consolidation of preventive measures (e.g. testing of imported animals, biosecurity measures at farm level), the risk of disease recurrence is likely to decline and should be reflected in the surveillance activities adopted. Importantly, continuing Stage I mitigation programmes for a prolonged time period should be avoided without regular revision and updating of models with new data.

Where many resources have already been invested in a long-term Stage III mitigation programme, the question arises as to the continuation of the programme or its cessation and a shift to Stage I. After successful intervention, decision-makers are expected to shift to Stage I to sustain the acceptable status. This should be done as soon as evidence shows that the desired level of mitigation has been robustly achieved to avoid institutionalisation of the programme. If the level desired is not achieved within the specified time frame, economic and epidemiological analyses need to be used to assess the programme's future. As shown for salmonella, economic assessment demonstrates whether an implemented programme is efficient or not. If not, further analyses should be conducted to assess alternative strategies. Owing to diminishing returns, the marginal cost of the last increment towards reduction or eradication may exceed the marginal benefit. In such cases, sustaining a defined level of prevalence over time may be the solution. If the eradication or reduction target has been defined by non-economic criteria, it may well be that the achieved target is already inefficient. However, veterinary services in developed countries are highly unlikely to allow consciously a prevalence increase after economic analyses showed the inefficiency of a policy. In such cases, the best that can be done from an economic point of view is to define an acceptable prevalence level based on non-economic criteria and identify the cheapest strategy to sustain that level over time. Such situations can be avoided by conducting *ex ante* economic assessments and updating them during the implementation process.

6.2.5 The practical solution

Practical constraints on the possibilities for empirical research were crucial for the design of a practical guide for decision-makers to aid the economic assessment of surveillance. The practical guide builds on the experience of the case study analyses and draws together lessons from both theoretical and empirical work. Its transparent and user-friendly design is constructed to guide the user step by step through a set of questions that will make him/her aware of the context of analysis, the important technical and economic relationships, and the data needed for the economic analysis.

It has been shown that the *ex post* economic assessment of an implemented programme can only demonstrate if a given policy was justifiable, i.e. if the benefits at least equal the costs of a strategy. The estimation of benefits resulting from a strategy may be further constrained by legislative requirements, data and time limitations and/or the unavailability of suitable epidemiological models. Therefore, taking into account the current institutional reality and the limitations described, the guide focuses on what is currently possible and presents approaches to determine acceptability and cost minimisation criteria. However, its structure is flexible and any additional information to take account of optimisation criteria can be easily added.

The practical guide contributes to the understanding of the place of economic principles in the assessment of surveillance, and lays a foundation for more complex future analyses. It embeds surveillance in the wider context of decision-making and is a good starting point for decision-makers to become familiar with economic concepts and relationships by stimulating reflection about relevant questions. After further development, the three dimensional mitigation surface for one or more diseases could be investigated, either by integrating epidemiological and economic models at national level or by collecting international data. By adopting a step-by-step approach to the application of economic principles in decision-making, the increasing complexity of the analysis will keep pace with the capacity of non-economist animal health professionals to interpret and use the outcomes provided.

6.2.6 Interdisciplinarity

To investigate the specific characteristics of any three dimensional mitigation surface so as to determine the economic optimum for disease mitigation effort, as well as to conduct a CBA of a mitigation programme, dialogue between economists, epidemiologists and veterinary scientists is required from the start. This is of particular importance for *ex ante* assessments which inevitably rely on predictions subject to uncertainty.

Economic models need to take into account all possible consequences of disease and its relationships with mitigation efforts, thus to define the data required to analyse

technical and economic efficiency. Epidemiological models built on a thorough understanding of the biology of production systems can predict disease dynamics in a population, taking into account transmission pathways, risk and preventive factors and investigate the impact of mitigation strategies. Resulting outputs, such as prevalence or incidence rates and relationships expressing the consequences for surveillance and intervention activities, are indispensable inputs in economic models. To make economic and epidemiological models fully compatible, they should be planned and designed together from the start.

Another essential step in using economic criteria in conjunction with epidemiological models to determine the optimum level of disease mitigation is to link economic and epidemiological models with feedback loops (Rich, 2007; Horan et al., 2010). Such feedback loops capture the dynamic impacts of mitigation policy on the evolution of disease in the population, and vice versa. The inclusion of up-to-date inputs in integrated epidemiological and economic models will allow real-time modelling, which is particularly relevant for policy decisions in outbreak situations (Perry and Randolph, 2004). It is important to remember that the optimal level of disease mitigation may change over time with changing characteristics in the livestock sector (Rushton et al., 2007), as well as with different relative prices and new mitigation technology. There are examples of projects that successfully integrated economic and epidemiological aspects in bioeconomic models, such as Bicknell et al. (1997), Kompas et al. (2006) and Rich (2007), but they are still sparse.

Even though the call for interdisciplinary integration is nothing new, it is difficult to implement due to training, thinking and working in unidisciplinary environments that are often separated physically or administratively. Heady (1952) advocated inter-disciplinary research by observing that “agricultural production economics must necessarily be integrated with that of other physical and social sciences”. Putt et al. (1988) stated that disease control policy needs an “inter-disciplinary approach involving the close and continuous cooperation of the various disciplines concerned”. Perry and Randolph (2004) made a case for a more standardised approach to integrated economic and epidemiological modelling. Interdisciplinary work does not only require an understanding of the basic concepts and terminology of the other

discipline(s), but also a willingness to share, exchange and collaborate. Interdisciplinary research faces barriers due to disciplinary identity, its performance evaluation, inadequate reward structures, lack of a support structure as found in disciplinary research and power struggles (Heberlein, 1988).

Veterinary services have the institutional capacity to bridge such conflicts of interest by funding interdisciplinary research. This may help to overcome barriers to interdisciplinary collaboration and to promote mechanisms suggested to bring disciplines together (Heberlein, 1988), such as changes in faculty governance and setting of the research agenda.

6.3 Future directions

The economic framework presented is a new way of looking at disease mitigation, in particular by exploring the possibility that the surveillance and intervention activities by which it is achieved are substitutes rather than complements. Owing to time restrictions and only partly compatible epidemiological models, it was impossible to test this hypothesis. Thus setting up an interdisciplinary research project with epidemiological and economic expertise for one or more specific diseases where data abundance is likely is strongly recommended. Economic models will define the data required to analyse technical and economic efficiency for the diseases selected. Epidemiological models can then be developed to simulate the technical relationships between surveillance, intervention and loss avoidance. The epidemiological outputs translated into monetary values will provide information about the economic implications of the specific technical characteristics of the given disease mitigation surface. In principle, investigating such surfaces from international data would be desirable, reflecting different national surveillance and intervention practices and their respective resource endowments. But this would only be possible given a network of people with a common interest in the economics of disease mitigation, especially modelling and methods for production function estimation, and access to relevant data.

To conduct an economic assessment of surveillance, it is important to have a thorough understanding of animal health problems at farm, national or international level as well as the institutional setting within which the veterinary services operates. The detailed description of objectives of surveillance and constraints impacting on surveillance is an essential pre-requisite to phrasing analytical questions best suited to provide the information decision-makers need. By following the steps outlined in the practical guide, decision-makers generate information about the economic value of surveillance. However, this does not facilitate decision-making in general, a process that integrates a wider range of criteria including political and epidemiological considerations. As long as there is no structured decision-making process in place to factor in all information collected in an objective and systematic way, certain findings may be ignored if they do not corroborate a decision already taken, whether consciously or not. A standardised process for interpreting and combining the information provided should ensure the objective consideration and integration of all sources. For example, Mourits et al. (2010) presented a multi-criteria decision-making framework for the mitigation of classical swine fever taking into account epidemiological, economic and ethical criteria. Incorporating economic criteria in a systematic and holistic decision-making framework has the potential to promote the application of economic principles in formulating and appraising animal health policy.

The basic principles outlined in this thesis are valid for both known and emerging diseases. However, assessing the consequences of an unknown hazard poses a considerable challenge. No information is available about the nature of any such hazard, the population it affects, or its transmission and physiological characteristics. The EU Animal Health Strategy for 2007-2013 advocates the precautionary principle "where proportionate provisional measures should be taken to ensure a high level of health protection pending further scientific information clarifying the extent of the risk". More epidemiological research is needed to provide generic frameworks that allow the likelihood of categories of hazards occurring to be estimated. Based on such frameworks, 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, which will avoid 'fishing in the dark'.

The practical guide provides a simple and transparent tool that decision-makers can apply in their everyday practical work. It is developed for non-economist users with limited economic expertise and experience. Its structure is targeted to the needs of a developed country, but could be readily adapted to the decision-making context of developing countries. International trade in livestock has a positive effect on the animal health status in developing countries, which are increasingly becoming free from classical diseases such as tuberculosis and brucellosis (Rushton and Upton, 2006). Thus, these countries correspondingly will be interested in setting up efficient surveillance systems, reinforcing the case for adapting the guide for use in developing countries.

Because the Swiss veterinary service competently and consistently implements and enforces national legislation (Rüsch and Kihm, 2003), it was assumed that surveillance data would be collected correctly and effectively (e.g. submission of samples for salmonella in laying hens by farmers and official veterinarians). However, in a country where the quality of the veterinary service or the compliance of agents in the system is in doubt, the effectiveness of implementation needs to be taken into account. Further, the decision-making process at farm level and the behaviour of livestock holders such as reporting behaviour in case of an outbreak may greatly impact on the technical efficiency of surveillance. The economically optimal level of surveillance on holding level may be at a lower prevalence than the one at national or regional level (Carpenter and Howitt, 1982), thereby creating a disincentive to adopting a higher level of surveillance, which may be encouraged by government subsidies. Distrust among the farming community towards the veterinary service may impede the correct adoption of mitigation measures. Such factors are difficult to quantify and are themselves worthy of socio-economic research. Thus, further research should also take into account the behaviour of livestock holders that may impact on the technical and economic efficiency of surveillance.

This project focused on the economics of veterinary disease mitigation with particular reference to surveillance, but has not considered the wider dimensions of resource

allocation. Each case study focused only on resource allocation options for a defined disease without making inter-disease comparisons. A next step could be to identify and compare the best options for resource allocation across a range of possible disease control programmes, thus pointing towards strategies for assuring society's optimal allocation of resources for disease mitigation as a whole.

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Glossary

Economics

- **Economic cost:** The loss in economic value because of disease felt by an individual person, or society as whole, as a result of some combination of a) unplanned reduction in the quantities or qualities of animal products available, and b) resource reallocation away from producing other goods and services that people value aimed at restoring quantities and qualities of animal products to desired levels. The other goods and services consequently reduced are the 'opportunity cost' of reallocating scarce resources to mitigate disease effects.
- **Economic efficiency:** Economic efficiency is interested in using resources in a way that maximises a defined objective relevant to the economic unit under consideration, such as farm, sector or national level. For example, if national welfare is to be maximised, economic efficiency aims at combining resources in a way to achieve this objective.
- **Economic value:** The feeling of personal well-being or benefit gained by an individual person as a result of consuming an animal good or service created by the transformation of resources. Summed over all individuals, it is the value to society. The conversion of feed into milk, or horses into recreational riding are examples of resource-to-product transformations.
- **Expenditure:** The use of resources transformed into animal products or for disease mitigation, expressed either in real (i.e. physical or technical) or monetary units. Physical resources are tangible, e.g. veterinary scientists, field workers, test kits, or vaccines. Technical resources are intangible, e.g. hours worked, technology, or scientific knowledge.
- **Iso-quant maps:** An isoquant (*iso* in greek meaning equal) is a contour line that is drawn through a set of points at which the same quantity of output is produced while changing the quantities of two or more inputs. It shows to ability to substitute between two different inputs to produce the same level of output.

- **Marginal cost and marginal benefit:** The marginal cost of mitigation is the increase in cost when an extra unit of mitigation resources is added. Analogously, the marginal benefit of mitigation is the increase in benefit (loss avoidance) when an extra unit of mitigation resources is added.
- **Marginal physical product:** It is defined as the change in output resulting from a unit increment or unit change in variable input.
- **Microeconomics:** Refers to the study of the economic behaviour of components of a national economy, such as households, farms, firms or industries.
- **Monetary cost:** The monetary value of a) lost quantities of animals and the products they provide, and b) additional quantities of resources expended, obtained by multiplying quantities either by market prices or, in cases where market prices cannot be observed, sometimes monetary valuations derived by indirect economic methods.
- **Production function:** The generic name for any resource-to-product transformation. Commonly, output is a synonym for product. It is a technical, not economic, relationship though sometimes variables are expressed in monetary units. Normally it comprises a single dependent variable (output), functionally related to one or more variable resources (inputs).
- **Production or output loss:** Unplanned reduction in the quantities of animal goods and services produced from a given quantity of resources, including for replacements or additions to breeding stock, or the monetary equivalent.
- **Supply:** The quantity of a good or service producers are willing to sell at each possible price. The illustration between price and the quantity supplied is called the supply curve.
- **Surplus:** The difference between the amount a producer paid for a good and the lowest price that he/she would be willing to accept for that good is the producer surplus. Analogously, the amount of money by which consumers value a good or service in relation to its purchase price is the consumer surplus.
- **Technical efficiency:** The level of technical efficiency is a measure of product output divided by factor input. It reflects the ability to use a given set of inputs in a way to produce the maximum possible outputs without wasting resources.

Mitigation

- **Hazard:** Any biological, chemical or physical agent in, or a condition of, an animal or animal product with the potential to cause disease.
- **Intervention:** The process of implementing measures directed at mitigation.
- **Mitigation:** Sometimes regarded as synonymous with control, the process of making disease less severe by avoiding, containing, reducing, or removing a hazard.
- **Prevention:** The total exclusion of disease from a susceptible animal population.
- **Surveillance approach*:*** Can be passive or active. The selection of the surveillance approach is a key design decision because of its impact on bias and cost.
- **Surveillance design*:*** Describes activities and methods used for implementing, analysing and communicating surveillance system components, e.g. populations, sampling, diagnostics, case definition, and statistics.
- **Surveillance system:** A method of surveillance that may involve one or more component activities that generates information on the health, disease or zoonosis status of animal populations.
- **Surveillance system component*:*** Has its self-contained surveillance protocol that focuses on a particular data source, such as serological bulk milk surveillance and surveillance of pathological lesions in the abattoir.

I Appendix to Chapter 1

I.1 List of surveillance programmes that are part of the Swiss multi-annual national control plan

I.1.1 Multi-annual national control plan 2007-2009

Animal health: Surveillance to

- document freedom from brucellosis in sheep and goats, infectious bovine rhinotracheitis, enzootic bovine leucosis, Aujeszky disease in domestic pigs, porcine reproductive and respiratory syndrome in domestic pigs, transmissible spongiform encephalopathies in cattle and sheep, BT disease, and avian influenza in poultry
- inform the intervention programme for *Salmonella* spp. in breeding and laying hens

Feed and food: Surveillance of

- imported feed of animal origin for *Salmonella* spp. and residues of bovine tissues
- imported food of animal origin for drug residues, environmental and microbiological contaminants, additives and fraudulent misrepresentation
- antimicrobial resistance of *Salmonella* spp., campylobacter, *E. coli* and enterocci in meat and milk products
- various zoonotic hazards (variable - planned and implemented annually)

I.1.2 Multi-annual national control plan 2010-2014

The following changes have been made in comparison to the 2007-2009:

- Bluetongue surveillance is no longer conducted to document disease freedom, but to inform the ongoing intervention programme
- Surveillance to inform an eradication programme for BVDV in cattle has been added
- Surveillance of all slaughtered pigs for trichinellosis has been added

II Appendix to Chapter 2

II.1 Three examples to illustrate the proposed classification system

II.1.1 Avian influenza

With the emergence of HPAIV H5N1 in South-East Asia in the past decade and its spread to Europe, policy makers have recognised the need for multidisciplinary surveillance teams that detect a hazard early to limit its spread, clinical effects, and economic losses. The Food and Agricultural Organisation of the United Nations implemented an early warning system for the worldwide integration and exchange of AI surveillance information (Martin et al., 2007). The EU introduced new legislation to accommodate the altered risk. Many countries that have never had a case of HPAIV implemented extensive surveillance system in wild birds and poultry to detect an incursion of HPAIV quickly and enable rapid response. This strategy proved to be successful, as all sporadic HPAIV outbreaks in EU member states could be contained within a few months using classical response measures. However, in other regions of the world, similar measures were not successful. For example in China, Vietnam, Egypt and Indonesia, the disease spread widely despite the implementation of response measures (Domenech et al., 2009). The situation in Vietnam that reported HPAIV for the first time in 2003 is used to illustrate the proposed classification system.

A. Mitigation objective

The current objective of the Vietnamese programme against H5N1 HPAIV is the 'sustained country-wide elimination of the virus' (Sims and Dung, 2009).

B. Surveillance and intervention

After detecting the disease for the first time in 2003, Vietnam implemented a stamping out programme for infected and at risk flocks to control the disease (Domenech et al., 2009). However, culling of 45 million poultry could not eliminate infection and it

became necessary to adapt the strategy. Surveillance information was used to inform the development of a vaccination campaign that aimed at complementing existing measures (Sims and Dung, 2009). The intervention programme includes: 1) rapid identification and response to disease outbreaks, 2) risk-based vaccination, 3) enhanced management, and 4) control of poultry movements, and development of disease-free compartments (Anonymous, 2006b). Surveillance activities for HPAIV in Vietnam include clinical case reporting, surveys on markets and slaughterhouses to improve knowledge of virus circulation, and mapping of temporal and spatial distributions of wild birds (Anonymous, 2006b). Further, surveillance is conducted to assess vaccination protection and to investigate the cause and implement corrective measures if the results are not satisfactory (Sims and Dung, 2009). It is also used to demonstrate whether viruses are still circulating and to assess their antigenic makeup and their distribution. Based on new information that is continuously becoming available, Vietnamese animal health authorities have been modifying the intervention programme to increase its effectiveness.

C. Transition

Vietnam may cease vaccination once the risk of infection has considerably decreased, surveillance and disease reporting systems manage to detect and investigate all cases of suspected HPAIV, and production and marketing methods that are risk factors for virus transmission have been changed (Sims and Dung, 2009).

Conclusion

With respect to HPAIV, Vietnam is currently in Stage III mitigation. After successful eradication, it is expected to move from Stage III to Stage I mitigation and related surveillance.

II.1.2 Salmonella in the EU

The EU regulation 2160/2003 laid the foundation for enhancing food safety by obliging member states to run national control programmes to reduce salmonella in poultry and pigs. Its purpose was to ‘ensure that proper and effective measures are taken to

detect and control salmonella'. It provided a framework for the definition of targets, the approval of mitigation programmes, and the adoption of rules regarding intervention methods and trade. For each target group (breeding flocks, laying hens, broilers, turkeys, breeding and fattening pigs) it was envisaged to conduct a baseline survey, define reduction targets for all member states and to implement national mitigation programmes to reduce prevalence in the EU. The mitigation programme in laying hens is used to illustrate the proposed classification system.

A. Mitigation objective

The two main objectives of the programme were to set Community targets for the reduction of salmonella and to achieve the defined targets by implementing national mitigation programmes.

B. Surveillance and intervention

The primary objective of the baseline survey in laying hens was to estimate the prevalence of *Salmonella* spp. in commercial large-scale holdings to inform the Community targets. Other objectives were to investigate the relative sensitivity of faecal and environmental samples, the role of vaccination and to collect additional epidemiological information such as serotypes and flock sizes (Anonymous, 2006a). The EU decision 2004/665 stipulated requirements regarding the sampling frame, laboratory analysis, data collection, analysis and communication. The results from the baseline survey were used to formulate Community targets and all member states had to submit plans for their national programmes setting out the envisaged intervention measures. After getting the approval from the European Commission, member states have implemented surveillance programmes to detect *Salmonella* spp. and the related interventions following case detection. The EU regulation 1168/2006 outlines the surveillance scheme necessary to 'verify the achievement of the Community target for the reduction of salmonella'. Thus, surveillance data provided during this phase are not only an important element for effective and successful intervention, but are also used to check the progress of the intervention programme.

C. Transition

The results from the baseline survey have been used to define Community targets and to design national mitigation plans for the reduction of salmonella. Member states have implemented these plans and consequently moved to the 'implementation' stage.

Conclusion

The EU mitigation programme for salmonella in laying hens and related surveillance and intervention measures have passed Stage II and are now in Stage III.

II.1.3 Foot-and-mouth disease in Europe

Foot-and-mouth disease was endemic in Europe from the 17th until the mid 20th century. The development of effective vaccines allowed the implementation of vaccination campaigns that reduced the number of FMD outbreaks from almost 900,000 in 1951/52 to 34 between 1977 and 1987 (Kihm, 1990). These vaccination plans were accompanied by surveillance activities on farms, import restrictions and outbreak response measures. In the late 1980s, vaccination was forbidden in Denmark, the UK and Ireland, while the other nine EU member states were still using vaccination. At the same time, evidence accumulated that there were no endemic foci in the EU anymore (Leforban, 1999). Because the EU aimed for an intra-Community market with the free movement of animals and their products, the political pressure for a unified strategy on EU level increased despite reluctance among veterinarians and farmers to abandon the vaccination strategy. The EU decided to implement a FMD vaccination ban in 1992, which ended several decades of vaccination (Leforban, 1999). The cessation of the vaccination programme was only possible, because internal (e.g. vaccine producing laboratories) and external (e.g. illegal trade of animals and animal products) sources of infection were considered to be of negligible risk and high quality veterinary services were in place that enabled the transition to the 'sustainment ' stage (personal communication U. Kihm). A recurrence of FMD would trigger outbreak control measures as laid down in national contingency plans until the re-declaration of freedom from FMD. Hence, FMD in Europe passed all stages in the past 60 years. The

mitigation programme for FMD in Switzerland that suffered its last FMD outbreak in 1980 is used as an example to illustrate the proposed classification system.

A. Mitigation objective

Switzerland is officially free from FMD and aims at sustaining this status over time as stipulated in the Swiss Animal Health Ordinance (SR 916.401).

B. Surveillance and intervention

Foot- and-mouth disease is notifiable, but there is no active surveillance programme in place. A national contingency plan is available that stipulates the response measures to be applied in the event of an outbreak. It lays down specific requirements regarding stamping out activities, hygiene, bio-security, cleaning and disinfection, and quarantine measures in protection and surveillance zones. Furthermore, there are several mobile contingency teams available to cull and dispose of affected animals and clean and disinfect holdings. There are clear emergency reporting mechanisms in place, a transparent organisation and communication network, as well as an animal movement database. Responsibilities and collaboration on regional, national and international level are guaranteed.

C. Transition

In a first phase of a potential outbreak, Switzerland would strictly follow a stamping out policy that would be supported by epidemiological simulation models. If the outbreak response measures failed and the disease spread widely, the situation would be re-assessed and a change in strategy towards a vaccination policy considered (Perler, 2001).

Conclusion

Switzerland is an example of a country that has been FMD free for many years after successful eradication of disease and aims at sustaining the free status (Stage I). This includes surveillance activities to ensure that an incursion can be recognised and outbreak response measures to avoid spread of the disease within the country in case of incursion.

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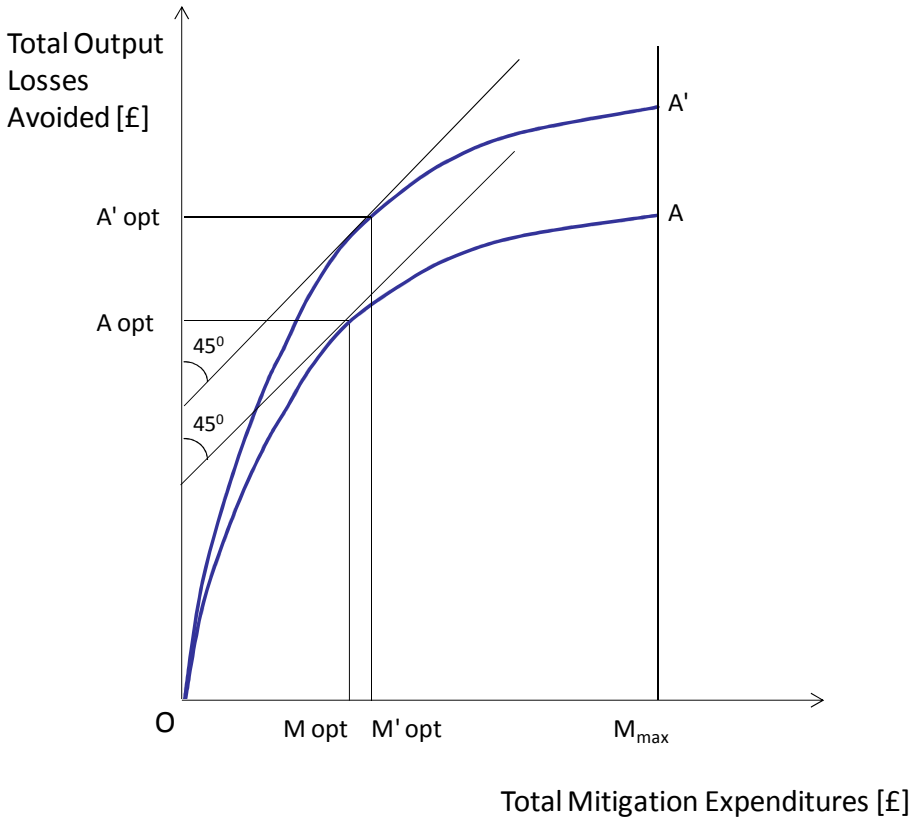
III Appendix to Chapter 3

III.1 Consequences of changing values or mitigation technology

Appendix Figure III-1 illustrates how the economic optimum changes from $A_{opt}M_{opt}$ on production function OA to $A'_{opt}M'_{opt}$ on production function OA' with increased P_A or improved mitigation technology. Now a higher value of production losses is avoided for a higher expenditure on mitigation resource use.



Appendix Figure III-1: Optimal economic efficiency for disease mitigation changes with mitigation technology and price inputs.

IV Appendix to Chapter 4

IV.1 General information

Appendix Table IV-1: lists the main surveillance and intervention steps used to calculate surveillance and intervention costs. Subsequent tables listing surveillance and intervention steps refer to the numbers used in this table.

Appendix Table IV-1: Main surveillance and intervention steps used to structure and calculate surveillance and intervention costs.

Surveillance step	Intervention step
1) Planning	1) Planning
2) Preparation	2) Preparation
3) Supervision	3) Supervision
4) Sampling	4) Implementation
5) Laboratory testing	5) Data collection, transfer, and administration
6) Data collection, transfer & administration	6) Data analysis and interpretation
7) Data analysis and interpretation	7) Dissemination & communication of results
8) Dissemination & communication of results	8) Revision and adaptation of running programme
9) Revision and adaptation of running programme	

The distributions used in @Risk for Excel are the following:

- 'Normal' = normal distribution with mean and standard deviation in brackets
- 'Lognorm' = lognormal distribution with the mean and standard deviation of the logarithm in brackets
- 'Logistic' = logistic distribution with location parameter alpha and scale parameter beta in brackets
- 'Pert' = Pert distribution with minimum, most likely and maximum values in brackets
- 'Uniform' = uniform distribution with minimum and maximum values in brackets

IV.2 Calculations, input data and detailed results for the bluetongue virus serotype 8 (BTV-8) programme

IV.2.1 Calculation of surveillance costs

Input data used to calculate serological and entomological BTV-8 surveillance cost in Switzerland can be found in Appendix Tables IV-2 and IV-3.

Appendix Table IV-2: Main surveillance steps (SS), surveillance activities, cost categories (CC; LB=labour, OE=operations and expenses), job position (FVO=Federal Veterinary Office) or price/unit, and number of working hours or input units used to calculate serological surveillance cost for BTV-8 in Switzerland. ELISA=enzyme-linked immunosorbent assay, PCR=polymerase chain reaction, CHF=Swiss francs.

SS	Activity	CC	Job position or price/unit	No of working hours or units for 2009-2012
1)	Sample size estimation	LB	FVO researcher	40
	Specification of surveillance activities	LB	FVO researcher	120
	Budget calculation	LB	FVO researcher	40
2)	Development of sampling plan	LB	FVO researcher	40
	Preparation of forms	LB	FVO researcher	20
	Ordering sampling material	LB	FVO doctoral student	20
	Assembling sampling material	LB	FVO doctoral student	20
	Sending sampling material to cantons	OE	250 CHF (Lump sum)	1
3)	Supervision of surveillance activities	LB	FVO researcher	20
4)	Call-out fee	OE	0 CHF/visit[1]	---
	Blood sampling cattle by veterinarian (incl. material)	OE	8.50 CHF/sample taken	*2009:* 2,092 *2010-2012:* Pert(200,250,300)
	Postage to send samples to laboratory	OE	25 CHF/holding	*2009:* 250 2010-12: Pert(200,250,300)
5)	ELISA testing (incl. data recording)	OE	16 CHF/sample	*2009:* 2,092 *2010-2012:* Pert(2000,2100,2200)
	PCR testing of ELISA positive samples (incl. sequencing)	OE	Uniform(150,250) CHF/sample	*2009:* 182 *2010-12:* Pert(2000,2100,2200)·$Prop_{SP}$[2]
6)	Electronic collation of data	LB	FVO researcher	20
	Standardisation of data into electronic format	LB	FVO researcher	20
	Quality control of collected data	LB	FVO researcher	40
7)	Descriptive statistics	LB	FVO researcher	20
	Exploratory data analysis	LB	FVO researcher	20
	Collation and interpretation of results	LB	FVO researcher	20

Appendix Table IV-2 continued

SS	Activity	CC	Job position or price/unit	No of working hours or units for 2009-2012
8)	Creation/update of websites	LB	FVO researcher	10
	Writing of annual report	LB	FVO researcher	40
	Create layout of annual report	LB	FVO communication	10
	Reporting to the European Bluetongue net	LB	FVO researcher	10
	Translation	LB	FVO staff	20
9)	Interim report with discussion	LB	FVO researcher	40

[1] Integrated into intervention costs, see Chapter 4

[2] $Prop_{SP}$ = proportion of seropositive animals, see Chapter 4

Appendix Table IV-3: Main surveillance steps, surveillance activities, cost categories (CC; LB=labour, OE=operations and expenses), job position (FVO=Federal Veterinary Office) or price/unit, and number of working hours or input units used to calculate annual entomological surveillance cost for BTV-8 in Switzerland. CHF=Swiss Francs.

SS	Activity	CC	Job position or price/unit	No of working hours or units
1)	Specification of surveillance activities	LB	FVO researcher	10
	Budget calculation	LB	FVO researcher	10
2)	Development of sampling plan	LB	FVO researcher	10
	Ordering sampling material (traps)	LB	FVO doctoral student	10
	Assembling sampling material (traps)	LB	FVO doctoral student	20
3)	Supervision of surveillance activities	LB	FVO researcher	10
4)	Holding visit (twice) and installation of traps and dismantling (incl. cleaning and storage)	LB	FVO doctoral student	40
	Collecting midges (weekly during 34 weeks)	LB	Agricultural employee	10
	Sending midges to laboratory	OE	5 CHF/sample	646
5) & 6)	Identification of midges (incl. data recording)	LB	20,000 CHF (lump sum)	1
7)	Descriptive statistics	LB	FVO researcher	10
	Collation and interpretation of results	LB	FVO researcher	20
8)	Report writing for public, cantonal veterinary services, and European Bluetongue net	LB	FVO researcher	10
	Translation	LB	FVO staff	10
9)	Revision of sampling design	LB	FVO researcher	10

IV.2.2 Calculation of intervention costs for BTV-8 in Switzerland

The total number of holdings visited *(N_{HV})* for vaccination in 2008 and 2009 to calculate intervention cost using the inputs in Appendix Table IV-4 was calculated as follows:

$$N_{HV2008} = VCOV \cdot (N_{HC} \cdot 2 + N_{HSG})$$

$$N_{HV2009} = VCOV \cdot (0.50 \cdot N_{HC} \cdot 2 + N_{HC} \cdot 0.50 + N_{HS})$$

where *VCOV* is the vaccination coverage, N_{HC} number of holdings with cattle and optionally sheep or goats (= 43,267), N_{HSG} number of holdings with sheep and/or goats, but no cattle (=10,023), and N_{HS} number of holdings with sheep (=7,457).

The total number of vaccines given *(N_V)* was calculated as follows:

$$N_V = N_S \cdot VCOV \cdot N_D$$

where N_S is the number of animals suitable for vaccination and N_D the respective number of vaccine doses applied per animal. In 2008, 1,389,108 cattle, 334,100 sheep and 81,316 goats were suitable for vaccination; in 2009, 1,449,134 cattle and 328,308 sheep were suitable for vaccination.

For the retrospective and prospective baseline scenarios, the price per dose of vaccine and registration cost were assumed to be the same as in the implemented programme, but the call-out fee for the vaccination and the price of injecting the vaccine were changed to a regular call out fee (PCO_R) and injection price (PI_R), respectively (Appendix Table IV-5).

Appendix Table IV-4: Main intervention steps (IS), intervention activities, cost categories (CC; LB=labour, OE=operations and expenses), job position (FVO=Federal Veterinary Office, CVS=Cantonal Veterinary Service) or price/unit, and number of working hours or input units used to calculate intervention cost for BTV-8 in Switzerland. CHF=Swiss francs

IS	Activity	CC	Sub-category or price/unit	No of working hours or units	
				2008	2009
1)	Description of problem & literature research	LB	FVO researcher	89	89
	Epidemiological modelling work	LB	FVO post doc	310	852
	CVS conference (working group discussions)	LB	FVO researcher, FVO head and CVS head	736	368
	CVS conference travelling cost	OE	64 CHF/person	56	28
	Outline intervention strategy, identify detailed intervention activities, describe expected outcomes	LB	FVO researcher	89	89
	Budget calculation	LB	9,680 CHF for 2008 and 6,776 CHF for 2009 (lump sums)	1	1
2)	Coordination of activities with collaborators	LB	FVO researcher	178	178
	Formulation of vaccination lists	LB	FVO researcher	89	89
	Establishment and administration of electronic registration system for vaccinated animals	OE	450,000 CHF for 2008 and 250,000 CHF for 2009 (lump sums)	1	1
	Ordering of vaccines	LB	FVO researcher	17	17
	Distribution of vaccines to CVS	LB	FVO researcher	178	125
	Preparation of information letters & brochures	LB	FVO researcher	267	267
	Translation thereof	LB	FVO staff	142	142
	Supervision of intervention activities	LB	FVO researcher	89	89
3)	Call-out fee	OE	Uniform(20,25) CHF/visit	86,901[1]	49,546[1]
4)	Cost of vaccines	OE	1 CHF/dose	2,874,270[1]	1,730,120[1]
	Injection of vaccine (incl. material)	OE	4 CHF/injection	2,874,270[1]	1,730,120[1]
	Registration of vaccination	OE	2 CHF/holding	86,901[1]	49,546[1]
	Quality control of collected data, database administration, maintenance & adaptations	LB	FVO researcher	726	588
5)	Descriptive statistics	LB	FVO researcher	89	89
6)	Collation and interpretation of results	LB	FVO researcher	89	89

Appendix Table IV-4 continued

IS	Activity	CC	Sub-category or price/unit	No of working hours or units	
				2008	2009
7)	BT information movie for stakeholders	LB	FVO communication	82	33
	BT information movie: production and distribution cost	OE	50,360 for 2008 and 13,700 for 2009 (lump sums)	1	1
	Information leaflets for animal owners and vets	LB	FVO communication	33	33
	Information leaflets for animal owners and vets, production and distribution costs	OE	23,000 CHF for 2008 and 76,000 CHF for 2009 (lump sums)	1	1
	Media releases, blogs, journal articles, reports	LB	FVO communication	124	66
	Talks with farmers	LB	FVO communication	21	21
	Information desk	LB	FVO communication	17	8
	Internet: Creation and updating of websites	LB	FVO communication	66	41
	Letters to CVS and presentation at CVS conference	LB	FVO researcher	267	267
	Translations	LB	FVO staff	142	142
	Information events, provision of information by phone, written replies to farmers, veterinarians, jurists, politicians, general public	LB	FVO researcher	712	1,139

[1] The numbers of holdings visited and vaccines applied were calculated based on FVO and national census data, see above

IV.2.3 Calculation of BTV-8 disease costs

The output losses due to mortality *(L_M)*, abortion *(L_A)*, prolonged calving interval *(L_{PCI})*, premature culling *(L_{PMC})*, reduced milk yield *(L_{RMY})*, wool reduction *(L_{WR})*, reduced weight gain *(L_{RWG})*, and export *(L_X)* as well as expenditures for export *(E_X)*, palliative treatment *(E_{PT})*, and cantonal response measures for suspect and confirmed cases *(E_{CVS})* were calculated as follows. All relevant input data are listed in Appendix Tables IV-5 and IV-6.

$$L_M = \sum N_{X1} \cdot Mt_{Y1} \cdot (MV_{X1} + RC_{Y1})$$

Where *N* is the number of animals on infected farms, *X1* the affected animal categories (dairy cows for commercial milk production, dairy heifers, dairy calves, dairy cows for non-commercial milk production, suckler cows, beef cattle, beef calves, breeding bulls, ewes, lambs, dairy ewes and rams), *Mt* the mortality rate, *Y1* the respective animal groups, *MV* the market value of the animals and *RC* the rendering costs.

$$L_A = \sum N_{X2} \cdot Mb_{Y2} \cdot PropA_{Y2} \cdot CA_{X2}$$

Where *X2* stands for cattle and sheep categories suffering abortion, *Mb* the morbidity rate, *Y2* the respective animal groups, *PropA* the proportion of morbid animals that have an abortion, and *CA* for costs per abortion.

$$L_{PCI} = N_{DC} \cdot Mb_{AC} \cdot PropPCI_{DC} \cdot d \cdot CPCI_{DC}$$

Where *DC* stands for dairy cows for commercial milk production, Mb_{AC} the morbidity in adult cattle (AC), $PropPCI_{DC}$ the proportion of morbid dairy cows for commercial milk production that have a prolonged calving interval, *d* the number of days of postponed gestation and $CPCI_{DC}$ the costs per day of a prolonged calving interval in dairy cows for commercial milk production.

$$L_{PMC} = \sum N_{X3} \cdot Mb_{Y3} \cdot PropPMC_{Y3} \cdot (MV_{X3} - SV_{X3})$$

Where *X3* stands for the animal categories prematurely culled (dairy cows for commercial milk production, dairy heifers, dairy cows for non-commercial milk

production, suckler cows, breeding bulls, ewes, and dairy ewes), *Y3* for the respective animal groups, *PropPMC* for the proportion of morbid animals that are culled prematurely and *SV* for slaughter value.

$$L_{RMY} = N_{DC} \cdot Mb_{DC} \cdot RMY_{DC} \cdot MY_{DC} \cdot PM + N_{NCC} \cdot Mb_{NCC} \cdot RMY_{NCC} \cdot MY_{NCC} \cdot PMR$$

Where *RMY* stands for the relative reduction in milk yield in morbid cows, *MY* for milk yield, *PM* for the production price per kg milk, *NCC* for dairy cows for non-commercial milk production, and *PMR* for the price per kg milk replacer.

$$L_{WR} = (N_{EW} + N_{DE}) \cdot Mb_{AS} \cdot WY \cdot PW$$

Where *EW* stands for ewes, *DE* for dairy ewes, Mb_{AS} the morbidity rate of adult sheep, *WY* the wool yield per sheep and *PW* the price per kg wool. It is assumed that the wool from all morbid animals cannot be used, as they render fragile wool (Gunn et al., 2008).

$$L_{RWG} = N_{AC} \cdot Mb_{AC} \cdot PropWL_{AC} \cdot ECG$$

Where *PropWL* stands for the proportion of morbid cattle showing weight loss and *ECG* the expenditures for compensatory growth per affected animal.

The number of export cattle in the retrospective and prospective comparative scenarios was not perceptibly affected by BT disease and related mitigation measures. For the baseline scenarios, the number of cattle destined for export that could not be exported (N_{NCX}) was estimated as follows. Assuming that there would be two suspect cases per confirmed case, the number of confirmed cases (N_{CC}) and suspect cases (N_{SC}) per scenario was:

$$N_{CC} = N_{IH} \cdot PropCC$$

$$N_{SC} = N_{CC} \cdot 2$$

Where N_{IH} is the number of infected holdings and *PropCC* the proportion of confirmed cases per total number of infected.

Then, the total number of movement ban days (N_{BD}) for the whole of Switzerland per year and scenario was calculated:

$$N_{BD} = N_{CC} \cdot t_{BCC} + N_{SC} \cdot t_{BSC}$$

Where t_{BCC} and t_{BSC} are the duration of movement bans in days for confirmed and suspect cases, respectively. Dividing N_{BD} by 365 produced the number of holdings that were banned from export (N_{BH}) for the duration of a whole year. This figure was taken to calculate the proportion of banned holdings per year per total holdings with cattle (PropBH), which was then used to estimate N_{NCX} and L_X:

$$PropBH = N_{BH} \cdot N_{HC}$$

$$N_{NCX} = PropBH \cdot N_{DCX}$$

$$L_X = N_{NCX} \cdot L_{NCX}$$

Where N_{DCX} is the number of cattle destined for export and L_{NCX} the export loss per animal not exported.

Export expenditures accrued from the sum of expenditures for vaccinating (E_{XV}) or blood sampling and testing (E_{XT}) of export cattle that were not already vaccinated. Non-vaccinated animals are all animals on non-vaccinated holdings or young animals on vaccinated holdings. For all scenarios, the number of export cattle to be vaccinated or tested (N_{CXVT}) was calculated by multiplying the number of export cattle by (1-VCOV). The E_{XV} and E_{XT} were calculated as follows:

$$E_{XV} = N_{CXVT} \cdot PropV \cdot N_D \cdot (PCO_R + PV + PI_R)$$

$$E_{XT} = N_{CXVT} \cdot PropT \cdot (PCO_R + PST_R + PTX)$$

Where *PropV* and *PropT* are the proportion of N_{CXVT} vaccinated and tested, respectively, *PV* is the price per vaccine dose as in the section intervention cost, PST_R the regular price of a blood sample taken by a veterinarian, and *PTX* the price for laboratory testing for export.

The E_{PT} were:

$$E_{PT} = \sum N_{Y4} \cdot Mb_{Y4} \cdot PropRVT \cdot PVT_{Y4}$$

Where *Y4* stands for adult cattle, adult sheep, calves or lambs, *PropRVT* the proportion of morbid animals receiving veterinary treatment, and *PVT* the price of veterinary treatment.

The expenditures of the CVS for a suspect case (ESC_{CVS}) were calculated as follows:

$$ESC_{CVS} = N_{SC} \cdot [PCO_R + 5 \cdot PST_R + 5 \cdot PPCR + PIT + (H_{MBP} + H_{EI} + H_{LMB}) \cdot w_{CVS}]$$

Where *PPCR* is the price of PCR testing for suspect and confirmed holdings, *PIT* the price of the insecticide treatment per holding, H_{MBP} the number of working hours to issue the movement ban provision, H_{EI} the number of working hours for the epidemiological investigation, H_{LMB} the number of working hours to lift the movement ban, and w_{CVS} the wage rate per hour of the CVS personnel.

The additional expenditures of the CVS for a confirmed case (ECC_{CVS}) were calculated as follows:

$$ECC_{CVS} = N_{CC} \cdot [PCO_R + N_{NV} \cdot (PST_R + PELISA + PropSP \cdot PPCR)]$$

Where *PELISA* is the price of ELISA testing and *PropSP* the proportion of seropositive samples as in the section surveillance cost.

Appendix Table IV-5: Input data used to estimate BTV-8 related disease costs in Switzerland. Input units in brackets (CHF=Swiss Francs).

Input	Notation	Value or distribution	Description/Source
Mortality rate adult cattle (year^{-1})	$Mt_{adult\ cattle}$	Pert(0.0011,0.0013,0.0015)	Mean BTV-8 mortality rate for cattle from OIE WAHID[1] data for all European countries for the years 2007 and 2008 =most likely (ML) value, lower and upper limit: -/+15%
Mortality rate calves (year^{-1})	Mt_{calves}	$Mt_{adult\ cattle} \cdot 3.5$	Mounaix et al. (2008): Calves found to have 3-4 times higher mortality than adult cattle
Mortality rate adult sheep (year^{-1})	$Mt_{adult\ sheep}$	Pert(0.03,0.035,0.04)	Mean BTV-8 mortality rate for sheep from OIE WAHID[1] data for all European countries for the years 2007 and 2008 =ML value, lower and upper limit: -/+15%
Mortality rate lambs (year^{-1})	Mt_{lambs}	$Mt_{adult\ sheep}/3$	Mounaix et al. (2008): Lambs found to have three times lower mortality than adult sheep
Rendering costs adult cattle (CHF)	$RC_{adult\ cattle}$	Uniform(210,315)	Estimate derived from price list of waste disposal company 'TMF Bazenheid'[2]
Rendering costs calves (CHF)	RC_{calves}	Uniform(50,100)	Ditto
Rendering costs adult sheep or lambs (CHF)	$RC_{adult\ sheep}=RC_{lambs}$	Uniform(25,50)	Ditto
Proportion of morbid adult cattle culled prematurely	$PropPMC_{adult\ cattle}$	Pert(0.026,0.03,0.035)	Mean value from Velthuis et al. (2010) for the years 2006 and 2007= most likely value, lower and upper limit: -/+15%
Proportion of morbid adult sheep culled prematurely	$PropPMC_{adult\ sheep}$	Pert(0.013,0.015,0.017)	Ditto
Morbidity rate adult cattle (year^{-1})	$Mb_{adult\ cattle}$	Pert(0.019,0.023,0.027)	Mean BTV-8 morbidity rate for cattle from OIE WAHID[1] data for all European countries for the years 2007 and 2008 =upper value; average Elbers et al. (2008) and Conraths et al. (2009)=ML value; ML minus difference between ML and upper value=lower value
Morbidity rate calves (year^{-1})	Mb_{calves}	$Mb_{adult\ cattle}/3$	Mounaix et al. (2008): Calves found to have three times smaller morbidity than adult cattle

Appendix Table IV-5 continued

Input	Notation	Value or distribution	Description/Source
Morbidity rate adult sheep (year^{-1})	$Mb_{adult\ sheep}$	Pert(0.059,0.060,0.061)	Mean BTV-8 morbidity rate for sheep from OIE WAHID[1] data for all European countries for the years 2007 and 2008 =upper value; average Conraths et al. (2009) for the years 2006 and 2007=ML value; ML minus difference between ML and upper value=lower value
Morbidity rate lambs (year^{-1})	Mb_{lambs}	$Mb_{adult\ sheep}$/6	Mounaix et al. (2008): Lambs found to have six times smaller morbidity than adult sheep
Proportion of morbid adult cattle with abortion	$PropA_{adult\ cattle}$	Pert(0.035,0.041,0.047)	Mean value from Velthuis et al. (2010) for the years 2006 and 2007= most likely value, lower and upper limit: -/+15%
Proportion of morbid adult sheep with abortion	$PropA_{adult\ sheep}$	Pert(0.022,0.026,0.03)	Ditto
Proportion of morbid dairy cows for commercial milk production with prolonged calving interval	$PropPCI_{dairy\ cows\ for\ commercial\ milk\ production}$	Pert(0.38,0.45,0.52)	Ditto
Costs per abortion dairy cows for commercial milk production or dairy cow for non-commercial milk production (CHF)	$CA_{dairy\ cows\ for\ commercial\ milk\ production}$=$CA_{dairy\ cows\ for\ non-commercial\ milk\ production}$	Normal(882.12, 504.97)	Häsler et al. (2006)
Costs per abortion suckler cow (CHF)	$CA_{suckler\ cow}$	Normal(794,454)	Häsler et al. (2006)
Costs per abortion ewe or dairy ewe (CHF)	CA_{ewe}=$CA_{dairy\ ewe}$	253	=Value of lamb lost · average number of lambs per ewe[3]
No of days postponed gestation	d	Pert(21,42,63)	Expert estimate: 1, 2 or 3 cycles of 21 days each, most likely 2 cycles
Costs per day of prolonged calving interval in dairy cows for commercial milk production (CHF)	$CPCI_{dairy\ cows\ for\ commercial\ milk\ production}$	Pert(5,6,7)	Stocker (2008) and Swissgenetics (www.swissgenetics.ch)
Relative reduction in milk yield in morbid dairy cows for commercial and non-commercial milk production (year^{-1})	$RMY_{dairy\ cows\ for\ commercial\ milk\ production}$ =$RMY_{dairy\ cows\ for\ non-commercial\ mik\ production}$	Pert(0.0005,0.0248, 0.05)	Expert estimate based on Gunn et al. (2008), Heimberg, P. (2008), Mounaix et al. (2008), Velthuis et al. (2010)

Appendix Table IV-5 continued

Input	Notation	Value or distribution	Description/Source
Proportion of morbid adult cattle showing weight loss	$PropWL_{adult\ cattle}$	Pert(0.077,0.09,0.108)	9% value from Gunn et al. (2008) = most likely value, lower and upper limit: -/+15%
Expenditures compensatory growth per animal (CHF)	ECG	Pert(8,8.5,9)	Expert estimate based on Velthuis et al. (2010)
Proportion of morbid animals receiving veterinary treatment	PropRVT	Pert(0.6,0.7,0.8)	Expert estimate based on information collected from Swiss veterinary practitioners
Regular call-out fee veterinarian (CHF)	PCO_R	Uniform(30,35)	Ditto
Regular price for injection by veterinarian (incl. material) (CHF)	PI_R	Pert(5.5,6,6.5)	Ditto
Regular price of blood sample taken by a veterinarian (incl. material) (CHF)	PST_R	Uniform(16,20)	Ditto
Price veterinary treatment adult cattle (CHF)	$PVT_{adult\ cattle}$	Uniform(200,300)	Expert estimate based on information collected from Swiss veterinary practitioners. Includes holding visit, material used, veterinary medicines, administrative and labour costs
Proportion of confirmed cases per total number of infected holdings	PropCC	Uniform(0.0075,0.048)	Expert estimate based on the proportion of confirmed cases per total number of infected holdings derived from IVI[4] data (0.75% in 2008 and 4.8% in 2009)
Duration of movement ban for confirmed cases (d)	t_{BCC}	75	Swiss legislation
Duration of movement ban for suspect cases (d)	t_{BSC}	5	Ditto

Appendix Table IV-5 continued

Input	Notation	Value or distribution	Description/Source
Export loss per animal not exported (CHF)	L_{NCX}	Pert(0,12350,22711)	Expert estimate based on an independent study conducted by P. Bosshard (unpublished data) to investigate the impact of a reduction of live cattle exports on domestic market prices. Assuming that a decrease in export of live cattle of 50-100% would cause a price reduction on the domestic cattle market of 10-15%, he estimated the mean economic loss for the years 2010 to 2012 per animal not exported at 22,711 CHF. This value was taken as the upper limit.
Proportion of export cattle tested	PropT	0.86	Estimate based on IVI[4] data from 2008
Proportion of export cattle vaccinated	PropV	0.14	Ditto
Price for laboratory testing for export (CHF)	PTX	55	Derived from IVI[4] data
Price polymerase chain reaction testing (CHF)	PPCR	Uniform(100,150)	Ditto
Price of insecticide treatment per holding (CHF)	PIT	Uniform(90,120)	Federal Veterinary Office
No of working hours to issue movement ban provision	H_{MBP}	Pert(1.5,2,2.5)	CVS Geneva
No of working hours for epidemiological investigation	H_{EI}	Uniform(3,5)	CVS Geneva
No of working hours to lift movement ban	H_{LMB}	Uniform(1,2)	CVS Geneva

[1] OIE=World Organisation for Animal Health, WAHID=World Animal Health Information Database (www.oie.int)

[2] http://www.tmf.ch Price for collection of slaughter waste: 210 CHF/ton for deliveries between 0 and 4999kg.

[3] Mean lamb value derived from data from Swiss Farmer's Union (www.sbv-usp.ch) and mean number of lambs per ewe (=1.545) calculated from the annual reports of the Swiss Sheep Breeders Association (www.caprovis.ch)

[4] IVI= Institute of Virology and Immunoprophylaxis (www.ivi.admin.ch)

Appendix Table IV-6: Market prices and production data used to estimate bluetongue virus serotype 8 disease costs in Switzerland. CHF=Swiss francs.

	Value or distribution			Source
	2008	**2009**	**2010-2012**	
Market value dairy cow for commercial milk production (CHF)	3,232	3,064	3,064	SFU[1]
Market value dairy heifer (CHF)	2,636	2,523	2,523	SFU[1]
Market value dairy calf (CHF)	1,150	1,117	1,117	SFU[1]
Market value cow for non-commercial milk production (CHF)	2,262	2,145	2,145	SFU[1]
Market value suckler cow (CHF)	2,779	2,718	2,718	SFU[1]
Market value breeding bull (CHF)	4,011	3,931	3,957	SFU[1]
Market value ewes (CHF)	436	415	424	SFU[1]
Market value rams (CHF)	622	508	566	SFU[1]
Slaughter value dairy cow for commercial milk production (CHF)	2,108	1,963	2,031	SFU[1]
Slaughter value dairy heifer (CHF)	1,796	1,880	1,773	SFU[1]
Slaughter value dairy cow for non-commercial milk production (CHF)	2,108	1,963	2,031	SFU[1]
Slaughter value suckler cow (CHF)	2,108	1,963	2,031	SFU[1]
Slaughter value breeding bull (CHF)	2,631	2,390	2,533	SFU[1]
Slaughter value adult sheep (CHF)	170	161	163	SFU[1]
Value beef cattle (CHF)	2,059	1,898	2,000	SFU[1]
Value beef calves (CHF)	1,390	1,385	1,419	SFU[1]
Value lamb (CHF)	256	230	245	SFU[1]
Milk yield dairy cow (kg/year)	6,367	Uniform(6288, 6367)	Uniform(6288, 6367)	SMS[2]
Wool yield sheep (kg/year)	Pert(1.8,2,2.2)	Pert(1.8,2,2.2)	Pert(1.8,2,2.2)	SSBA[3]
Production price cow milk (CHF/kg)	0.78	0.65	Logistic(0.72,0.03)	FOA[4]
Production price wool (CHF/kg)	0.83	0.50	0.50	SSBA[3]
Price milk replacer (CHF/kg)	Pert(0.7,0.74,0.78)	Pert(0.7,0.74,0.78)	Pert(0.7,0.74,0.78)	UFA[5]

[1] Swiss Farmers' Union, http://www.sbv-usp.ch/en/

[2] Swiss Milk Statistics, http://www.tsmtreuhand.ch/statistiken.htm

[3] Swiss Sheep Breeders Association, http://szv.caprovis.ch

[4] Federal Office for Agriculture, http://www.blw.admin.ch/

[5] Union des Fédérations Agricoles, http://www.ufa.ch

IV.2.4 Economic assessment of BTV-8 surveillance and intervention – detailed results

Appendix Table IV-7: Discounted serological BTV-8 surveillance cost calculated for Switzerland for the years 2010-12 for the prospective baseline scenario 1 (PBS1), prospective baseline scenario 2 (PBS2), and prospective comparative scenario (PCS) [in 1000 CHF].

Year	2010			2011			2012		
	PBS1	PBS2	PCS	PBS1	PBS2	PCS	PBS1	PBS2	PCS
1) Sampling	2.13	21.26	21.26	2.05	20.54	20.54	1.98	19.84	19.84
2) Preparation	0.81	8.14	8.14	0.79	7.87	7.87	0.76	7.60	7.60
3) Supervision	0.21	2.13	2.13	0.21	2.05	2.05	0.20	1.98	1.98
4) Sampling									
mean	2.33	28.72	23.29	2.25	27.75	22.50	2.17	26.81	21.74
5th percentile	2.24	27.12	22.39	2.16	26.20	21.63	2.09	25.31	20.90
95th percentile	2.42	30.36	24.19	2.34	29.34	23.38	2.26	28.34	22.59
5) Laboratory testing									
mean	6.78	67.77	67.77	6.55	65.48	65.48	6.33	63.26	63.26
5th percentile	5.95	59.48	59.48	5.75	57.46	57.46	5.55	55.52	55.52
95th percentile	7.63	76.31	76.31	7.37	73.73	73.73	7.12	71.23	71.23
6) Data collection, transfer and administration	0.85	8.50	8.50	0.82	8.21	8.21	0.79	7.94	7.94
7) Analysis and interpretation of data	0.64	6.38	6.38	0.62	6.16	6.16	0.60	5.95	5.95
8) Dissemination & communication of results	0.89	8.94	8.94	0.86	8.64	8.64	0.84	8.35	8.35
9) Improvement & adaptation of project	0.43	4.25	4.25	0.41	4.11	4.11	0.40	3.97	3.97
Total									
mean	**15.07**	**156.1**	**150.7**	**14.56**	**150.8**	**145.6**	**14.06**	**145.7**	**140.6**
5th percentile	**14.21**	**147.5**	**142.1**	**13.73**	**142.5**	**137.3**	**13.27**	**137.7**	**132.7**
95th percentile	**15.94**	**165.0**	**159.4**	**15.40**	**159.4**	**154.0**	**14.88**	**154.0**	**148.8**

Appendix Table IV-8: BTV-8 intervention cost calculated for Switzerland for the years 2008-12 for the retrospective baseline scenario (RBS), retrospective comparative scenario (RCS), prospective baseline scenario 1 (PBS1), prospective baseline scenario 2 (PBS2), and prospective comparative scenario (PCS) [in million CHF].

	2008		2009		2010[1]			2011[1]			2012[1]		
Intervention step	**RBS**	**RCS**	**RBS**	**RCS**	**PBS1**	**PBS2**	**PCS**	**PBS1**	**PBS2**	**PCS**	**PBS1**	**PBS2**	**PCS**
1) Planning	0.11	0.14	0.11	0.13	0.11	0.07	0.09	0.10	0.07	0.09	0.10	0.07	0.09
2) Preparation	0.25	0.54	0.17	0.34	0.06	0.14	0.28	0.06	0.14	0.26	0.05	0.13	0.25
3) Supervision	0.004	0.01	0.004	0.01	0.004	0.004	0.01	0.004	0.004	0.01	0.004	0.004	0.01
4) Vaccination													
mean	8.65	16.50	5.18	9.83	0	5.01	9.53	0	4.84	9.21	0	4.67	8.90
5th percentile	8.30	16.30	4.97	9.72		4.80	9.42		4.64	9.10		4.48	8.80
95th percentile	9.01	16.70	5.40	9.94		5.21	9.64		5.04	9.31		4.87	9.00
5) Data collection, transfer & administration	0	0.08	0	0.07	0	0	0.06	0	0	0.06	0	0	0.06
6) Data analysis & interpretation	0	0.02	0	0.02	0	0	0.02	0	0	0.02	0	0	0.02
7) Dissemination & communication	0.20	0.23	0.26	0.28	0.18	0.21	0.24	0.18	0.20	0.23	0.17	0.19	0.22
Total													
mean	**9.22**	**17.52**	**5.72**	**10.67**	**0.35**	**5.44**	**10.23**	**0.34**	**5.25**	**9.88**	**0.33**	**5.07**	**9.54**
5th percentile	**8.86**	**17.33**	**5.51**	**10.56**		**5.23**	**10.12**		**5.05**	**9.77**		**4.88**	**9.44**
95th percentile	**9.58**	**17.72**	**5.94**	**10.78**		**5.64**	**10.34**		**5.45**	**9.98**		**5.26**	**9.64**

[1] Prospective values are discounted

Appendix Table IV-9: Detailed BTV-8 disease costs calculated for Switzerland for the years 2008-12 for the retrospective baseline scenario (RBS), retrospective comparative scenario (RCS), prospective baseline scenario 1 (PBS1), prospective baseline scenario 2 (PBS2), and prospective comparative scenario (PCS) [in 1000 CHF].

	2008		2009		2010[1]			2011[1]			2012[1]		
Disease costs	**RBS**	**RCS**	**RBS**	**RCS**	**PBS1**	**PBS2**	**PCS**	**PBS1**	**PBS2**	**PCS**	**PBS1**	**PBS2**	**PCS**
Losses due to													
Mortality													
mean	7,017.36	1,121.13	1,925.03	162.65	3,543.12	2,103.52	243.78	2,587.49	1,427.07	643.41	2,505.66	1,406.65	621.65
5th percentile	6,529.17	1,037.20	1,784.15	145.42	3,295.17	1,952.33	220.71	2,403.10	1,323.03	592.28	2,327.66	1,303.37	572.36
95th percentile	7,501.25	1,206.36	2,065.46	181.60	3,792.00	2,256.01	267.94	2,773.15	1,533.18	695.47	2,683.74	1,509.78	671.96
Abortion													
mean	385.74	61.61	108.96	9.18	199.16	118.23	13.67	145.44	80.25	36.18	140.86	79.08	34.96
5th percentile	109.65	17.44	29.91	2.50	55.52	32.93	3.85	40.33	22.29	10.12	39.23	22.09	9.74
95th percentile	668.67	106.73	189.77	16.06	345.76	205.45	23.79	252.68	139.86	62.96	244.89	137.48	60.89
Prolonged calving interval													
mean	833.50	133.11	238.97	20.11	433.13	257.13	29.69	316.45	174.63	78.70	306.38	172.04	76.04
5th percentile	550.19	87.82	157.56	13.17	286.31	169.68	19.49	209.00	115.30	51.86	202.01	113.37	50.04
95th percentile	1,150.38	183.80	329.86	27.94	597.35	354.79	41.20	436.20	241.15	108.56	422.48	237.16	105.08
Premature culling													
mean	251.73	40.22	65.87	5.55	121.52	72.16	8.34	88.75	48.97	22.05	85.94	48.26	21.30
5th percentile	221.32	35.32	57.91	4.82	106.99	63.52	7.27	78.11	43.09	19.36	75.59	42.47	18.72
95th percentile	283.72	45.40	74.29	6.33	136.91	81.30	9.48	100.03	55.25	24.90	96.82	54.37	24.05
Reduced milk yield													
mean	979.45	155.42	236.17	19.89	473.07	280.87	32.44	345.63	190.70	85.98	334.49	187.89	83.07
5th percentile	377.03	59.69	91.13	7.63	180.57	107.11	12.27	132.48	72.90	32.72	127.87	71.57	31.66
95th percentile	1,603.01	254.66	386.67	32.76	782.83	465.44	53.93	570.40	315.43	142.10	551.67	310.60	137.58
Wool reduction													
mean	14.18	2.26	2.45	0.21	4.43	2.63	0.31	3.24	1.78	0.81	3.13	1.76	0.78
5th percentile	13.23	2.03	2.24	0.16	4.11	2.41	0.25	2.98	1.62	0.70	2.89	1.59	0.68
95th percentile	15.15	2.51	2.67	0.26	4.77	2.86	0.37	3.50	1.96	0.91	3.38	1.93	0.88

Appendix Table IV-9 continued

	2008		2009		2010[1]			2011[1]			2012[1]		
Disease costs	**RBS**	**RCS**	**RBS**	**RCS**	**PBS1**	**PBS2**	**PCS**	**PBS1**	**PBS2**	**PCS**	**PBS1**	**PBS2**	**PCS**
Reduced weight gain													
mean	11.21	1.79	3.21	0.27	5.82	3.46	0.40	4.25	2.35	1.06	4.12	2.31	1.02
5th percentile	9.69	1.55	2.77	0.23	5.03	2.98	0.34	3.67	2.03	0.91	3.56	2.00	0.88
95th percentile	12.81	2.05	3.68	0.31	6.65	3.95	0.46	4.86	2.69	1.21	4.72	2.65	1.17
Export													
mean	73.57	0.00	27.45	0.00	40.42	24.03	0.00	29.57	16.26	0.00	28.72	16.10	0.00
5th percentile	5.42	0.00	2.00	0.00	3.09	1.77	0.00	2.23	1.20	0.00	2.16	1.19	0.00
95th percentile	210.08	0.00	79.16	0.00	116.43	69.51	0.00	84.69	47.22	0.00	83.02	46.09	0.00
Expenditures													
Palliative treatment													
mean	3,797.41	606.80	1,088.67	91.86	1,972.93	1,171.32	135.55	1,441.03	794.84	358.26	1,395.31	783.42	346.15
5th percentile	3,143.10	501.50	899.15	75.04	1,631.96	967.97	111.46	1,191.91	656.59	295.63	1,154.26	647.53	285.84
95th percentile	4,516.89	722.59	1,295.92	110.53	2,347.20	1,394.12	162.10	1,712.67	946.49	426.90	1,659.97	931.94	412.35
Export													
mean	282.01	385.45	368.90	78.69	445.91	290.07	76.03	431.03	280.35	73.46	416.45	270.87	70.97
5th percentile	272.80	373.59	356.88	70.81	431.38	280.61	68.43	417.01	271.21	66.08	402.88	262.04	63.84
95th percentile	291.18	397.29	380.86	86.73	460.43	299.52	83.85	445.05	289.45	80.98	429.93	279.66	78.20
Cantonal response													
mean	4,835.47	3,112.77	1,387.12	469.47	2,747.21	1,492.20	694.47	2,007.46	1,012.72	1,836.88	1,942.65	998.03	1,775.79
5th percentile	1,658.06	1,059.83	474.19	161.52	943.00	508.89	238.76	688.32	347.07	627.71	664.07	340.82	604.45
95th percentile	8,055.82	5,225.82	2,308.28	786.42	4,575.16	2,488.44	1,160.81	3,346.72	1,689.24	3,082.67	3,234.66	1,665.92	2,970.01
Total													
mean	**18,484.23**	**5,620.56**	**5,452.77**	**857.88**	**9,946.32**	**5,815.93**	**1,234.68**	**7,370.79**	**4,030.52**	**3,136.77**	**7,135.00**	**3,966.60**	**3,031.74**
5th percentile	**15,009.87**	**3,564.46**	**4,462.45**	**548.18**	**8,027.80**	**4,738.52**	**777.11**	**5,959.98**	**3,298.33**	**1,926.22**	**5,773.75**	**3,252.89**	**1,860.61**
95th percentile	**22,026.25**	**7,744.21**	**6,470.71**	**1,178.77**	**11,894.6**	**6,907.52**	**1,704.39**	**8,799.91**	**4,780.31**	**4,387.15**	**8,510.90**	**4,698.91**	**4,239.13**

[1] Prospective values are discounted

Appendix Table IV-10: Total benefit, difference in intervention cost, margin over intervention cost, difference in surveillance cost and net benefit or net costs resulting from the comparison of the retrospective baseline scenario (RBS) and retrospective comparative scenario (RCS), the prospective baseline scenario 1 (PBS1) and prospective comparative scenario (PCS), and the prospective baseline scenario 2 (PBS2) and PCS [in million CHF].

	Comparison RBS and RCS			Comparison PBS1 and PCS				Comparison PBS2 and PCS			
	2008	2009	Aggregate	2010	2011	2012	Aggregate	2010	2011	2012	Aggregate
Total benefit											
mean	12.86	4.60	17.46	8.75	4.26	4.13	17.15	4.58	0.89	0.93	6.41
5th percentile	8.67	3.54	13.07	6.76	2.31	2.23	13.59	3.40	-0.59	-0.51	3.95
95th percentile	17.10	5.66	21.89	10.79	6.24	6.03	20.73	5.78	2.36	2.36	8.84
Difference intervention cost											
mean	8.30	4.95	13.25	9.87	9.54	9.21	28.62	4.79	4.63	4.47	13.88
5th percentile	7.93	4.73	12.66	9.77	9.43	9.11	28.31	4.58	4.42	4.27	13.27
95th percentile	8.67	5.17	13.84	9.98	9.64	9.31	28.93	5.00	4.83	4.67	14.50
Margin over intervention cost											
mean	4.56	-0.35	4.21	-1.12	-5.27	-5.08	-11.47	-0.21	-3.73	-3.53	-7.47
5th percentile	0.35	-1.43	-0.22	-3.12	-7.23	-6.98	-15.06	-1.41	-5.23	-4.99	-10.00
95th percentile	8.81	0.73	8.68	0.93	-3.29	-3.18	-7.87	1.00	-2.25	-2.10	-4.97
Difference surveillance cost											
mean	0.00	-0.01	-0.01	0.14	0.13	0.13	0.39	-0.01	-0.01	-0.01	-0.02
5th percentile	0.00	-0.01	-0.01	0.13	0.12	0.12	0.37	-0.01	-0.01	-0.01	-0.02
95th percentile	0.00	-0.01	-0.01	0.14	0.14	0.13	0.42	0.00	0.00	0.00	-0.01
Net benefit or net costs											
mean	4.56	-0.35	4.21	-1.26	-5.40	-5.20	-11.86	-0.20	-3.73	-3.53	-7.46
5th percentile	0.35	-1.43	-0.22	-3.25	-7.36	-7.11	-15.45	-1.41	-5.23	-4.98	-9.98
95th percentile	8.81	0.74	8.68	0.79	-3.43	-3.30	-8.27	1.01	-2.25	-2.10	-4.96

IV.3 Calculations, input data and results for the bovine viral diarrhoea virus (BVDV) mitigation programme

IV.3.1 Calculation of BVDV disease costs

The production losses included losses due to mortality *(L_M)*, premature culling *(L_{PMC})*, abortion *(L_A)*, and reduced milk yield *(L_{RMY})*, and were calculated as follows. Input data used are listed in Appendix Table IV-11.

$$L_M = \sum N_{X1} \cdot Mt_{X1} \cdot (AV_{X1} + RC_{X1})$$

Where *N* stands for the number of animals affected, *X1* for persistently infected (PI) or transiently infected (TI) calves (cv), heifers (h) and cows (c), *Mt* for extra mortality rate, *AV* for animal value, and *RC* for rendering costs.

$$L_{PMC} = \sum N_{X2} \cdot PMC_{X2} \cdot (AV_{X2} - SV_{X2})$$

Where X2 stands for TIh and TIc, *PMC* for the premature culling rate and *SV* for slaughter value.

$$L_A = \sum N_{X3} \cdot AR_{X3} \cdot CA$$

Where *X3* stands for TIh and TIc, *AR* for extra abortion rate, and *CA* for costs per abortion.

$$L_{RMY} = (N_{PIc} \cdot RMY_{PIc} + N_{TIc} \cdot PropML_{TIc} \cdot RMY_{TIc}) \cdot MY \cdot PM$$

Where *RMY* stands for the rate of reduced milk yield, *$PropML_{TIc}$* for the proportion of TIc showing milk loss, *MY* for milk yield, and *PM* for the production price per kg milk.

The E_{PT} for PIs (E_{PT1}), TIcv (E_{PT2}), and for TIh and TIc (E_{PT3}) were calculated as follows:

$$E_{PT1} = \sum N_{X4} \cdot PropRVT \cdot [Mt_{X4} \cdot PVT_{X4D} + (1 - Mt_{X4}) \cdot PVT_{X4S}]$$

$$E_{PT2} = \sum N_{TIcv} \cdot PropRVT \cdot [Mt_{TIcv} \cdot PVT_{TIcvD} + (1 - Mt_{TIcv}) \cdot Mb_{TIcv} \cdot PVT_{TIcvS}]$$

$$E_{PT3} = \sum N_{X5} \cdot PropRVT \cdot Mt_{X5} \cdot PVT_{X5D}$$

Where *X4* stands for PIcv, PIh, and PIc, *X5* for TIh and TIc, *PropRVT* for the proportion of morbid animals receiving veterinary treatment, PVT_{XD} for the price of veterinary treatment for animals that die despite treatment, PVT_{XS} for the price of veterinary treatment for animals that survive, and *Mb* for morbidity rate.

The E_{LT} for the baseline scenario were:

$$E_{LT} = \sum N_{X6} \cdot PT_{SP}$$

Where *X6* stands for the number of suspect PI animals tested (=Uniform(337,404)) and PT_{SP} the price for testing a suspect PI animal.

Appendix Table IV-11: Input data used to estimate bovine viral diarrhoea related disease costs in Switzerland. AC=adult cattle, CV=calves, PI=persistently infected, PIcv=PI calves, PIh=PI heifers, PIc=PI cows, TI=transiently infected, TIcv=TI calves, TIh=TI heifers, TIc=TI cows.

Input	Value or distribution	Description/source
Mortality rate PI animals (year^{-1})	Pert(0.45,0.5,0.55)	Derived from Viet et al. (2004) and observed data. The half-life of PI animals was set to 1 year and the mortality rate calculated accordingly. This value was taken as the most likely (ML) value. Minimum and maximum values: ML value -/+ 10%.
Mortality rate TI animals (year^{-1})	Pert(0,0.0025,0.006)	Expert estimate based on Houe et al. (1993) and Valle et al. (2005).
Rendering costs AC (CHF)	263	Price list of waste disposal company 'TMF Bazenheid'[1]
Rendering costs CV (CHF)	75	
Premature culling rate TIh and TIc (year^{-1})	Pert(0,0.025,0.057)	Expert estimate based on Valle et al. (2005)
Abortion rate TIh and TIc (year^{-1})	Uniform(0.00011,0.00018)	Calculated based on Rüfenacht et al. (2001)
Costs per abortion (CHF)	Normal(869.7, 497.7)	Derived from Häsler et al. (2006)
Rate of reduced milk yield in PIc (year^{-1})	Pert(0.43,0.48,0.53)	Derived from Voges et al. (2006) who reported a reduction in milk production in PI animals of 48% when compared with non-PI cows. ML value =0.48, minimum and maximum values: ML value -/+ 10%.
Proportion of TIc showing milk loss	Pert(0.30,0.30,0.35)	Derived from R. Bennett (Bennett, 1998) who reported that 30% of affected dairy cows suffer a significant drop in milk yield of 20% over a three-week period.
Rate of reduced milk yield in affected TIc (year^{-1})	Pert(0.013,0.014,0.015)	
Morbidity rate TIcv (year^{-1})	Pert(0.03,0.05,0.08)	Assumption based on information from Swiss veterinary practitioners
Proportion of morbid animals receiving veterinary treatment	Pert(0.79,0.84,0.89)	
Price of veterinary treatment (CHF) for		Information collected from Swiss veterinary practitioners. Includes average number of veterinary visits needed for a PI or TI clinical episode, farm visit, administrative costs and the veterinary medical treatment according to the severity of the case.
PIcv and TIcv that die	100	
PIh and TIh that die	170	
PIc and TIc that die	180	
PIcv and TIcv that survive	70	
PIh that survive	110	
PIc that survive	120	
Price for testing a suspect PI animal (CHF)	113	Information collected from Swiss veterinary practitioners. Includes farm visit, blood sampling and laboratory cost.

[1] http://www.tmf.ch Price for slaughter waste: 210 CHF/ton for deliveries between 0-4999kg

IV.3.2 Calculation of BVDV eradication cost

Appendix Table IV-12 lists the input data used to calculate BVDV eradication cost in Switzerland for the initial phase, calf phase up to 31st October 2010 and the calf phase from November 2010 to December 2011. Costs for epidemiological modelling and data analysis, establishment and maintenance of an electronic registration system, communication efforts, and reference laboratory function were added as lump sums (see Chapter 4). Further, the difference in market value and slaughter value of the removed PI animals was accounted for.

Appendix Table IV-12: Input data used to calculate bovine viral diarrhoea eradication cost in Switzerland. CC=cost category, LB=labour, OE=operations and expenses, CVS=cantonal veterinary service, CHF=Swiss francs.

Activity	CC	Job position of price per unit	No of working hours or units		
			Initial phase	Calf phase to 31 Oct 2010	Calf phase Nov 2010 to Dec 2011
Primary sampling					
Call-out fee veterinarian	OE	30CHF/visit	43,267	-	-
Take tissue sample by veterinarian	OE	5 CHF/sample	1,520,859	-	-
Ear tag adult cattle	OE	1.19 CHF/tag	1,520,859	-	-
Ear tag newborn calves	OE	2.70/tag	-	1,465,078	823,143
Cost ear tag pliers	OE	14 CHF/piece	43,293	-	-
Postage	OE	0.4 CHF/sample	1,520,859	1,465,078	823,143
Laboratory analysis					
Antigen test (incl. data recording)	OE	8 CHF/sample	1,553,526	1,481,836	832,558
Re-sampling					
Call-out fee for re-sampling (blood sample)	OE	30 CHF/visit	21,948	47,492	26,266
Take blood sample from calves with empty ear tag sample or from PI calf or PI mother	OE	15 CHF/sample	21,948	53,593	26,266
Laboratory testing of sampled animals	OE	27 CHF/sample	21,948	53,593	26,266
Impose movement ban	LB	CVS official veterinarian	12,125	6,933	50

Appendix Table IV-13: Input data used to calculate surveillance cost for bovine viral diarrhoea to demonstrate freedom from disease after eradication in Switzerland in the years 2012-17. S1, S2, S3 and S4 are the four surveillance strategies assessed (see Chapter 4). PI=persistently infected animals.

	Scenario	2012	2013	2014	2015	2016	2017
No of farms visited	S1	43,267	43,267	43,267	43,267	43,267	43,267
	S2	43,267	43,267	43,267	43,267	43,267	43,267
	S3	43,267	43,267	43,267	43,267	43,267	43,267
	S4	21,634	21,634	21,634	21,634	21,634	21,634
No of samples taken	S1	242,376	244,360	247,683	248,370	247,979	247,578
	S2	129,361	129,587	128,602	130,169	132,696	133,713
	S3 blood	121,308	121,961	123,954	124,112	124,061	123,750
	S3 milk	64,599	64,846	64,231	65,214	66,244	66,953
	S4 blood	121,280	122,048	123,934	124,052	124,055	123,666
	S4 milk	64,721	64,733	64,346	65,060	66,425	66,763
No of farms re-tested	S1	785	62	0	0	0	0
	S2	17,889	7,117	1,741	241	28	1
	S3	9,337	3,591	879	119	6	0
	S4	9,156	3,590	877	126	13	1
No of animals re-tested	S1	23,810	1,832	0	0	0	0
	S2	583,539	230,151	55,693	7,597	782	17
	S3	303,547	115,891	27,985	3,719	159	0
	S4	298,063	116,026	27,997	3,957	349	21
No of PIs detected	S1	0	0	0	0	0	0
	S2	0	0	0	0	0	0
	S3	0	0	0	0	0	0
	S4	0	0	0	0	0	0

IV.4 Probability and uncertainty estimates for avian influenza virus case study

Appendix Table IV-14 lists in detail the rationale as well as the probabilities and uncertainties determined in the qualitative risk assessment for AIV.

Appendix Table IV-14: Comprehensive rationale for probability (P) and uncertainty (UC) estimates for the risk assessment to estimate the probability of primary and secondary avian influenza virus (AIV) outbreaks in commercial (comm.) and backyard holdings in Switzerland with and without surveillance. HPAIV=Highly Pathogenic AIV H5N1, LPAIV=Low Pathogenic AIV of the H5 or H7 type. Expert group conclusions are described in blue.

Probability	Rationale	Comm.		Backyard	
		P	UC	P	UC
1) P of detecting HPAIV in wild birds (given defined prevalence)	Knight-Jones et al. (2010) conducted scenario tree analysis to assess which surveillance system component had the greatest probability of detecting HPAI H5N1 in Switzerland from September 2006 to August 2007 given that infection was present in wild waterbirds. The probability of detection was reported for six surveillance components including 'birds found dead' and 'sentinel surveillance' at 1%, 5% and 0.1% prevalence. The expert group concluded that 0.1% prevalence in wild birds was clearly overestimated. They expected HPAIV prevalence in wild birds to be <<0.1%. They stated that prevalence is expected to stay very low even during an outbreak in wild birds, even though there might be clusters of higher prevalence. Taking into account the international AIV disease situation at the time of analysis, it was agreed that the most likely prevalence was one of <0.1%. Therefore, the probabilities of detection for the 0.1% prevalence from Knight-Jones et al. (2010) were taken: Probability of detecting HPAIV H5N1 (mode and 5th and 95th percentiles in brackets) *Birds found dead:* September–April 0.03 (0.01–0.07) May–August 0.04 (0.02–0.10) *Sentinel:* September–April 0.12 (0.05–0.20) May–August 0.08 (0.04–0.15)	L	M	L	M
2) P that preventive measures are implemented if outbreak detected	Hauser et al. (2006) developed a scenario tree to facilitate the decision about implementing a protection zone in the case of detection of HPAIV in wild birds. In the protection zone, special measures (e.g. housing of birds, movement restrictions) are to be implemented as stipulated in the technical guidelines regarding measures in the case of suspect and confirmed cases of HPAIV in wild birds (Reg. 2007/09-08/1). In four of seven possible scenarios (=57%), a protection zone would be implemented.	H	L	H	L

Appendix Table IV-14 continued

Probability	Rationale	Comm.		Backyard	
		P	UC	P	UC
3) P that preventive measures are effective	The expert group agreed that preventive and intervention measures as well as their implementation would be highly effective (these considerations also apply to the probabilities 11, 12, 13, 25, 26 and 27). All prevention and intervention measures are clearly documented in national legislation, guidelines and contingency plans. They are based on current scientific knowledge and respect Swiss specific practicalities, such as farming practices and the institutional setting. Federal and cantonal veterinary offices and related officials have unrestricted access to this information and all modern communication tools are available and in use. The quality of the veterinary service is considered to be high (Rüsch and Kihm, 2003; Anonymous, 2009).	H	L	H	L
4) P that surveillance and prevention are effective	Combination of probabilities 1, 2 and 3 using matrix 1: Both commercial and backyard holdings: L x H x H = L	L		L	
5) P that surveillance and prevention are NOT effective = 1 -P4)	1 minus probability 4)= 1 – L = H	H		H	
6) P of direct and indirect contact wild birds – poultry	Saurina J. (2009) conducted a cross-sectional survey from August to December 2007 to quantify the contacts between wild birds and domestic poultry in Switzerland and to determine factors influencing the contacts. 13% of respondents owning a free-range area reported to have observed waterbirds. Personal interviews with poultry holders showed that birds had not necessarily been observed directly in the free-range area, but overall around the free-range area, e.g. flying over it. 61% of professional holdings and 92% of hobby holdings indicated to have a free-range area (significant difference). Other birds were observed more frequently: 75% of respondents indicated to have seen small birds and 53% birds of prey. Further it was found that the degree of professionalism did not did not impact on contacts between wild waterbirds and poultry. The expert team agreed that only wild water birds were of relevance for the transmission of either LPAIV or HPAIV to poultry (Artois et al., 2009). Indirect contacts would also include flying over the free-range area and contamination with droppings. Hence, it was concluded to use the observations of wild water birds as a conservative estimate for direct and indirect contacts. Because the transmission to intensively reared or indoor flocks was considered to be negligible (Anonymous, 2006), the proportion of holdings with a free-range area was taken into account according to the following equation: $PropC_{FR} * PropFR + PropC_{ID} * (1-PropFR)$	L	M	L	M

Appendix Table IV-14 continued

Probability	Rationale	Comm.		Backyard	
		P	UC	P	UC
	Where $PropC_{FR}$ is the proportion of free-range holdings that have contacts with wild waterbirds extrapolated to whole Switzerland according to Saurina J. (12%), *PropFR* the proportion of poultry holdings with a free range area (61% of commercial and 92% of backyard holdings) and $PropC_{ID}$ the proportion of indoor holdings with contacts with wild waterbirds (0%). For commercial holdings: *0.12·0.61 + 0·(1-0.61) = 7.32%* For backyard holdings: *0.12·0.92 + 0·(1-0.92) = 11.04%*				
7) P of transmission to poultry given contact	In the European Food Safety Authority's risk assessment (Anonymous, 2006) the probability of transmission of Asian lineage H5N1 HPAIV to poultry given exposure was classified as high with a low uncertainty.	H	L	H	L
8) P of HPAIV transmission from wild birds/migratory birds to poultry (primary outbreak)	Combination of probabilities 6) and 7) for the scenario without surveillance and probabilities 5) to 7) for the scenario with surveillance using matrix 1: Both commercial and backyard holdings: **Without surveillance:** L x H = L **With surveillance:** L x H x H = L	 L L		 L L	
9) P of release and exposure of LPAIV by illegal imports of live birds, poultry meat/- products, and eggs	Läubli C. (2010) assessed the qualitative risk for the introduction of notifiable avian influenza viruses (NAIV) via illegal imports into Switzerland. The probability of release and exposure for different commodities were reported as follows (the uncertainty was 'high' throughout): **Commodity** / **P release C** / **P release B** / **P exposure C** / **P exposure B** Live birds: L / L / L / M Meat and meat products: L / M / L / M Eggs: N / L / - / L Feathers: N / N / - / - The probabilities of release and exposure were combined using matrix 1 and the highest estimate was taken as a starting point for the commercial and backyard holdings.	L	H	M	H
10) P of detecting LPAIV in poultry holding	Decision 2007/268/EC stipulates that the number of poultry holdings to be sampled shall be defined to 'ensure the identification of at least one infected holding if the prevalence of infected holdings is at least 5%, with a 95% confidence interval'. Because the prevalence is expected to be much lower if LPAIV is present in the poultry population, the expert team agreed that the P of detecting LPAIV in poultry holdings with the current sample size was low for commercial farms and negligible for backyard farms as they are not included in the sample.	L	L	N	L
11) P of implementing intervention measures given LPAIV is detected	See 3)	H	L	H	L

Appendix Table IV-14 continued

Probability	Rationale	Comm.		Backyard	
		P	UC	P	UC
12) P that intervention measures are implemented effectively	See 3)	H	L	H	L
13) P that intervention measures are effective	See 3)	H	L	H	L
14) P that surveillance and intervention are effective	Combination of probabilities 10) to 13) using matrix 1: Commercial holdings: L x H x H x H= L Backyard holdings: N x H x H x H = N	L		N	
15) P that surveillance and intervention are NOT effective=1-P14)	1 minus probability 14): Commercial holdings: 1 – L = H Backyard holdings: 1 – N = H	H		H	
16) P that LPAIV mutates into HPAIV	Evidence of mutation of LPAIV to HPAIV was shown in Canada, Italy, United States, Netherlands, Mexico and Chile (Bowes et al., 2004). Poultry and farm densities have been suggested to be risk factors for mutation. Fiebig et al. (2009) reported that of the total 49,437 recorded poultry farms in Switzerland, 95% had less than 500 birds. The expert team agreed that a mutation from LPAVI to HPAIV is extremely unlikely in backyard holdings because of the low poultry density (negligible probability). However, in commercial holdings with high poultry densities, the mutation was deemed more likely to occur. However, as most holdings in Switzerland have rather small numbers of poultry compared to other countries, the P of mutation was considered to be low for commercial farms.	L	H	N	H
17) P that LPAIV which was introduced and transmitted via wild birds/migratory birds or illegal trade to poultry mutates into HPAIV	Combination of probabilities 6), 7), 9) and 16) for the scenario without surveillance and probabilities 6), 7), 9) 15) and 16) for the scenario without surveillance **Without surveillance:** Commercial holdings: L x L = L Backyard holdings: M x N = L **With surveillance:** Commercial holdings: L x L x H = L Backyard holdings: M x N x H = L	L L		L L	
18) P of infected poultry showing clinical signs	Only AIV of the H5 and H7 subtypes are known to cause disease in susceptible bird species, but not all H5 and H7 viruses are highly virulent (Alexander, 2007). Chickens infected with HPAI strains show a wide range of clinical symptoms from respiratory and digestive disorders to death within 24 hours (Elbers et al., 2005; Pantin-Jackwood and Swayne, 2009).	H	L	H	L

Appendix Table IV-14 continued

Probability	Rationale	Comm.		Backyard	
		P	UC	P	UC
19) P that farmer notices clinical signs	A cross-sectional study conducted among Swiss poultry keepers from August to December 2007 showed that the mean knowledge of hobby keepers (backyard holders) was significantly lower than the knowledge of professional holders (Saurina, 2009). The expert team agreed that the AIV knowledge of backyard holders was very limited and that only very few would contact a veterinarian if their birds showed clinical symptoms. The most likely action of backyard holders would be to dispose of sick or dead birds without reporting it. On the other hand, commercial holdings are considered to operate at a high professional level, are generally knowledgeable about AIV and have regular visits by their veterinarian.	H	M	L	M
20) P that farmer reports to private veterinarian	See 19)	H	M	L	M
21) P that private veterinarian reports to veterinary service	Veterinarians in charge of commercial herds are expected to have a higher understanding of poultry diseases and the importance of national disease mitigation measures and are therefore expected to report any suspect case of AIV they find in commercial flocks. Veterinarians who treat backyard flocks are expected to be less experienced with poultry diseases and the expert team agreed that they would only have a medium P to report disease.	H	M	M	M
22) Impact of wild bird and poultry surveillance on disease awareness & preparedness of veterinary service	Experts agreed that surveillance activities would have a low positive impact on disease awareness and preparedness of staff working for the Swiss veterinary service. They concluded that the general population and farmers would not be affected by having in place surveillance programmes or a detection of a case in either wild birds or poultry. A case of HPAIV in wild birds was determined to have a medium impact and a case of LPAIV in poultry a high impact on disease awareness and preparedness of veterinary services. In case of several factors contributing to the probability of increased disease awareness and preparedness, the highest estimate was considered.	L	H	L	H
23) Impact of detection of HPAIV case in wild birds on disease awareness & preparedness of veterinary service	See 22)	M	H	M	H

Appendix Table IV-14 continued

		Comm.		Backyard	
Probability	**Rationale**	**P**	**UC**	**P**	**UC**
24) Impact of detection of LPAIV in poultry on disease awareness & preparedness of veterinary service	See 22)	H	H	H	H
25) P that vet service implements intervention	See 3)	H	L	H	L
26) P that implementation is effective	See 3)	H	L	H	L
27) P that intervention measures are effective	See 3)	H	L	H	L
28) P that outbreak is detected and contained	Combination of probabilities 18), 19), 20), 21), 25), 26), 27) for scenario without surveillance using matrix 1 and probabilities 18) to 27) for scenario with surveillance using matrices 1 and 2. **Without surveillance:** Commercial holdings: H x H x H x H x H x H x H = H Backyard holdings: H x L x L x M x H x H x H = L **With surveillance:** Commercial: H x H x H x H x (H x H) x (H x H) x (H x H) = H Backyard: H x L x L x M x (H x H) x (H x H) x (H x H) = L	H H		L L	
29) P that outbreak is NOT detected and contained= 1 – P 28)	1 – probability 28) 1 – H = L 1 – L = H	L L		H H	
30) P that infectious live birds, meat, products, equipment leave farm	Hauser et al. (2005) assessed the risk of introduction of AIV into Swiss poultry holdings. They stated that the virus is likely to be shed in faeces as well as respiratory secretions. Further, both hatching eggs and eggs for human consumption may contain the virus in an early stage of infection and a high concentration of virus is expected to be found in blood. The expert team agreed that it is highly probable that infectious live birds, poultry products, and/or equipment leave the farm.	H	H	H	H

Appendix Table IV-14 continued

Probability	Rationale	Comm.		Backyard	
		P	UC	P	UC
31) P that infectious material gets into contact with poultry/poultry holdings	Fiebig et al. (2009) conducted a study to identify between-farm contacts of commercial and non-commercial poultry holdings in Switzerland. Poultry movements were identified for 65% of the participating farms, with 79% among commercial and 55% among non-commercial farms. Commercial and non-commercial farms were directly connected by between-farm poultry movements. The European Food Safety Authority concluded (2008) that spread of AIV is facilitated by the high integration of the poultry industry.	H	M	H	M
32) P of transmission given contact with infectious material	See 7)	H	L	H	L
33) P of secondary spread of HPAIV to other poultry farms	Combination of probabilities 29) to 32) **Without surveillance:** Commercial holdings: L x H x H x H = L Backyard holdings: and H x H x H x H = H **With surveillance:** Commercial holdings: L x H x H x H = L Backyard holdings: H x H x H x H = H	 L L		 H H	

IV.5 Additional information, input data used, and equations for salmonella in laying hens case study

IV.5.1 Sampling protocols in Switzerland and the EU

Appendix Table IV-15: Sample taking for salmonella in laying hens according to the Swiss technical guidelines regarding the sample taking for salmonella in poultry.

Time of sample taking	Sample taking by holder	Sample taking under supervision by official vet
Aged 15-20 weeks, the latest two weeks before moving to the laying shed		One sample of pooled faeces from 60 fresh faeces
First time during laying in the 22 to 26 week	Boot swabs and/or drag swabs (two samples per flock)	
All 15 weeks during laying	Boot swabs and/or drag swabs (two samples per flock) or eggs or blood samples from 0.5% of the animals (at least 20 samples)	
At least nine weeks before the end of the laying period		Boot swabs and/or drag swabs, two samples per flock plus one dust sample

Appendix Table IV-16: Sample taking for salmonella in laying hens according to the EU Regulation 1168/2006.

Time of sample taking	Sample taking by holder	Sampling taking under supervision by official vet
24 +/- 2 weeks for first sample	Two pairs of boot swabs or socks	Must take at least one sample of the holding (first one if previously infected building) and must also collect 100 grams of dust (or 150 g naturally pooled faeces or another pair of boots if dust not available)
Every 15 weeks (at least)	Two pairs of boot swabs or socks	

IV.5.2 Surveillance and intervention costs

Appendix Table IV-17: Main surveillance steps (SS), surveillance activities, cost categories (CC; LB=labour, OE=operations and expenses), job position (FVO=Federal Veterinary Office, CVS=cantonal veterinary service) or price/unit, and number of working hours or input units used to calculate surveillance cost for salmonella in commercial layer flocks in Switzerland. CHF=Swiss francs.

SS	Activity	CC	Job position or price/unit	No of units or working hours S1	No of units or working hours S2
1)	Outline of surveillance tasks/sampling plan	LB	FVO researcher	10	10
2)	Preparation of sampling material/forms/lists	LB	CVS assistant	5	5
3)	Integrated in 7)	-	-	-	-
4)	Call-out official veterinarian including labour	OE	40 CHF/visit	624	293
	Dead chicks, hatcher basket linens, boot socks/swabs, pooled faecal samples, dust samples	OE	1 CHF/sample	1560	1170
	Send samples to laboratory	OE	5 CHF /sample	1560	1170
5)	Bacteriological testing in accredited laboratory (incl. data recording)	OE	Pert(40,68,86) CHF/sample	936	1170
	Serological testing in accredited laboratory (incl. data recording)	OE	Uniform(94,100)/ sample	624	-
6)	CVS completion of questionnaire for FVO once a year	LB	CVS assistant	15	15
	Collate data from questionnaires	LB	FVO researcher	10	10
7)	Descriptive stats and exploratory data analysis and collation and interpretation of results	LB	FVO researcher	10	10
8)	Reporting to the EU: Zoonosis report for Switzerland and the EU	LB	FVO researcher	5	5
	Translation into English and French	LB	FVO translator	5	5
9)	None	-	-	-	-

Appendix Table IV-18: Main intervention steps (IS), intervention activities, cost categories (CC; LB=labour, OE=operations and expenses), job position (FVO=Federal Veterinary Office, CVS=cantonal veterinary service) or price/unit and number of working hours or input units used to calculate intervention cost for an outbreak of salmonella in a commercial layer flock in Switzerland. CHF=Swiss francs.

IS	Activity	CC	Job position or price/unit	No of units or working hours
1)	None	-	-	-
2)	None	-	-	-
3)	None	-	-	-
4)	Farm visit to impose animal movement ban on suspect farm, postage of 20 dead birds	OE	400 CHF (lump sum)	1
	Laboratory testing of 20 dead birds (incl. data reporting)	OE	1,500 CHF (lump sum)	1
	Culling and disposal of affected flocks: Lost birds	OE	Pert(0,9,17) CHF	Lognorm(3622.3,5441.7)
	Culling and disposal of affected flocks: Culling costs		Uniform(5800;20,000) CHF	1
	Cleaning and disinfection, visual control of cleaned premises including completion of control sheet plus taking of samples for bacteriological control and laboratory testing , lift ban	OE	10,000 CHF (lump sum)	1
5)	Data reporting to FVO	OE	CVS assistant	1
6)	Integrated in surveillance activities			
7)				
8)	None	-	-	-

IV.5.3 Epidemiological model

Differential equations for the number of holdings being restocked with new birds, N(t), number of susceptible holdings, S(t), number of undetected infected holdings, U(t), number of detected infected and culled holdings, I(t), and number of slaughtered holdings, M(t). Input data used are listed in Appendix Table IV-19.

$$dN/dt = -n_S N(t) - n_U N(t) + rI(t) + rM(t)$$

$$dS/dt = n_S N(t) - S(t)[\lambda + \beta U(t)] - m_S S(t)$$

$$dU/dt = n_U N(t) + S(t)[\lambda + \beta U(t)] - m_U U(t) - fU(t)$$

$$dI/dt = fU(t) - rI(t)$$

$$dM/dt = m_S S(t) + m_U U(t) - rM(t)$$

Appendix Table IV-19: Input data used in the epidemiological model for salmonella in Swiss layer holdings.

Input	Notation	Value or distribution	Source/description
Infected restocking rate	n_U	0	InfoSM (www.infosm.bvet.admin.ch)
Susceptible restocking rate	n_S	1- n_U	n/a
Slaughter rate for susceptible holdings (1/month)	m_s	1/14	After the standard production cycle of 14 months, a flock will be slaughtered (Swiss Aviforum, www.aviforum.ch)
Slaughter rates for infected undetected holdings (1/month)	m_u	1/14	Ditto
Infection rate (1/month)	λ	Uniform(0.00075,0.00125)	Horizontal transmission due to environmental exposure like outdoor exposure, contact with rodents or wildlife. Because the surveillance of poultry feed for Salmonella has shown only negative results in the past two years (personal communication Michel Geinoz, Agroscope), feed was not considered as a source of infection. Assumption based on current levels of prevalence and sensitivity estimates.
Contact rate	β	Uniform(0.0025,0.0042)	Derived from Fiebig (2009) who estimated that approximately 4% of people co-work at multiple holdings. This value +/- 25% were the upper and lower limits of the distribution.
Detection rate	f	Uniform(0.30,0.40)	Reflects sensitivity of surveillance protocol and laboratory tests. The laboratory tests have nearly 100% sensitivity (Love and Rostagno, 2008; Kuijpers et al., 2009). Because sampling methods are interchangeable, they were evaluated as one group for sensitivity. Based on Arnold et al. (2010) who found that 2 boots and 1 dust sample have a sensitivity of 34% and Carrique-Mas (2008) who found that two pooled faeces and one dust sample with official veterinarian had 49.2% sensitivity while with operator it was 28.9%.
Restocking rate after slaughtering or culling	r	2	Based on restocking data received from Swiss Aviforum (www.aviforum.ch)

Appendix Table IV-20: Number and serotypes of isolates of salmonella detected in humans, pigs, broilers, layers and imported poultry meat in Switzerland in the years 2006 to 2009.

Sero type no	Serotype name	No sporadic cases humans	No outbreak cases humans	Pigs	Broilers	Layers	Imported poultry meat
2006							
1	Agona	8					
2	Anatum						
3	Bareilly						
4	Benfica						
5	Bovismorbificans						
6	Brandenburg	7					
7	Bredeney	14					2
8	Chester						
9	Corvallis	9					
10	Derby	12		1			
11	Dublin						
12	Ealing			1			
13	Eboko			1			
14	Enteritidis	741	59	4		2	5
15	Hadar	13					
16	Heidelberg						
17	Indiana						
18	Infantis	24					7
19	Javiana	7					
20	Kentucky	39					
21	Kottbus	7					
22	Livingstone	9					
23	London						
24	Mbandaka						
25	Minnesota						
26	Montevideo	8					
27	Muenchen						
28	Napoli	30					
29	Newport	14					
30	Oranienburg						
31	Panama						
32	Paratyphi A	8					
33	Paratyphi B;Java 3;1	4					
34	Poona	7					
35	Reading	7					
36	Rissen						
37	Saintpaul	8					
38	Sandiego						
39	Schwarzengrund	8					
40	Senftenberg						
41	Stanley	72					
42	Stanleyville						
43	Szentes			1			
44	Thompson						
45	Typhi	16					
46	Typhimurium	317		5		1	2
47	Veneziana						

Appendix Table IV-20 continued

Sero type no	Serotype name	No sporadic cases humans	No outbreak cases humans	Pigs	Broilers	Layers	Imported poultry meat
48	Virchow	27			1		
49	Weltevreden	9					
50	4,12 : i : - (mono)	84		2			
51	I 4,12:b:- monoph.						
52	Unspecified	215					
2007							
1	Agona	9					
2	Anatum						
3	Bareilly						
4	Benfica						1
5	Bovismorbificans	8					
6	Brandenburg	13					
7	Bredeney						
8	Chester						
9	Corvallis	8					
10	Derby	22		1			
11	Dublin						
12	Ealing			1			
13	Eboko			1			
14	Enteritidis	1066	45	4		3	3
15	Hadar	9					
16	Heidelberg						
17	Indiana						
18	Infantis	41					
19	Javiana						
20	Kentucky	21					
21	Kottbus						
22	Livingstone						
23	London						
24	Mbandaka						
25	Minnesota						1
26	Montevideo	8					
27	Muenchen	17					
28	Napoli	13					
29	Newport	16					
30	Oranienburg						
31	Panama	14					
32	Paratyphi A	9					
33	Paratyphi B;Java 3;1	22					
34	Poona						
35	Reading						
36	Rissen						
37	Saintpaul						
38	Sandiego	8					
39	Schwarzengrund						
40	Senftenberg						
41	Stanley	64					
42	Stanleyville						
43	Szentes			1			
44	Thompson	11					

Appendix Table IV-20 continued

Sero type no	Serotype name	No sporadic cases humans	No outbreak cases humans	Pigs	Broilers	Layers	Imported poultry meat
45	Typhi	18					
46	Typhimurium	279		5	1		
47	Veneziana	10					
48	Virchow	28					
49	Weltevreden	9					
50	4,12 : i : - (mono)	68		2			
51	I 4,12:b:- monoph.						
52	Unspecified	207					
2008							
1	Agona	10			1		
2	Anatum	9					
3	Bareilly						
4	Benfica						
5	Bovismorbificans	8					
6	Brandenburg	8					
7	Bredeney						
8	Chester	8					
9	Corvallis	13					
10	Derby	11		1			
11	Dublin						
12	Ealing			1			
13	Eboko			1			
14	Enteritidis	986	36	4		2	1
15	Hadar	11					
16	Heidelberg						
17	Indiana						
18	Infantis	35			1		
19	Javiana						
20	Kentucky	26					
21	Kottbus						
22	Livingstone						
23	London	12					
24	Mbandaka						
25	Minnesota						1
26	Montevideo						
27	Muenchen	14					
28	Napoli	17					
29	Newport	34			1		
30	Oranienburg	9					
31	Panama						
32	Paratyphi A						
33	Paratyphi B;Java 3;1	29					
34	Poona						
35	Reading						
36	Rissen	11					
37	Saintpaul	12					
38	Sandiego						
39	Schwarzengrund						
40	Senftenberg						

Appendix Table IV-20 continued

Sero type no	Serotype name	No sporadic cases humans	No outbreak cases humans	Pigs	Broilers	Layers	Imported poultry meat
41	Stanley	30					
42	Stanleyville						
43	Szentes			1			
44	Thompson	9					
45	Typhi	16					
46	Typhimurium	433	150	5		1	
47	Veneziana						
48	Virchow	28					
49	Weltevreden	10					
50	4,12 : i : - (mono)	107		2			
51	I 4,12:b:- monoph.						
52	Unspecified	200			1		
2009							
1	Agona	8					
2	Anatum						
3	Bareilly	9					
4	Benfica						
5	Bovismorbificans						
6	Brandenburg	6					
7	Bredeney	7					
8	Chester						
9	Corvallis	19					
10	Derby	22		1			
11	Dublin	6					
12	Ealing			1			
13	Eboko			1			
14	Enteritidis	489	3	4	2		
15	Hadar	12					
16	Heidelberg						
17	Indiana				1		
18	Infantis	29			2		
19	Javiana						
20	Kentucky	19			1		
21	Kottbus						
22	Livingstone						
23	London						
24	Mbandaka				1		
25	Minnesota						
26	Montevideo	7			1		
27	Muenchen						
28	Napoli	16					
29	Newport	31					
30	Oranienburg	10					
31	Panama						
32	Paratyphi A	6					
33	Paratyphi B;Java 3;1	13					
34	Poona						
35	Reading						
36	Rissen				1		
37	Saintpaul	13					

Appendix Table IV-20 continued

Sero type no	Serotype name	No sporadic cases humans	No outbreak cases humans	Pigs	Broilers	Layers	Imported poultry meat
38	Sandiego						
39	Schwarzengrund						
40	Senftenberg	10					
41	Stanley	10					
42	Stanleyville	8					
43	Szentes			1			
44	Thompson						
45	Typhi	19					
46	Typhimurium	232		5	2		
47	Veneziana						
48	Virchow	31					
49	Weltevreden						
50	4,12 : i : - (mono)	194		2	1		
51	I 4,12:b:- monoph.	8					
52	Unspecified	190					

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V Appendix to Chapter 5

V.1 Measures of effectiveness

Effectiveness measures the ability of achieving a defined objective. Cost-effectiveness analysis (CEA) measures the cost of a unit change in the outcome. The effectiveness measure must be clearly linked to the surveillance objective. As a pre-requisite, the following questions need to be addressed:

1. What is the surveillance objective?
2. What measure of effectiveness reflects best the surveillance objective?
3. How can effectiveness be assessed?

Whenever possible the measure of effectiveness should reflect a final output and not an intermediate output, even though the use of intermediate outputs is valid if they have a value on their own (Drummond, 1997). For instance, the reduction of zoonotic diseases at farm level that do not cause production losses is an intermediate output, while the avoidance of human illness is the final output. The choice of effectiveness is critical in conducting CEA and impacts substantially on the outcome of the analysis. Measures of effectiveness for example are the time of introduction of disease until its detection, the probability of detecting an outbreak, the ability to document disease freedom for a certain hazard with a specified probability, or the number of cases detected or avoided. Obtaining measures of effectiveness are primarily an epidemiological issue. Therefore to determine the effectiveness of alternative surveillance strategies it is essential to select and determine appropriate measure of effectiveness using epidemiological approaches.

V.2 Calculation of cost-effectiveness ratios

Commonly the results of a CEA are expressed in the form of a ratio that expresses the price per effectiveness unit. The cost-effectiveness ratio (CER) can be calculated as either an average ratio (ACER) or incremental ratio (ICER):

$$ACER = \frac{\text{cost of surveillance}}{\text{effectiveness of surveillance}}$$

The ACER does not contemplate programme alternatives, but deals with independent programmes that are evaluated against a baseline (e.g. no programme), i.e. it facilitates the decision-making process for the allocation of resources among independent programmes. Further it provides a useful description of a programme independent of its alternatives (Laska et al., 1997).

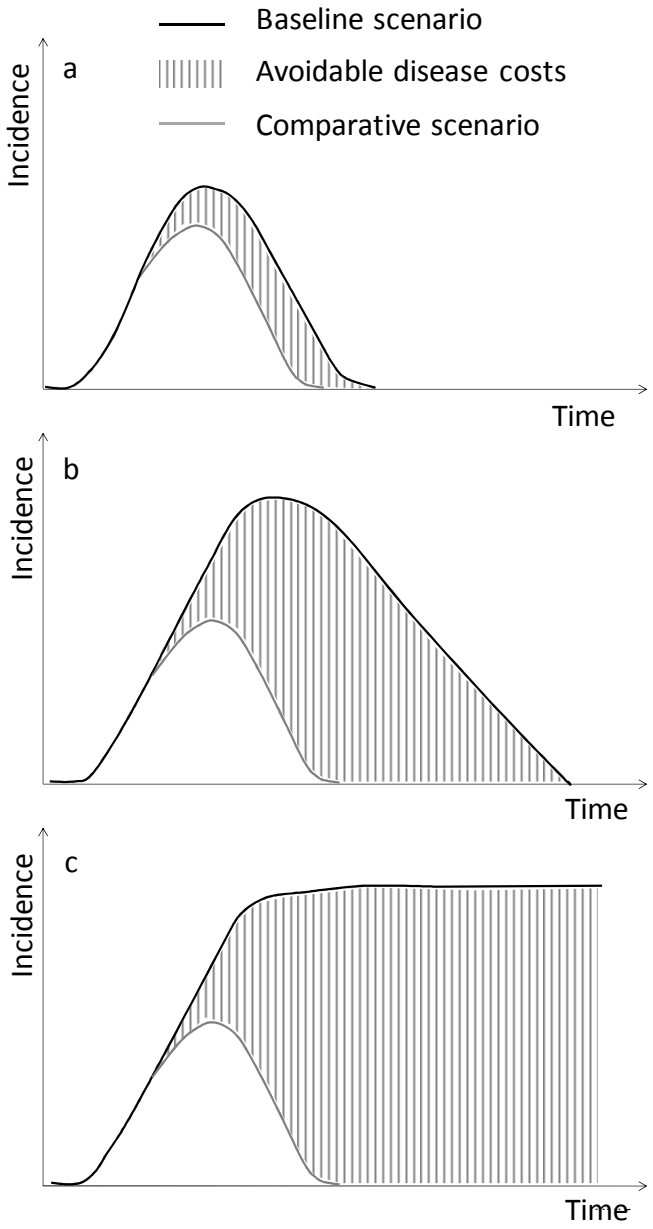
$$ICER = \frac{\text{Cost surveillance } - \text{Cost alternative}}{\text{Effectiveness surveillance} - \text{Effectiveness alternative}}$$

The ICER is generally used to compare mutually exclusive programmes (Eichler et al., 2004), i.e. the additional costs and additional effects are compared to the implemented programme. The new programme to be assessed should be compared to the best alternative to avoid distortions in the calculations and potential wrong conclusions (Cohen and Reynolds, 2008). Generally, ICERs are estimated to compare a current strategy with a new option but do not provide information about the efficiency of the current practice (Hutubessy et al., 2001).

V.3 Baseline and avoidable disease costs

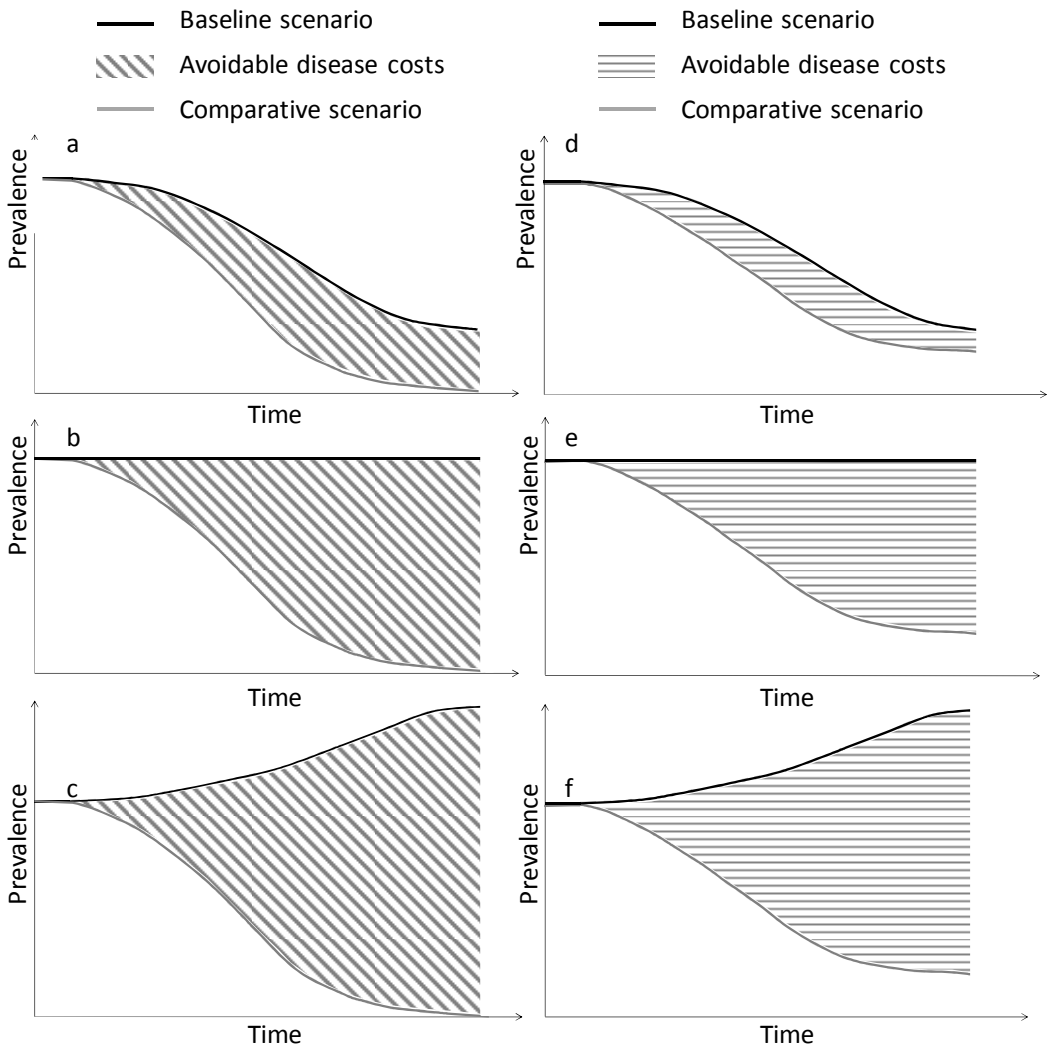
A baseline could be a situation of endemic equilibrium, increasing, decreasing or fluctuating prevalence. To get an idea of the best baseline it is necessary to have a good understanding of the disease dynamics in the population and also to assess what the behaviour of people will be in absence of government action and if this behaviour may impact on the baseline. Thus, it may be equally challenging to formulate a baseline as to assess the impact of government action on the baseline. In many cases, the use of epidemiological models to simulate the baseline will be indispensable.

Appendix Figure V-1 is an example of Stage I mitigation. It depicts three hypothetical baseline (magnitude of outbreak without mitigation) and comparative (magnitude of outbreak with mitigation) scenarios and the resulting avoidable disease costs.



Appendix Figure V-1: Avoidable disease costs for Stage I surveillance reflected in the difference in magnitude of an outbreak illustrated for three hypothetical baseline and comparative scenarios. A) Situation where small difference in magnitude of outbreak between baseline and comparative scenario. B) Situation where large difference in magnitude of outbreak between baseline and comparative scenario. C) Situation where outbreak in baseline scenario results in endemicity.

Appendix Figure V-2 is an example of Stage III mitigation. It illustrates various hypothetical baseline and comparative scenarios for disease eradication (a-c) and reduction (d-f) in a population and the resulting avoidable disease costs.



Appendix Figure V-2: Avoidable disease costs for Stage III mitigation illustrated for hypothetical baseline and comparative scenarios for disease eradication (a-c) and disease reduction (d-f).

V.4 Estimation of non-monetary benefit or cost

Non-monetary benefits are benefits that are not, or cannot be, directly measured in terms of monetary units. These include for example animal welfare, the pleasure people derive from the company of a healthy pet, feelings of safety, consumer confidence or international reputation. The valuation of non-market benefits or costs is a challenging but important element of appraisal. Four common approaches to valuate such benefits or costs are:

1) **Willingness-To-Pay (WTP) or contingent valuation (CV):** This approach has been widely used to assess the value of ecological systems, health attributes and safe food. It was developed to assess non-market environmental benefit (e.g. clean water and air), but has increasingly been used in health economics. It consists of estimating the value that individuals attribute to a good or service, i.e. ask them what they are willing to pay, sacrifice or exchange for a good. The approach is based on the assumption that the maximum amount an individual is willing to pay for a commodity reflects the value it has for this person. The main criticism of the WTP is that it does not give reliable valuations. Since the choices are more hypothetical than real, there is the possibility that what people say that they are willing to pay and what they would actually pay may be different. Another drawback is that non-users of a good or service might find it difficult to attribute a value to it because their knowledge of it is very limited. The approach has been used to value the expected benefits from improvements in food safety and animal welfare. 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 $0.10 more for certified safer pork, but only very few would increase their pork consumption. Bennett (1998) used a hypothetical market scenario in the UK to investigate people's WTP to support legislation to phase out the use of battery cages in egg production in the EU by 2005. The survey showed a mean WTP of £0.43 increase in price per dozen eggs (with a market price of around £1.40 per dozen), thus indicating that most respondents were concerned about animal welfare and supported the proposed legislation.

2) **Quality- and disability-adjusted life year (QALY and DALY)**: People suffer losses caused directly by zoonoses and/or foodborne hazards, which requires the use of appropriate methods to estimate the consequent costs of human death and illness. The QALY attempts to quantify the benefits of an intervention (e.g. treatment) by measuring the quality and longevity of the extra life provided (Brazier, 2007). It is calculated as the value given to a particular health state after an intervention multiplied by the duration of that state and presented as

a common denominator. It uses a scale of health quality that goes from 1 (optimal health) down to a value of 0 (health state equivalent to death). One of the most widely used instruments to determine the weight associated with a particular health state is to use the standard descriptive systems EuroQol (EQ)-5D questionnaire. Another comparable health measure used in CEA is DALY which quantifies the impact of premature mortality and years lived with disability on a population (Murray, 2002). It is calculated as the sum of the years lost due to disability (YLD) and the years of life lost due to premature mortality (YLL). The DALY also avoids the assignment of a monetary value to human life by giving disability weight factors: value 0 represents full health and 1 a disability equivalent to death. In comparison to QALY, the standard formulation for DALY is age-weighted, i.e. it gives more weight to the life years of young adulthood accounting for the social role of those people (young adults are considered as breadwinners and caretakers as they generally support infants and old people). The key issue in the construction of DALYs is the same as for the QALYs, namely the definition and interpretation of weights attached to non-fatal health outcomes.

3) **Welfare scores:** Disease can cause suffering and pain in an animal hence adversely affecting the animal's welfare, which is likely to be manifested in reduced animal and herd productivity. However, an animal in pain or distress may strongly upset or disturb human beings, and hence have an impact on human welfare. Bennett and IJpelaar (2005) assessed the animal welfare implications of 35 livestock diseases by means of a survey of veterinarians and animal welfare scientists. The questionnaire aimed to obtain scores about the extent to which each disease affects the welfare of the afflicted animal. The experts were asked to make subjective assessments of the welfare impact according to the following qualitative estimates: 'no impact' or 'mild' or 'medium' or 'severe' impacts on animal welfare.

4) **Value of information:** One major purpose of surveillance systems is to provide information to guide the action of policy makers. Information can be regarded as a commodity which has a certain value to society. Even though most people

would agree that information may be valuable, there is no common, standardised system available to view, define, valuate and measure information. The costs for gathering, interpreting, communicating and managing information should not exceed the benefit that results from having the information. Several studies integrated the worth of information in the value of information approach. This approach evaluates the benefit of (additional) information in a specific decision making context. A recent study estimated the costs of the Global Polio Laboratory Network and used the VOI framework to assess the value gained from the laboratory surveillance (De Gourville et al., 2006). The value of information approach is based on decision-tree analysis that compares different courses of action that may be taken depending on the amount of perfect or imperfect information available. Each possible action produces a certain amount of costs, depending on the probability of occurrence of a threat, e.g. disease. This framework allows policy makers to identify areas in which the combinations of probabilities and costs lead to a high value of information.

V.5 Epidemiological models

An epidemiological model is "A mathematical model, which may be a computer simulation model, of a disease for the purpose of studying the behaviour of the disease in a variable animal population under variable conditions of climate, density of population, mix of population, and so on. It may be an analytical model, an economic decision making model, an explanatory model or a predictive model. It may also be a causal model, which allows the operator to vary the determinants of prevalence and observe the respective outcomes. It may permit only the use of fixed numbers so that it will always return the same answer to the same question, in which case it is a *deterministic* model, or it may introduce the element of chance into the selection of outcomes, in which case it is a *stochastic* model." (Blood et al., 2007)

In general, epidemiological models are created to predict patterns of disease occurrence and study the impact of mitigation strategies on the disease dynamics in a population. A wide range of epidemiological simulation models has been developed to

inform economic analyses of mitigation programmes (Perry et al., 2001). Useful proxies to estimate disease costs in economic analyses are incidence or prevalence in a population over time under different scenarios. Ideally, both economic and epidemiological models also capture the impact of behaviour of individuals, such as compliance with mitigation programmes and how people react to incentives.

V.6 Discounting

Discounting is a method used to convert future costs or benefits to present values using a discount factor. This enables the comparison of the costs and benefits that occur in different time periods. Discounting is necessary, because a unit of money is considered more valuable today than in the future, a phenomenon called time preference. In other words, people rather enjoy benefits today than in the future (Sloman, 2007). The following equations apply:

Discounting of benefit:

$$Present\ value\ benefit\ (PVB) = \frac{Future\ benefit}{(1+r)^t}$$

Where r is the discount rate and t the time in years.

Discounting of cost:

$$Present\ value\ cost\ = \frac{Future\ cost}{(1+r)^t}$$

The present value for a stream of benefits or costs over *n* years *is*:

$$PVB = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} \quad \text{or} \quad PVC = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

To evaluate government programmes, analysts must decide on appropriate weights to apply to costs and benefits that occur in different years. The choice of the discount factor matters, because it impacts on the decision-making process. High discount rates tend to encourage projects with short-term benefits and long-term costs, while low discount rates tend to favour programmes with benefits in the future (Krahn and

Gafni, 1993). There are no internationally recognised guidelines available on the use of discount rates to assess government disease mitigation programmes. Discount rates for example may be chosen based on observed values in the past, predictions from forecasting agencies, or market rates. The literature provides a wide range of justifications for the selection of a wide range of discount factors.

V.7 Cost-benefit analysis

Cost-benefit analysis attempts to quantify the costs and benefits of a project in terms of common units, i.e. all aspects are to be valued in monetary terms. Social cost-benefit analysis (SCBA) refers to the impact assessment of a programme on societal level, these impacts may be economic, environmental, biological and medical (Rushton et al., 1999). The quantification of costs and benefits that do not have market values is challenging, but should be attempted whenever possible. A major advantage of the approach is that it is applicable to a wide range of problems and that it provides decision-makers with an objective tool. Drawbacks of conventional SCBA are that price effects and linkages across sectors are often omitted and that it is not ideal for capturing longer-term dynamic effects (Rich et al., 2005). However, many of these drawbacks can be overcome by supplementing the analyses with other economic methods and integrating the outputs into the SCBA.

Three key steps in the SCBA are to:

1. Identify programme options to be assessed
2. Identify their costs and benefits
3. Measure and value the costs and benefits in the same monetary unit
4. Compare the costs and benefits of the options identified

Three measures of economic efficiency are commonly used to assess a project: net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR) (Thrusfield, 2005).

The NPV is the difference between the sum of the present value of the benefits and the sum of the present value of the costs and should be positive for an investment to be worthwhile:

$$NPV = \sum \frac{B_t}{(1+r)^t} - \sum \frac{C_t}{(1+r)^t}$$

The BCR is the ratio between the sum of the present value of benefits and the sum of the present value of costs and should be ≥1 for a programme to be viable:

$$BCR = \sum \frac{B_t}{(1+r)^t} / \sum \frac{C_t}{(1+r)^t}$$

The IRR is the discount rate that will make that net present value zero. If the IRR is bigger than the minimal acceptable discount rate, the investment is considered worthwhile. It is calculated by solving for r such that:

$$NPV = \sum \frac{B_t}{(1+r)^t} - \sum \frac{C_t}{(1+r)^t} = 0$$

In a government setting where many costs and benefits may be difficult to quantify, these measures are likely to be only one of many decision-making criteria. The results need to be seen in the wider context and the weight of qualitative impacts that could not be quantified and uncertainties should be taken into account in the decision-making process.

V.8 Sensitivity analysis

Sensitivity analysis is used to measure how the outputs of a model vary when values of input parameters are changed, thereby highlighting how strongly an input impacts on the output (Thrusfield, 2005). Sensitivity analysis is usually done by varying the inputs to assess how the model outcome responds to these changes. This can either be done manually or using special software designed for sensitivity analysis. Sensitivity analysis is particularly important when dealing with uncertain inputs. In such cases, studying the uncertainties provides insights into the dynamics of the model and highlights the

inputs with the most influence on the outcome. If deemed necessary, such inputs can then be scrutinised and data collected to reduce their uncertainty. Sensitivity analysis provides information about the robustness of results and enhances the modeller's confidence in the outcomes. This in turn facilitates communication between the analyst and policy makers and the decision-making process.

When doing sensitivity analysis, three main steps should be considered (Drummond, 1997):

1) Identification of uncertain parameters
2) Definition of a realistic range over which they can vary
3) Calculation of outcome under different scenarios (e.g. worst case, most likely, best case).

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