Chapter 28

Resource allocation for prevention, monitoring and control of Avian Influenza: A conceptual framework

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Abstract

In recent years the world has experienced an unprecedented number of outbreaks of Avian Influenza (AI). These outbreaks have led to substantial economic losses and in some cases human illness and loss of life. In some countries, extensive social impacts have also been documented among farmers and the public in general. Decision-makers will have to choose future strategies for prevention, monitoring and control of AI to reduce these impacts. The objective of this paper is to present a conceptual framework appropriate for strategic decision-making regarding epizootic animal diseases with potential implications for human health, where the emphasis is placed on the allocation of resources between three important areas of action: prevention, monitoring and control. Within this framework, the objective of decision-makers is to maximise the annual social welfare (or minimise the loss of social welfare) associated with preventing and controlling AI. Social welfare is an aggregation of individual utilities; utility is an economic concept reflecting individual welfare and is a combination of both physical impacts and the preferences associated with these impacts. Any number of factors can theoretically contribute to utility such as money income (ability to purchase goods), health state, environmental quality, animal welfare etc.

The conceptual framework developed illustrates the interrelatedness of prevention, monitoring and control and the trade-offs that exist between these actions. Key characteristics of the decision-problem and the implications for decision-making are explored, such as the issue of risk averseness and ‘dread’ in relation to societal preferences.

The value of this conceptual framework is two-fold: prevention, monitoring and control strategies are considered in an integrated manner allowing for trade-offs between these actions, and a social welfare maximisation approach is used such that not only the size of impacts but also their importance for stakeholders and society is included. Impacts are not restricted to epidemiological and financial-economic impacts but include others such as impacts on human health and animal welfare. This framework realistically captures the decision-making problem and allows for a clear understanding of the trade-offs and critical factors involved. The conceptual framework will be further used as a basis for a quantitative analysis of the decision problem using epidemiological and economic modelling and for the subsequent provision of guidelines for decision-makers.

1. Introduction

Until fairly recently, highly pathogenic avian influenza (HPAI) was considered a rare poultry disease with only 17 outbreaks in the forty years between 1959 and 1998 (Alexander, 2000). Since 1999 an unprecedented number of outbreaks have caused significant socio-economic losses and in some cases human illness and loss of life.

Avian Influenza (AI) is a contagious viral infection which can affect all species of birds. AI viruses are classified according to pathogenicity and subtype and almost all combinations of subtypes have been isolated from wild birds. HPAI viruses can cause mortality of up to 100 per cent in poultry flocks, while low pathogenic avian influenza (LPAI) causes much milder disease. HPAI viruses have been restricted to subtypes H5 and H7 and current theories suggest that highly virulent viruses emerge from LPAI viruses by mutation, and that mutation occurs in poultry flocks and not in wild birds (EFSA, 2005). AI (defined as all H5 and H7 subtypes or viruses with a pathogenicity index greater than 1.2) is a notifiable avian disease in the Terrestial Animal Health Code of the World Animal Health Organisation (OIE) which provides a standard for the regular reporting of animal diseases. The genetic pool for AI viruses is primarily in aquatic and shore birds which are responsible for the perpetuation of these viruses in nature. Current evidence suggests that wild birds and particularly migratory birds play a role in the introduction of LPAI into new areas; the role that they might play for HPAI and in particular H5N1 is the subject of continuing debate (Olsen et al., 2006). In addition to all species of birds, AI viruses can also infect mammalian species, including cats, ferrets, rats and mice, pigs and humans.

Outbreaks of HPAI and even LPAI can have a significant impact on countries, depending on the size and length of the outbreak. Economic impacts include both direct losses (the costs of the eradication strategy and organisational factors) and consequential losses due to movement restrictions and market disruptions. Direct losses caused by the 2003 HPAI outbreak in the Netherlands were estimated at 270 million euro, while consequential losses were much higher at 750 million euro (Landman and Schrier, 2004). Other impacts arise from the animal welfare considerations of disease outbreaks and control methods, and the psychological impacts for farmers and backyard poultry holders. Though rarely quantified, these 'intangible' impacts of animal disease outbreaks can be large and pervasive (Bosman et al., 2004; Haaften and Kersten, 2002)

In contrast to many other contagious animal diseases such as Foot-and-Mouth Disease (FMD), AI viruses can have a direct impact on human health. AI viruses can be transmitted to humans causing a range of illness from conjunctivitis and influenza-like illness to severe respiratory disease and death. To date (until 27 December 2006), 261 human cases of H5N1 have been confirmed by the World Health Organisation (WHO), of which 157 were fatal. Although this represents a very high mortality rate, it is unclear how many human cases remain undetected. Current evidence of human infections of H5N1 is consistent with bird-to-human transmission, possible environment-to-human transmission and limited, non-sustained human-to-human transmission (The Writing Committee, 2005). In general, the human infections have resulted from close direct contact with live or dead poultry (Perdue and Swayne, 2005). Given the widespread nature of outbreaks of H5N1, relatively few people have become infected and only a very small percentage have become clinically ill (Perdue and Swayne, 2005). In addition to the direct health risks of AI viruses, a much bigger health threat is posed by the possibility of a pandemic influenza strain arising from reassortment between avian and human influenza viruses. A pandemic influenza strain could also arise from adaptation (mutation) of an AI virus to humans. Reassortment could take place in a human co-infected with an AI virus and a seasonal human influenza virus, or in other mammalian mixing vessels such as pigs. The likelihood of a pandemic influenza strain arising from AI viruses is unknown. Two of the influenza pandemics in the 20th century (1957 and 1968) arose from genetic reassortment of avian and human influenza viruses, while the third may have been the result of the adaptation of an avian strain to humans (De Jong and Hien, 2006). The risks of pandemic influenza clearly influence the strategies used to manage both HPAI and LPAI in poultry.

Decision-makers at the national and supranational level in the European Union will need to select future strategies for managing AI. An overall management strategy will consist of elements of prevention, monitoring and control. In selecting an overall strategy two questions can be considered: (1) what is the optimal combination of prevention, monitoring and control and (2) which measures should be chosen to achieve this combination? To date, most analyses of strategies for contagious animal diseases have focused on the second question and have not considered the trade-offs that exist between prevention, monitoring and control. In this paper we present a conceptual framework appropriate for considering the first question. An overview of the framework is presented and a simple example is used to explore the implications of human health risks for the allocation of resources. Following the conceptual framework, we highlight a number of important characteristics of the decision problem. Particular attention is given to perceived risk in the context of human health risks. At the end of this paper we present a brief overview of methods that can be used to assess specific strategies and measures. These methods can be used to address the second question and will be the focus of further research.

2. Conceptual framework

Choosing an appropriate overall strategy for prevention, monitoring and control of Avian Influenza is a complex problem. A schematic outline of this decision problem for countries within the European Union (EU) is provided in *Figure 1*. The schema clearly highlights the interrelatedness of prevention, monitoring and control actions and places the epidemiological system within a wider socio-economic perspective.

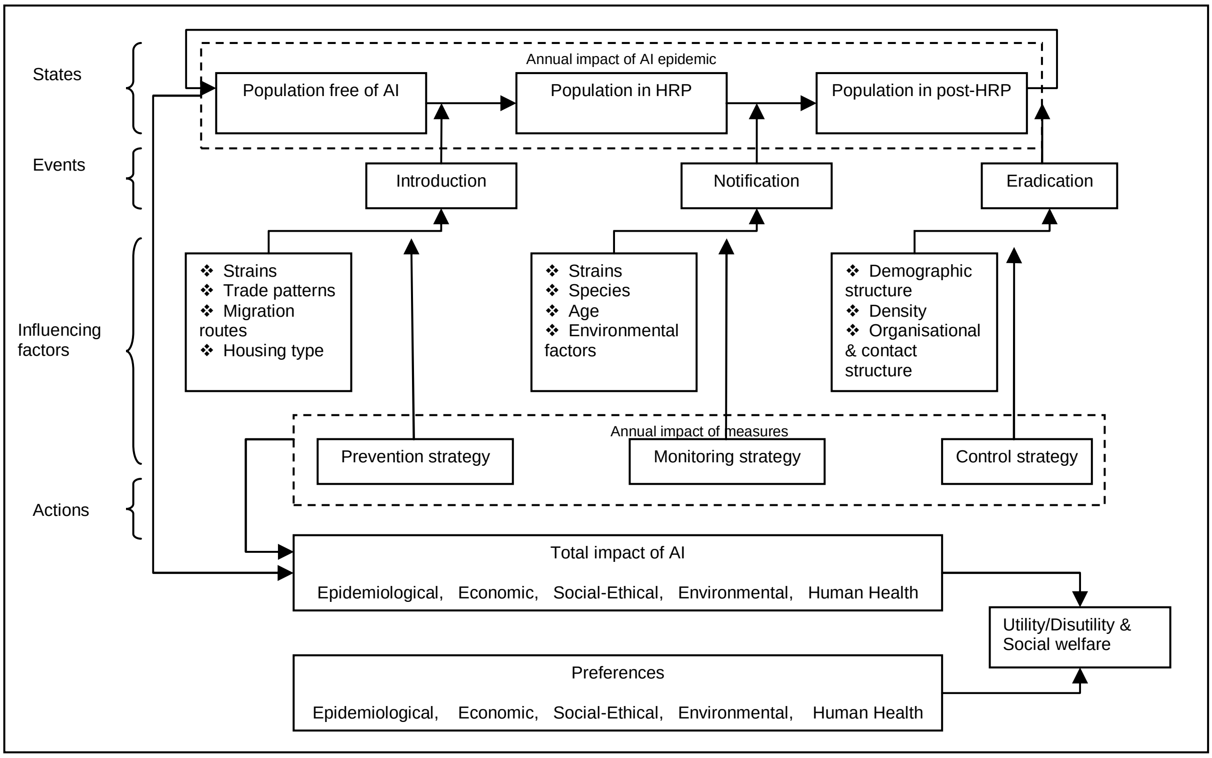

Figure 1. Schematic overview of the decision problem for management of avian influenza

The key elements of this schema are indicted on the left of the Figure: states, events, influencing factors and actions. The domestic, commercial poultry population of a region or country can be in one of three mutually exclusive states at any one time: AI-free, the High Risk Period (HRP), or the post-HRP. Transitions between states take place following the occurrence of a particular event. The normal situation[1] is AI-free where the disease is not present in the domestic population. Following disease introduction, the population enters the

[1] This can be considered as the normal situation within the European Union. In some parts of Asia, where the disease could be considered as enzootic in domestic poultry, this classification would be inappropriate.

HRP. The HRP is defined as the period following introduction of the virus until detection and notification. During the HRP the virus is present but undetected in the population and virus spread occurs largely unhindered. The length of the HRP is an important determinant for the subsequent development of the epidemic. Following detection and notification of the disease the population enters the post-HRP state and control measures are implemented. This period continues until the disease is eradicated and the population re-enters the AI-free state.

The timing of events and therefore the length of time that a population spends in each state is affected by a number of influencing factors, as shown in *Figure 1*. These factors differ according to the event and population state. By addressing these factors, actions can influence the timing of events. An action is defined as a group of measures with the same common purpose; a measure is a specific activity. Examples of measures within the action of control include ring-vaccination, pre-emptive culling and transport restrictions. Three types of actions are considered: prevention, monitoring and control. Prevention is defined as all measures aimed at reducing the likelihood of disease introduction into the domestic population; monitoring includes all measures related to the surveillance of the domestic population aimed at reducing the HRP and control includes all measures aimed at controlling disease spread and eradicating the disease as quickly as possible. An overall strategy is a combination of specific measures for each of these three actions.

Within this scheme the key elements depict the epidemiological system. Decision-makers must consider the epidemiological system in the context of the socio-economic system. The total annual impact of AI is a combination of the impacts of a disease outbreak and the measures implemented. Impacts are classified into five categories: epidemiological, economic, social-ethical, human health and environmental. From a decision-making perspective, not all categories of impact will be important and importance will differ across time and space. Importance is determined by two aspects, the size of the impact and the value given to the impact by individual and societal preferences.

An economic concept that captures the two dimensions of importance is that of utility. Utility is a theoretical measure of happiness or satisfaction. In theory, any element can contribute to utility – consumption of a particular good, the state of the environment, individual health state etc. According to neo-classical economics, individuals make decisions so as to maximise their individual utility. In the context of *Figure 1*, we can consider that individuals' utility (in relation to AI) is a function of some or all of the five categories of impacts. A social welfare function (SWF) represents a conceptual measure for the aggregated welfare of society, which is some aggregation of the utilities of individuals in society. An optimal strategy for prevention, monitoring and control of AI would be one where society's social welfare (aggregated utility) is maximised, or equivalently where society's disutility is minimised. Using these concepts we can illustrate the important factors which determine an optimal allocation of prevention, monitoring and control.

Figure 2 provides an overview of these economic concepts. The possibilities curve (*PC*) represents the feasible combinations of prevention and control efforts, given technical and resource constraints. The SWF portrays the level of social welfare associated with a particular combination of prevention and control. As depicted in *Figure 2*, SWF curves to the right and above (such as SWF_2) represent higher levels of social welfare. The optimal combination of prevention and control arises where the SWF is tangent to the possibilities curve, point *f*. This is the highest level of social welfare achievable given the possibilities curve. Point *g* represents an inefficient combination of prevention and control, while point *e* represents an efficient allocation but a higher level of welfare can be obtained by shifting from point *e* to *f* (a shift from SWF_1 to SWF^*).

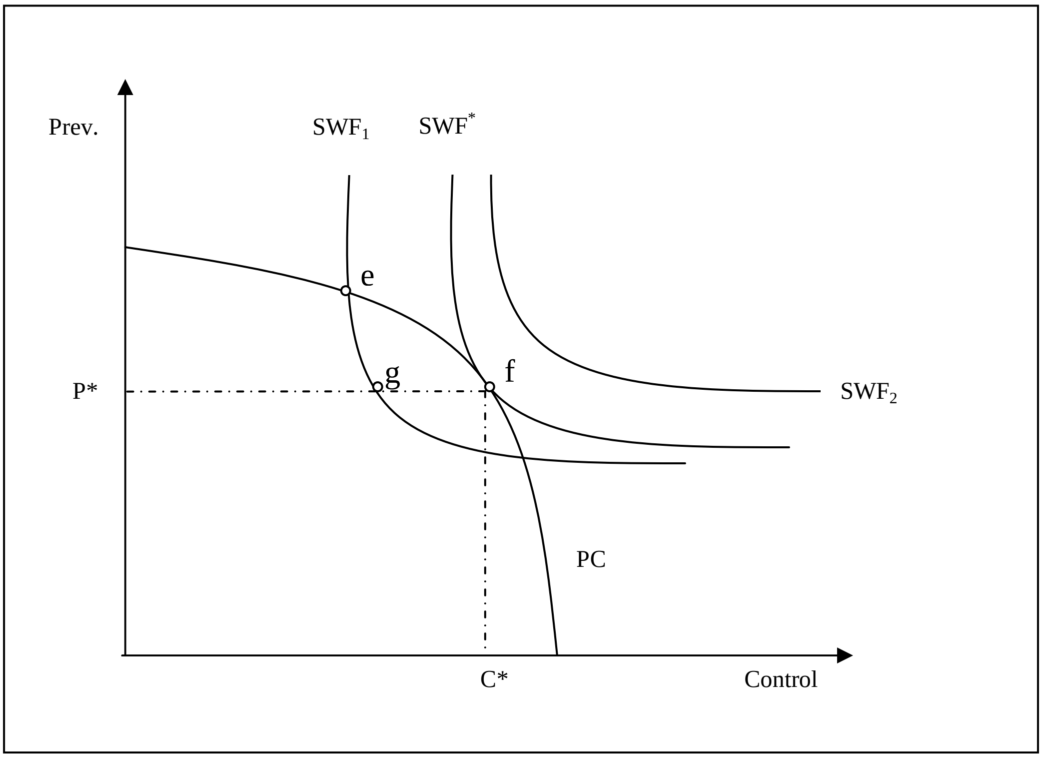

Figure 2. Theoretically optimal allocation of prevention and control efforts to maximize social welfare

3. Application of the framework – a simple example

Using the concepts presented in *Figure 2,* the potential differences between epizootic animal diseases with and without risks for human health can be illustrated. Consider the situation for an epizootic animal disease without implications for human health, such as Classical Swine Fever (CSF) or FMD. The feasible combinations of prevention and control are given in *Figure 3* by the possibilities curve PC_E and the applicable social welfare function is SWF_E, representing some aggregation of the utilities of individuals. For an epizootic animal disease individual utilities could be a function of the economic losses and gains, the level of animal welfare, the psycho-sociological impacts of an outbreak and so forth. The optimal levels of prevention and control are P_E and C_E (point e).

Now consider the situation for an epizootic animal disease with zoonotic aspects, such as AI. Initially, assume that the technical and resource constraints for prevention and control are similar to that for non-zoonotic epizootic animal diseases, therefore $PC_E=PC_Z^1$. However the presence of possible adverse effects for human health has an impact on the shape of the social welfare function. In addition to those factors listed for non-zoonotic epizootic animal diseases, individual utility functions will also be a function of the expected health state of individuals. The effect of health risks on the social welfare function will depend on how individuals value health in relation to other factors such as money income or animal welfare and how large the possible health effects could be. One possible function is depicted in *Figure 3* by SWF_Z^1. The optimal combination of prevention and control in this case is P_Z and C_Z^1 (point f) representing a shift of resources from control to prevention when compared to the non-zoonotic situation. The assumption that technical and resource constraints are the same for both zoonotic and non-zoonotic epizootic diseases may be inappropriate. If this assumption is relaxed, the new possibilities curve could be represented by PC_Z^2, which depicts a situation where a higher level of prevention is not technically possible but higher levels of control are possible (relative to the non-zoonotic disease) through either technical advances or increased resources. The expansion of the possibilities curve allows a higher level of social welfare to be achieved, point *g* in *Figure 3,* consistent with the same level of prevention but a higher level of control.

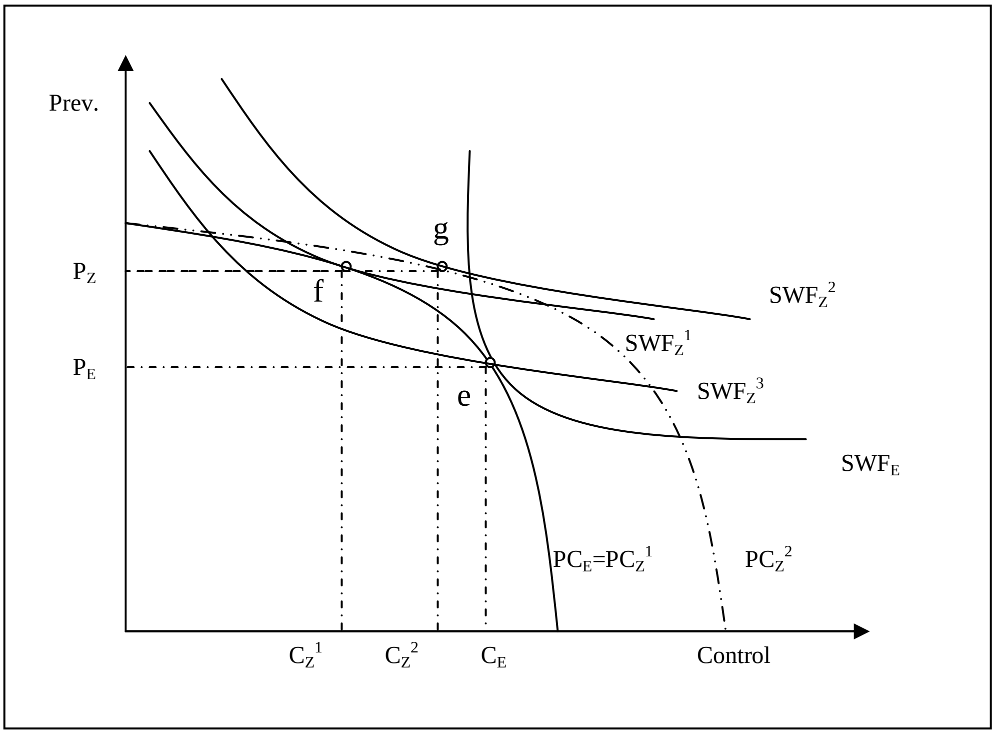

Figure 3. An example of the possible effect of risks to human health for the optimal allocation of prevention and control efforts

The above exposition highlights the potential role that human health aspects can play in decision-making for epizootic animal diseases. Ignoring the impact of human health on individual and societal welfare (that is, assuming that the appropriate social welfare function is still SWF_E when the true social welfare function is SWF_Z^1), the same allocation of prevention and control would be obtained as for a non-zoonotic disease but as depicted in *Figure 3*, this would result in a much lower level of social welfare (SWF_Z^3).
Obviously, a concrete analysis requires a large amount of information regarding the form of the individual utility functions and aggregating social welfare function, the impacts of AI outbreaks on these functions, and the effectiveness and costs of prevention, monitoring and control measures. In further research, the conceptual framework presented here will be extended by specifying further the relationships in the form of an analytical model. Mathematical optimisation and comparative static techniques will be used to show which specific factors influence the optimal allocation of prevention, monitoring and control for AI. Particular attention will be given to the role of human health. This model will remain a general tool for exploring trade-offs and allocation issues. Exact calculation of levels of social welfare for specific strategies using this method is infeasible due to the impracticalities of calculating individual utility functions and the theoretical difficulties of aggregation.

4. Important characteristics of the decision problem – some implications

A number of characteristics of the decision problem can be identified which should be taken into consideration in any theoretical or practical framework. These include: the level of decision-making, stakeholders, elements of risk and risk perception and variability and uncertainty. Each of these elements and their potential implications are discussed. Particular attention is given to risk perception.

Level of decision-making: AI is an OIE notifiable disease and also subject to regulations at the EU level. In December 2005 a new Council Directive was adopted (2005/94/EC) which lays out the measures to be taken in the event of an outbreak of AI. This repeals the existing legislation governing control of AI, Directive 92/40/EC. Although effective, Member States are only required to implement the new Directive as of 1 July 2007. The Directive provides th possibility to adopt additional measures where required; to date these measures have focused on preventative measures. The conceptual framework presented here is consistent with the level of decision-making.

Stakeholder groups: A wide range of stakeholder groups can affect and/or are affected by the management strategy for AI. This includes stakeholders in the production chain (breeders, multipliers, businesses with layers or broilers, slaughterhouses etc.), stakeholders who provide auxiliary services (transporters, feed suppliers, veterinarians etc.), and consumers. For AI, stakeholder groups also include owners of susceptible animals (backyard poultry owners, zoo's etc.) and the general public due to the risk for human health. These stakeholder groups are likely to hold a wide range of opinions regarding appropriate strategies and be impacted in different ways. A strategy which has taken the preferences of these stakeholder groups into account is more likely to be accepted.

Variability and uncertainty: Variability is the effect of chance and is a property of the system under consideration, while uncertainty is the lack of knowledge about the parameters which characterise the same system (Vose, 2000). Both the likelihood of introduction of AI and the subsequent development of an epidemic are inherently variable processes. In addition to variability, there exist a large number of uncertainties in the current level of knowledge regarding introduction and spread of AI viruses. This body of knowledge is constantly being updated in response to ongoing research and new experiences with AI outbreaks.

Risk and risk perception: The traditional paradigm for decision-making under uncertainty in economics is that of subjective expected utility (SEU) maximisation, decisions are made by assessing the likelihood and consequences of the possible outcomes of alternative choices and integrating this information through expectation-based calculus (Loewenstein et al., 2001). A large body of evidence in the fields of behavioural economics, psychology and risk analysis suggests that the expected utility theory is a poor predictor of decision-making under uncertainty. People depart systematically from this rational approach. For example many studies have shown that people have difficulties in interpreting low probabilities (Kunreuther et al., 2001) and that in some situations people appear to either neglect or be insensitive to changes in probabilities (Sunstein, 2003). Tversky and Kahneman (1974) conceptually characterise these departures by suggesting that people rely on heuristic principles which reduce the complexities of assessing probabilities and values. Therefore people do not only rely on probabilities and consequences in making decisions in risky situations. In this line, a growing body of research highlights the role that emotions play in making decisions (see e.g. Loewenstein et al., 2001; Slovic et al., 2004 and, Wardman, 2006). The common theme is the interaction between a cognitive rational process based on the analysis of likelihood and consequence and a feeling-based evaluation based on emotions. The interaction of these dual processes determines behaviour. Although generally considered complementary (emotions play an informational role in decision-making), emotions can also induce individuals to depart from what they consider is the best course of action (Loewenstein et al., 2001). People's emotional reactions to risk are determined by factors such as the vividness of the potential consequences, time-course of the decision, personal exposure to, or experience with, outcomes and past history of conditioning (Loewenstein et al., 2001).

These findings appear particularly relevant for considering how individuals assess and value the risks associated with AI: both the risks in terms of economic losses but also risks for human health. Sunstein (2003) considers the aspect of probability neglect in the face of terrorism and suggests that fear causes people to only focus on the bad outcome and ignore the likelihood of occurrence. Similar phenomena could be expected in regard to AI and the risks of pandemic influenza. These findings suggest that the SEU, which underlies the conceptual framework presented here, does not adequately explain peoples' behaviour in situations under risk. However it is still useful as a basis for decision-making at the national and supra-national level, as long as due consideration is also given to the role emotions might play in individual decisions.

5. Discussion and conclusions

In this paper we suggest that decision-makers must address two questions in choosing an overall management strategy for AI. The first question – what is the optimal combination of prevention, monitoring and control – is the focus of the conceptual framework presented. In most research on strategies for prevention, monitoring and control of contagious animal diseases, each action is considered individually and there is rarely any integration. The framework presented here highlights the value in first considering how resources should be allocated between the three actions before addressing which particular measures are optimal for each action. Such an approach can lead to a more efficient allocation of resources for both research effort and practical implementation of management strategies. In considering the integration of these three actions, attention should be paid to critical factors which may influence the allocation and trade-offs. We suggest that for AI, one of these critical factors will be how society assesses and values the risks to human health. In this regard, the role of risk and perceived risk is identified as a crucial characteristic of the decision problem. This aspect is complicated by the dual nature of the risk to human health of AI viruses: the risk of direct transmission and illness and the risk of pandemic influenza. These two risks have different likelihoods and different consequences for both individuals and society; however for pandemic influenza both the likelihood and the possible outcomes are largely unknown. Emotions such as dread and fear are likely to play an important role in the assessment and valuation of pandemic influenza. In the context of terrorism, Sunstein (2003) suggests that the presence of fear leads to phenomena such as probability neglect, where people focus only on the consequences and ignore the likelihood of their occurrence. Although he considers that basing government decisions on emotion-driven assessments will lead to sub-optimal outcomes for governments, he acknowledges that fear, anxiety and worry present a real cost to society. A similar approach seems applicable for AI. That the presence of fear and worry in a society has real costs has already been demonstrated for AI, many EU member states have seen a large drop in the consumption of poultry products as a response to consumer concerns regarding the risk of AI infection via consumption of poultry products. Understanding the role the emotions play in these decisions will be important for improving risk communication regarding the risks of AI for human health.

The conceptual framework is relevant for epizootic animal diseases both with and without zoonotic aspects. Using a simple example it was shown how using the same analysis for both types of animal diseases could result in sub-optimal allocation of resources for diseases with zoonotic implications. Depending on the magnitude of the risks to human health and how these risks are valued by society, the optimal allocation of resources is likely to favour prevention relative to a non-zoonotic disease. To further explore the role of risks to human health in decision-making, this framework will be further developed into an analytical model. This will allow further analysis of the critical factors affecting the optimal allocation of prevention, monitoring and control for AI.

For a concrete analysis of specific strategies a practical framework is needed which approximates the conceptual framework and takes specific characteristics of the decision problem into account. Two alternative approaches for assessing specific options are cost-benefit analysis (CBA) and multiple criteria decision-making methodologies (MCDM). CBA consists of identifying, quantifying and monetising all the costs and benefits of different alternatives and is the most widely used technique for evaluating policies and projects. CBA is considered as a relatively objective method for assessing policies with an established literature for quantifying and monetising impacts. It is based on the criterion of potential compensation; if winners can potentially compensate the losers a particular alternative represents a Pareto-improvement. In reality, monetisation of all impacts is very difficult and rarely attempted. CBA has been widely used in the field of contagious animal diseases (e.g. Berentsen et al., 1992; Risk Solutions, 2005). Multiple criteria decision methods (MCDM) or multiple criteria analysis (MCA) are general terms for a large group of techniques for decision-making in situations of multiple criteria. Seo and Sakawa (1989) define two phases in MCDM: an analytical (objective) and a judgemental (subjective) phase. The analytical phase is concerned with determining the non-dominated alternatives and the judgemental phase is concerned with identifying the most preferred of these options. Conceptually this is very similar to the framework presented in this paper. In terms of the decision characteristics highlighted in this paper, both CBA and MCDM adequately address the decision-perspective, while the flexibility of MCDM techniques makes them particularly suitable for addressing the aspects of stakeholders and risk perception. Variability can be addressed in both methods (though this is rarely done) and uncertainty is usually taken into account with sensitivity analysis. Although the flexibility of MCDM techniques provides considerable advantages, it also gives rise to method-uncertainty, with different techniques resulting in different outcomes for the same problem. Finally, the focus of CBA is towards finding the best solution while MCDM techniques are generally process-oriented and aimed at providing an analysis of the decision problem.

Both CBA and MCDM require quantification of effects although some MCDM techniques allow for qualitative assessment. An assessment of combined prevention, monitoring and control strategies requires models for the processes of virus introduction and virus spread. Epidemiological modelling of prevention strategies is often undertaking using a scenario tree model (e.g. Sutmoller et al., 2000; De Vos et al., 2004). Main approaches for modelling an animal disease epidemic include mathematical models (e.g. Klinkenberg et al., 2003), state-transition models (e.g. Durand and Mahul, 2000) and dynamic and spatial Monte Carlo models (e.g. Mangen et al., 2001; Karsten et al., 2005). The latter models are particularly suited to analysing control strategies in situations where regional-specific factors play an important role. The results of the epidemiological models for introduction and spread can be used as the basis for the assessment of economic and human health effects.

In further research, a practical framework will be developed using some of the methods outlined. To simulate epidemiological consequences, the results from a scenario-tree model of disease introduction will be linked to a Monte Carlo simulation model of disease spread. The quantitative results will be integrated in an MCDM assessment framework.

In this paper we have stressed the importance of first considering the allocation of resources between prevention, monitoring and control before considering specific measures. In addressing this question, an analysis of the decision problem and a conceptual framework are presented. In further research this conceptual framework will be further refined and a practical assessment approach will be developed.

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