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PRO-POOR HPAI RISK REDUCTION

Costs and Benefits of HPAI Prevention and Control Measures: A Methodological Review

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Table of Contents

Page

List of Tables

List of Figures

Preface

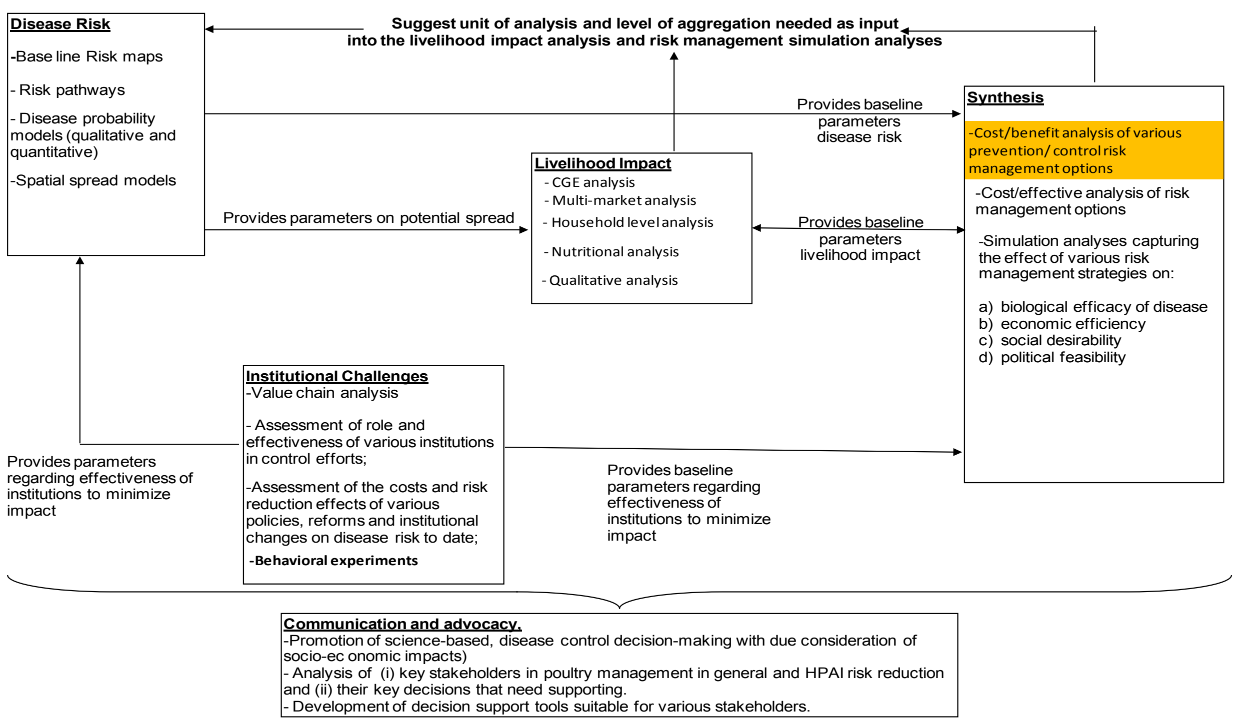
Since its re-emergence, HPAI H5N1 has attracted considerable public and media attention because the viruses involved have been shown to be capable of producing fatal disease in humans. While there is fear that the virus may mutate into a strain capable of sustained human-to-human transmission, the greatest impact to date has been on the highly diverse poultry industries in affected countries. In response to this, HPAI control measures have so far focused on implementing prevention and eradication measures in poultry populations, with more than 175 million birds culled in Southeast Asia alone.

Until now, significantly less emphasis has been placed on assessing the efficacy of risk reduction measures, including their effects on the livelihoods of smallholder farmers and their families. In order to improve local and global capacity for evidence-based decision making on the control of HPAI (and other diseases with epidemic potential), which inevitably has major social and economic impacts, the UK Department for International Development (DFID) has agreed to fund a collaborative, multidisciplinary HPAI research project for Southeast Asia and Africa.

The specific purpose of the project is to aid decision makers in developing evidence-based, pro-poor HPAI control measures at national and international levels. These control measures should not only be cost-effective and efficient in reducing disease risk, but also protect and enhance livelihoods, particularly those of smallholder producers in developing countries, who are and will remain the majority of livestock producers in these countries for some time to come.

To facilitate the development of evidence based pro-poor HPAI control measures the project is designed so that there are five work streams: disease risk, livelihood impact, institutional mechanisms, risk communication, and synthesis analysis. Project teams are allocating and collecting various types of data from study countries and employing novel methodologies from several disciplines within each of these work streams. So that efforts aren't duplicated and the outputs of one type of analysis feeds into another the methodologies in each work stream will be applied in a cohesive framework to gain complementarities between them based on uniformity of baselines and assumptions so that policy makers can have consistent policy recommendations. The figure below is the methodological framework used to depict how work stream outputs fit together. This brief discusses the methodologies to be used when conducting the cost and benefits analysis highlighted in the methodological framework below.

Methodological Framework



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Disclaimer

More information

For more information about the project please refer to www.hpai-research.net.

Abstract

A number of empirical and theoretical contributions for analyzing costs and benefits of control and prevention of animal diseases in the developed and developing countries from the literature are reviewed. The purpose of this literature review is to assess the various ways that have been used to quantify costs and benefits of different control and prevention measures associated with diseases with the aim of identifying an appropriate methodology for analyzing the mitigations measures used to control/prevent Highly Pathogenic Avian Influenza (HPAI) in the study countries.

1. Introduction

This brief presents a review of empirical and theoretical contributions for analyzing costs and benefits of control and prevention of animal diseases in the developed and developing countries. The purpose of this review is to assess the ways to quantify costs and benefits of control or risk mitigation measures associated with animal diseases with focus on the emerging infectious disease, Highly Pathogenic Avian Influenza (HPAI). Several economic and disease risk spread models are reviewed from existing literatures related to animal and plant diseases, microbial pathogens, spread of invasive species, and acts of bioterrorism. This brief serves as background information to achieve one of the objectives of the Pro-poor HPAI Risk Reduction Strategies project,[1] which is to provide decision-makers evidence-based information on their costs and benefits, their cost-effectiveness, and the implication of control management strategy on livelihood. To achieve this objective, a evidence based-analysis is essential for informing decision-makers.

Cost and benefit analysis (CBA), which evaluates the impact of an intervention versus the cost of such intervention is typically used by governments to evaluate the desirability of a given intervention in markets. The costs and benefits of the impacts of an intervention are evaluated in terms of the public's willingness to pay for them (benefits) or willingness to pay to avoid them (costs) (see Narrod 2008 for more details). According to Perry et al. (2001), CBA in the animal health field can take multiple forms, particularly when it comes to the timely prediction of the interaction between disease control efforts and outbreaks and deciding how to quantify its indirect effects. The challenge for the decision makers is to appropriately define and quantify costs and benefits of different control strategies so that it can be compared given the actual time available to them to conduct the analysis and data availability. To overcome these constraints, CBA, in the context of animal health strategies, has often been based on relatively straightforward computation of estimations of key cost and benefits. In terms of cost the parameters of interest are the systems affected by the disease, livestock population at risk, disease incidence and possible control measures, leading to estimates of financial costs and losses and/or prevention/control cost. In terms of benefits the key parameters of interest are marginal value of avoided costs of prevention and control measures, reduced values of expected losses in production and income from poultry, and reduced incidence of disease outbreak.[2]

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[1] This is an on-going project funded by the Department for International Development (DFID) of the United Kingdom implemented in a number of Asian and African countries that have recently experienced HPAI outbreaks, including Cambodia, Ghana, Indonesia, Nigeria, Thailand and Vietnam, and Ethiopia and Kenya in which there has been no outbreak of the disease. The International Food Policy Research Institute, along with the International Livestock Research Institute (ILRI), Food and Agricultural Organization, Royal Veterinary College, and University of California at Berkeley, in collaboration with national research partners, are carrying out this multi-disciplinary research project to identify and promote pro-poor Highly Pathogenic Avian Influenza (HPAI) risk reduction strategies in Africa and Asia. The main purpose of this project is to aid decision makers in developing pro-poor HPAI control and prevention strategies that are not only cost-effective and efficient, but also livelihood enhancing, particularly for the rural poor in developing countries. For more details about the project and its activities, please visit www.hpai-research.net.

[2] Prevention and control costs of animal diseases are costs incurred by measure undertaken ex ante and ex post in response to an anticipated disease outbreak. These include emergency preparedness and coordination such as preventive vaccination generally undertaken by the state of Veterinary Services; surveillance networks including diagnostic capacity/laboratories and border controls; early warning, development of animal health strategies including biosecurity measures (isolation of newly sick animals, movement of animals, people and

The main merit of the CBA framework for decision makers is that it can easily be applied and understood. In addition the rational for model choice and data assumptions can readily be explained in cases where rapid analysis needs to be made (in an acute outbreak situation) and analysis can be updated as more information becomes available.

2. Measuring Costs

Though there exist unlimited applications to measuring costs, there are basically three approaches that have been used to estimate the costs; the economic-engineering analysis approach, the cost survey analysis approach, the econometric estimations of costs (Fearne et al. 2004; Valeeva et al 2004; Havelaar et al. 2006). In the economic-engineering analysis approach, the costs of control programs are estimated for each individual procedure needed to implement the program, and then the total costs is the summation of individual costs. This approach also allows for efficiency analysis via estimation of cost functions based on available technical and economic data. The main advantage of the engineering approach is its transparency as it is easy to understand how the numbers were estimated (Fearne et al., 2004).

In the cost survey approach, costs are measured through surveys of farms. An advantage of this method is that it can capture the variability in costs amongst farms or firms regarding the control measures that get implemented. This approach is fairly simple to use to gather actual costs at the household and institutional level as well as along the value chain where the cost of implementing and managing control measures are straight forward. However, according to Fearne et al. (2004), the quality of the analysis is strongly dependent on the quality of the survey, and it does not allow the assessment of the effect on efficiency of control measures.

In the econometric approach, cost estimations are done by deriving econometrically estimated cost functions using a dataset that is representative for a particularly group of producers. A number of different econometric modeling approaches with different underlying assumptions have been used. Examples of econometric approach are multivariate analysis and parametric estimation applied to cost functions. One of the major strength of the econometric approach is that it captures the experience of entire industries reflecting actual production choices (Fearne et al. 2004). In addition, depending on the econometric model used it can estimate potential trade effects within a sector, and/or depending on the sophistication of the models, as well as spill-over effects on other sectors/markets. A major drawback of this approach is that it requires large data sets if analysis is multi-sectoral and at the national level. Further often decisions need to be made rapidly and it is not always the case that data is available, so such approaches are not always feasible. In addition, the results are vulnerable and strongly dependent on the proxies used to measure variables.

Bennett (2003) developed a framework for the economic assessment of the direct costs of a variety of livestock diseases using a standardized methodology and valuation base which is basically the economic-engineering approach described above. The framework defines **C** as the 'direct disease cost' associated with HPAI, where **C = (L + R) + T + P**, where **L** is defined as the value of the loss in expected output (production) due to the presence of a disease; **R** is the increase in expenditures on

equipment, cleaning/disinfection procedures). FAO (2004) recommends a combination of these control measures to be in place in every country, regardless of whether an HPAI outbreak has occurred.

non-veterinary resources due to a disease (feed, farm labor, etc.), **T** is the cost of veterinary inputs used to treat the effects of the disease following infection, and **P** is the cost of disease prevention measures (such as cost of vaccine to control the disease, cost of foot bath and other related cost to improve biosecurity , etc). A slight modification of the model developed by Bennett (2003) provides a starting point for cost-benefit analysis of disease control options in for this project where **T** is dropped from the equation since experience has shown that no treatment is done following an AI outbreak or infection, rather culling of infected and in-contact poultry (see Narrod 2008).

3. Measuring Benefits

The main potential benefits of preventing and controlling a disease are: 1) enhancing food security and poverty alleviation through productivity improvements and production systems; 2) maintaining or improving trade and market access; 3) savings in potential outbreak costs and avoided economic damages, and 4) reduction in the levels of infection. Capturing the value of these benefits is not an easy task. For instance, in the case of vaccination, the benefits could be reduction in the number of animals culled and the number of infected areas. Benefits can be derived from the value of reduction of economic costs of AI outbreak in terms of the reduced number of culled and/or infected animals and reduced occurrence of new outbreak due to compliance of a control strategy. The value of reduction of economic costs is based on the costs associated with the control measures (Smith et al. 2007; Disney et al. 2001). Another approach would be to calculate the difference of expected values of supply loss (or increase) with and without control strategy (Sumner et al. 2006). Given the constraint of not getting adequate data to assess the benefits associated with various control options from the study countries, we adapt the spreadsheet model that Bennett et al. (2004) used when they assessed the economic impact of bovine tuberculosis and its control. They estimated the expected benefits in monetary terms by estimating the costs of implementing each control strategy that would likely reduce the level of disease incidence. So at the institutional level, benefits, **B** can be expressed as the summation of the avoided losses of the expected output and the decrease in the cost of prevention **P**.

Another approach be to measure benefits of preventing and controlling the disease at the farm level is by determining the individual's willingness to pay (WTP) for a benefit (or for avoidance of a cost). Commonly used valuation methods are based on how people trade-off risk with wealth.) Valuation can be done by measuring revealed preference and stated preferences using contingent valuation method under hypothetical markets (e.g., how much do individuals state their willingness to pay for a specified risk reduction?). Unfortunately, conducting hypothetical experiments to collect information on household behavior before and after control strategies were implemented is costly and may not be feasible in all cases when resources are scarce.[3].

Once the costs and benefits have been estimated, we then calculate for the net benefits. Following Glauber and Narrod (2001), we equate the expected marginal benefits with the expected marginal

[3] For this project, we will try to use such approaches where household surveys are conducted. Currently we have the data to use such an approach to conduct choice experiments in Indonesia after the outbreak. In addition plans are to conduct choice experiments in Nigeria as part of the livelihood impact analysis, from these analyses CBA can be done. In addition, we will try to estimate production costs and consumer .welfare effects, which is affected and constrained by income, as measures of benefits of control measures.

costs to determine the optimal control measure (see Narrod (2008) for more details). In this study, we will be estimating production efficiency, production costs, and consumer welfare as a measure of the benefits of control measures at the farm, institutional level, and along the value chain.

4. More Approaches to Quantify Costs and Benefits of Controlling Diseases with Applications from Developed and Developing Countries

A variety of models have been used to estimate the magnitude of economic impacts of plant and animal diseases and to quantify the costs and benefits for disease control strategies. Some of these studies are presented here highlighting the methods used. Attention is also given to those models that consider disease prevention and control costs. Table 1 presents examples of methods used for quantifying costs controlling animal diseases with applications from the literature. In general, the approaches can be divided into three major groups: a) cost-accounting, b) simulation (static or dynamic); and c) optimization. In calculating costs, it is important to consider farm locations and spread of the disease. This is where spatial spread models are very useful. These models are important particularly if the strategy is spatially targeted, like ring vaccination or contiguous slaughter.

Spatial spread models are increasingly being recognized as valuable tools for assessing adoption of alternative strategies for disease control and impacts on disease prevalence and household welfare as location may matter (Beach et al 2006). These models help to highlight the importance of considering the ways that various policy measures such as emergency vaccination, affect the incentives facing producers and their behavior in developing policies to mitigate the spread and impact of HPAI particularly in terms of location. Comparisons between alternative control strategies must reflect the incentive structures under each strategy. Appropriately designed policies that account for producer response can help overcome the coordination failure that otherwise arise under market equilibrium conditions and improve household welfare. This is true not only for prevention and control of HPAI, but more broadly for prevention and control of other animal diseases, invasive species, or acts of bioterrorism. Quite a number of studies, particularly in the developed countries, have been done combining disease spread models and economic frameworks. Some of the recent studies are briefly discussed below.

Teklehaimanot et al. (2007) have employed a GIS-based method to estimate the population in Africa at risk of contracting malaria, and then calculated the cost of providing this population a comprehensive set of interventions (differing by level of malaria endemicity and differing for rural and urban populations) to reduce malaria incidence by 75% and also mortality.

A number of studies on invasive species management use spatial models in understanding and monitoring invasions across landscapes (Horan et al. 2005; Randosevich et al. 2003; Kalkhan and Stohlgren 2000). For example, Horan et al. (2005) developed develop a simple spatial model to illustrate how harvest strategies, inside and outside a disease reservoir, could affect disease prevalence rates within the reservoir, dispersion into new areas, and the associated economic tradeoffs. They found that the efficiency of disease control could be improved by developing policies around economic thresholds as opposed to ecological thresholds, and that these economic thresholds and the associated optimal management strategies could change significantly when dealing with spatially interacting systems (e.g., disease transmission and wildlife dispersal).

The following models and methodologies provide a basis for choosing or developing a method for the cost-benefit analysis of HPAI control and prevention strategies in each of the study countries.

Simulation Models and its Applications

Simulation models can be used to estimate the economic impact (cost) of an intervention and the associated benefits of controlling for a disease. Some simulation models are designed to look at the impact at the national, regional, or sectoral level while others are designed to look at the impact at the household level. In addition, some have integrated the output of the simulation model with the dynamics of the spatial spread of disease so as to better evaluate risk management strategies. Simulation models are appropriate in providing base-case estimates when data on costs and benefits are limited, and the results are very much dependent on the validity of the existing data. A few examples on application of simulation models that have been used to measure the cost and benefits of disease control are discussed below.

Rendelman and Spinelli (1999) combined economic and biological models to assess the social costs and benefits of African swine fever prevention in the U.S. The analysis used a partial equilibrium model combining a dynamic simulation model of the hog and pork sector, which accounted for producer and consumer decision-making and assessed the costs (farm-level, slaughter-site and demand-site costs). In addition, they incorporated a disease spread model using a state-transition matrix. The state-transition matrix takes animals from one disease period and distributed them to other states in the next period. They found that the benefit-cost ratio for the Swine Health Prevention program were high, over 450. Further the net benefit of prevention efforts was estimated to be almost $4,500 million at a cost of $10 million for the 10-year period considered. The model is simple and flexible that it can be easily modified to allow analysis for other hog diseases such as hog cholera, however, it cannot handle impacts of diseases that affect other species or multiple species, such as foot and mouth disease.

Wadsworth et al. (2000) evaluated the circumstances under which control programs reduce the range of two widespread invasive weeds of riparian habitats (Himalayan balsam and giant hogweed). The spread of the species was modeled using MIGRATE, a model that uses realistic demographic parameters and multiple dispersal mechanisms. Additionally, simulations of range of control scenarios were run with a GIS using real landscapes based on topographic, hydrological and land cover maps of the area looked at six strategies for weed control including; at random, in relation to human population density, by size, by age (young or old), and by spatial distribution of the weed. A positive finding was a reduction in weed range after any control strategy was implemented. Wadsworth et al. (2000) asserted that successful control of both species is only possible when strategies based on species distribution data are used, and when they are undertaken at relatively high intensities and efficiencies.

Mangen et al. (2001) used a stochastic simulation model linked with an economic model to evaluate various culling and vaccination strategies of the classical swine fever (CSF) outbreak in the Netherlands. They used the InterCSF simulation model developed by Jalvingh et al. (1999) simulates disease spread from day to day from infected farms through three contact types: animals, vehicles, persons, and through local spread up to one kilometer. Direct costs including vaccination costs, compensation paid to the farmers, and consequential losses for farmers and associated industries subject to control measures were calculated using EpiLoss. EpiLoss is based on partial budgeting that calculates these costs and losses but does not take into account benefits such as higher profits of farmers outside the restricted areas or profits of industries selling vaccines. They found that a preemptive culling policy (selective culling for potentially exposed herds) was an effective strategy to reduce the spread of epidemic and an emergency vaccination was an effective alternative approach

Bates et al (2003) used a spatial stochastic simulation model to assess relative costs and benefits (and cost-effectiveness) of vaccination and preemptive herd slaughter and other strategies to control transmission of foot-and-mouth (FMD) virus for a three –country region in the Central Valley of California post-outbreak. In their model, cost information was based on the assumption that FMD affected US livestock herds would be quickly slaughtered and facilities cleaned in the event of an FMD diagnosis, as well as restriction imposed on local movement of animals. From this baseline strategy, alternative control strategies were compared. The alternative strategies were vaccination of all noninfected animals in herds within a designated distance of each infected herd, preemptive slaughter of all animals in herds within a designated distance of each infected herd, and preemptive slaughter of all animals in the highest-risk herds as determined by use of the model. The results were then combined with the findings from previous published simulation studies for FMD to derive net-benefit figures and benefit-cost ratios based on cost estimates from the results of the simulations. In addition a sensitivity analysis was carried out for greater precision of estimates and assumptions which were inherent in the model. All alternative strategies involving use of vaccination were economically efficient (B/C range, 5.0 to 10.1) and feasible, whereas alternative strategies involving use of slaughter programs were not economically efficient (B-C, 0.05 to 0.8) or feasible. Further, the authors concluded that vaccination may be cost-effective if the vaccinated animals were not subsequently slaughtered and that selective slaughtering of high-risk herds was preferable to other preemptive slaughtering.

Yoona (2006) applied the stochastic and spatial simulation model of between-farm spread of disease, using InterSpread Plus to evaluate the effect of alternative strategies for controlling the 2002 epidemic of foot-and-mouth disease (FMD) in the Republic of Korea.[4] InterSpread Plus was parameterised to simulate epidemics of FMD in the population of farms containing susceptible animal species in the Korean counties of Yongin, Icheon, Pyongtaek, Anseong, Eumseong, Asan, Cheonan, and Jincheon. The results of simulations of alternative epidemic-control strategies were compared with a reference strategy, which approximated the real epidemic. Results showed that ring vaccination (when used with either limited or extended pre-emptive depopulation) reduced both the size and variability of the predicted number of infected farms. Reducing the time between disease incursion and commencement of controls had the greatest effect on reducing the predicted number of infected farms. Kung et al (2006) used a similar approach in modeling AI virus transmission dynamics in the local chicken farms and retail markets in Hong Kong. Using InterSpread Plus, various simulations were conducted such as AI disease spread from a possible source live bird market to farms, from an infected farm to other farms and to live poultry markets through three contact types

[4] InterSpread Plus is a computer program designed to provide a geographically referenced framework for modeling the spread of diseases among populations using Monte Carlo techniques (http://www.interspreadplus.com/).

(animals, vehicles, persons) and through local farm-to-farm spread within a specified area. The main disease-control mechanisms which influence the disease spread included diagnosis of infected farms and live poultry markets, depopulation of the infected farms and of live poultry markets, movement restrictions, tracing and pre-emptive slaughter, and other alternative control strategies such as vaccination.

Nin Pratt and Falconi (2006) used a partial equilibrium model to simulate ex-ante, the potential costs to the Latin American economy of an HPAI outbreak in 21 countries in Central and South America and used a cost/benefit analysis to assess investments to prevent and control the disease. The study reviewed the impact of recent outbreaks of AI in Southeast Asia and used this information to define two scenarios (rapid response versus slow response) in Latin America to estimate the different costs that may occur to an economy depending on the response rate. A probability of occurrence was assigned to each scenario based on the status and capacity of veterinary services in different countries to respond to an outbreak of AI. Investments to prevent and control AI in each of these countries were estimated and then evaluated using a probability distribution of costs and benefits that result from these investments. The control measure modeled included culling all infected stock, controlling movements of poultry around the infected zone, tracing sales of infected animals and implementation of an early warning system allowing farmers to take their own control measures. A simple partial equilibrium model for each country was used to calculate the impact of an HPAI outbreak, in which there are two equations for the supply of each kind of meat (poultry, beef, and pork): one calculating the number of animals in stock as a function of the price of meat, the other defining total meat supply as a function of the stock and a ratio of yield per head of stock. Benefit-cost ratios are also computed for operating and investing in different control strategies under both scenarios and thereafter, a sensitivity analysis is performed on the results to address uncertainty of investment needed to control HPAI, and the probability of an outbreak. A major limitation of this study is the lack of adequate data, therefore supporting employment of sensitivity analysis. The study concluded that high returns to investment in HPAI prevention and preparedness are expected based on their methodology.

Meuwissen et al. (2006) used a simulation model to describe the spread of HPAI virus between farms, focusing on the transmission that remains after the implementation of intervention measures required by EU directives (‘EU strategy’), i.e., culling the infected and contact farms and establishing surveillance (3 km) and protection (10 km) zones around such farms assuming the introduction of HPAI. The EU strategy measures for controlling the potential spread of HPAI between farms were then compared with another strategy, i.e., strictly implementing EU strategy with additional culling in 1 km radius around infected areas. Using the estimated transmission kernel (or the relative importance of spread over different distances) and the location data for all poultry farms in the Netherlands, the spatial propagation of HPAI was simulated. Probability distributions of size and duration of an epidemic that is likely to ensue once HPAI has been introduced into a poultry dense area were also calculated. Based on these distributions, a cumulative probability distribution of direct economic cost associated with such an epidemic was calculated. Direct costs included the veterinary costs directly associated to the control of an HPAI epidemic, such as the value of culled animals, and organizational and overhead costs. Indirect costs included losses due to business interruption that depend on uncertain factors such as farmers finding another job; losses due to price effects depend on many uncertain aspects, such as the response of other countries; and reduced export opportunities. Based on the analysis, HPAI was found to spread rapidly in only two poultry dense areas of the Netherlands, and the employed control methods were found to be ineffective. Greater preemptive culling of all farms within a 1-km radius around the infected farms however was found to be associated with short-lived epidemics.

Smith et al. (2007) developed a model to simulate bovine tuberculosis (TB) in badgers, the transmission TB from badgers to cattle, and control of TB by means of culling. Model simulation was carried out for both reactive and proactive control measures to estimate the rates of transmission. For reactive control, the response to a breakout of TB within a herd was a localized badger culling strategy and for proactive control, badgers in areas with predefined monitoring were culled probabilistically based on the assumption of full compliance with culling regulation and land access. Costs of compliance were then calculated based on data (supplied by Defra) on a team of two personnel while benefits were calculated based on the reduction in the number of TB breakdown herds and reactor animals on farms. The results from this study suggest that for reactive control measures, there was a reduction in the mean number of cattle herd over time and for proactive measures, short-term culling reduces the prevalence of TB but at slow recovery rate. Also the net present value (NPV) for reactive control strategies were generally negative and cumulative costs exceeded benefits in the short-term.

Most recently, Breukers et al. (2008) used a bio-economic model approach to quantify the costs of controlling a potato rot, a quarantine plant disease and the benefits of avoiding export losses, in relation to the effectiveness of control policies. They integrated an epidemiological model with an economic model into a bio-economic simulation model that allows for ex-ante evaluation of control strategies for their cost-effectiveness. The epidemiological model simulates the spread of brown rot over all potato-growing farms for a sequence of years, and provides detailed information on infected and detected lots and affected farms for each year (see detailed description of the epidemiological model in Breukers et al. 2006). The economic model determines the annual costs and benefits and the efficacy of a particular control strategy given the simulated spread of the disease; it consists of three modules: structural, incidental, and export losses. The structural costs module quantifies the enforcement and monitoring costs of preventive measures. The structural costs were assumed constant over time for a given control strategy because they do not depend on the level of incidence of the disease. The incidental costs module quantifies the costs incurred through reactive measures following detection of an outbreak. The incidental costs were assumed to depend on factors that vary per year such as the number, size, and category (seed, ware, or starch) of detected lots, the number of farms involved, and the potato production characteristics of these farms. The reactive measures include destruction of infected potato lots, no replanting for lots that were classified as "probably infected", no more cultivation on infected fields, and quarantine restrictions imposed on the infected field. The export losses module quantifies the losses from reduced exports of potatoes resulting from simulated observed incidence of brown rot in the Dutch potato production chain. In a simulation run, export restrictions occur in a particular year if an extremely large number of infections are found in the respective year ("incidental outbreak") or if the number of detections in previous years ("historical level") was relatively high. The level of export restrictions in a year was determined by the critical values, which represent the minimum number of brown rot detections that could lead to a particular level of export restrictions.

Optimization models and its applications

Optimization models can evaluate different control and prevention strategies when the resources are optimally used particularly during an outbreak. Optimization modeling overcomes the limitations of simulation-based studies, which allow a subset of all possible control strategies achievable given the objective function. Their weaknesses are that these type of models are complicated, which may not reach an optimal solution. They also do not account for flexible strategies that can vary over time. Applications of this decision-theory type of methodology have been made in a number of studies particularly aimed at finding optimal or efficient control strategies for epidemic and endemic diseases. Some applications of the optimization model are briefly discussed below.

Stott et al. (2003) use an optimization model to look at the control of bovine viral diarrhea (BVD). In this model, they combined epidemiological and economic parameters to integrate animal health into whole-farm business management to aid in farm-management decisions associated with BVD in cow-calf herds in Scotland. The Minimization of Total Absolute Deviation (MOTAD) model is used to assess the relative contribution of disease prevention to whole-farm income and to farm income risk. They also used the model to assess disease losses in the context of a farm business rather than as a disease outbreak in isolation (i.e. without taking into account the risk of outbreak). They found that the total costs related to optimal disease control level varies (constant if risk is not taken into account) according to the level of risk of contraction associated with each herd.

Ahmadi et al (2006) used a deterministic (which is based on average or expected value parameters) economic optimization model to calculate the costs of applying various decontamination methods (or a combined set) per beef-carcass quarter against E coli O157:H7. Data on some of the required cost items were obtained through interviews with slaughterhouse experts in Dutch industrial slaughterhouses. Price of other costs such as investment costs for machineries were derived from interviews or correspondence with supply companies, internet and personal communications. In the economic model, the basic situation before applying decontamination was compared with an alternative situation (with decontamination). Costs of decontaminations were categorized into two main groups: recurrent costs (variable costs that frequently occur) and non-recurrent costs (fixed costs incurred at the beginning of the implementation of a decontamination method). The total costs of decontamination methods were equated with the sum of the recurrent and non-recurrent costs, and then cost-effectiveness ratios were calculated.

Elbakidze and McCarl (2005) used a two stage stochastic programming model to examine the relative effectiveness of the surveillance and detection strategies before FMD outbreak, and response strategies before and after an FMD outbreak in the event of an act of bioterrorism. The aim was to determine the circumstances under which it would be beneficial to invest in detection programs incurring prevention costs thereby allowing for quicker detection of outbreaks, versus reliance on post outbreak response measures. In the first stage, investments were made in cattle testing facilities and in conducting tests, including the option of doing nothing. It was assumed that if investment in detection mechanisms was not made in the first stage, the disease would spread until the time of recognition and appearance of clinical signs. In the event of no outbreak, cattle operations would continue as usual. In stage two, a probability of occurrence of a disease outbreak and its prevention and control—vaccination and depopulation of infected cattle including those in the vicinity of an outbreak—were taken into account. Total costs included pre-outbreak expenses on surveillance and detection, along with a probabilistic outbreak under which society encounters the costs of response strategies, and economic damages from the outbreak. Surveillance and detection costs included pre outbreak fixed and variable costs of installing testing facilities and administering tests that are incurred regardless of outbreak occurrence. Response costs included post outbreak costs associated with vaccination and/or depopulation, which take place only if an outbreak occurs. Economic costs when an outbreak occurs included value livestock lost due to infection and earnings, lost for infected animals and those destroyed in the process of outbreak management. Findings suggest that the optimal level of investment for pre outbreak scenarios highly depends on probability of introduction, rate of disease spread, relative costs, and ancillary benefits, and effectiveness of mitigation strategies. Also, the higher the likelihood of disease introduction, the more advantageous it would be to invest in pre outbreak mechanisms.

To capture the infection risk of disease at the farm level, Beach, et al (2006) developed a conceptual model capturing both disease risk and the economic impact on agricultural households. The model combined the economic decisions of a farm household into a single framework and allowed the derivation of household demand functions for private control measures and responsiveness to changes in risk and alternative policy measures related to HPAI. They used a profit maximizing model to quantify the benefits of private control measures by estimating the increased revenue which is due to the reduced probability of HPAI introduction in the farm. This approach could be extended to assess adoption of control strategies and its effect on livelihood and nutrition particularly of poor smallholders (see Birol 2008 for discussion on how this model can be applied to quantify livelihood impacts of HPAI outbreak). In the case where risk of infection is exogenous to an individual producer, an increase in the probability of AI infection definitely decreases optimal allocation of resources to poultry production for an individual producer assuming minimal market-level effects—the presence of AI infection is likely to decrease demand for poultry products enough to raise equilibrium market output prices. In the case where disease risk is endogeneous to producers, adoption of private control measures would happen only when it is optimal. Results of this household model such as elasticities and expected profits could be used to model impacts for price changes, impacts on other sectors, and non-market impacts in the economy as a whole.

Kobayashi et al. (2007a; 2007b) modeled management of FMD control strategies—depopulation and vaccination—using a dynamic cost-minimization optimization framework. The model minimizes total regional outbreak cost by choosing herd depopulation and vaccination strategies, given epidemiologic relationships of dynamic disease spread and constraints on disease control capacity. With this model, it is possible to evaluate different preparation strategies when the resources are optimally utilized during an outbreak. The model explicitly incorporates local disease dynamics in an optimization model and evaluates all possible combinations of control strategies simultaneously, focusing on tradeoffs at a local level that can be captured by local disease dynamics. This model however is deterministic as opposed to stochastic (considers variability and uncertainty), using mean disease transmission parameters, and does not internalize the impacts of local disease control strategies outside the region because it assumes equal risk of infection (did not take into consideration farm locations into the disease transmission computations). This limits the use as a predictive tool because each epidemic or disease outbreak follows a unique pattern, which is most likely different from average.

Based on a vast array of approaches that have been reviewed, a methodology that can be applied in this project is proposed below to identify the optimal control approach by simulating the effect of various risk management strategies on the biological efficiency of the disease, economic efficiency, social desirability, and political feasibility.

Table 1. Selected studies and methodologies used for quantifying costs to controlling animal diseases

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
Dynamic Simulation model to estimate the cost of implementing a prevention program for African Swine Fever (ASF) taking into account producers' decision making and assesses social costs and benefits.	Rendelman C.M., Spinelli F.J. (1999)	Assumes a closed economy; only considers the US domestic swine market (assumes the US produces to meet its own demand because linkages outside the local pork and hog sector are expected to be insignificant).	Prevention measures include: depopulation, quarantine, indemnity, surveillance, screening and testing of affected hogs	Combines economic and biological models to assess costs and benefits of disease prevention. Estimates can be revised (with simple spreadsheet models) if new probabilities of disease outbreaks occur or are estimated. Employs a state-transition matrix which takes animals from one disease state in a period and distributes them in other states in a subsequent period.
Spatial Stochastic simulation model to assess relative costs and benefits of controlling transmission of FMD virus. Analysis calculates net-benefits and benefit-cost ratios of control strategies and compares these estimates to a baseline strategy.	Bates T.W., Carpenter T.E., Thurmond M.C (2003)	Cost-effectiveness of strategies are compared to a set of guidelines from an ideal baseline strategy which requires slaughtering herds diagnosed of FMD, closure of sale yards, initiation of a 10km infected area and a 20km surveillance strategy around each	Vaccination and preemptive slaughter of herds that have a high probability of exposure to FMD	Model combines economic analysis with the disease risk/epidemiological models from a previous study by the same authors (Bates et al., 2003b) so as to quantify effectiveness of eradication strategies. The study also utilizes sensitivity analysis to determine the

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
		infected herd. In addition and in some cases, supplemental strategies which entailed ring vaccination and preemptive slaughter within a specified distance of infected herds were considered along with the baseline strategy.		assumptions that are driving the results.
Static Simulation model to estimate *ex ante* costs and benefits associated with prevention of HPAI in Latin America by comparing simulated results from two extreme scenarios: poor prevention and surveillance response from an underequipped economy (as in the case of Vietnam) versus an effective and well-equipped prevention and surveillance system in anticipation of HPAI (as in the case of Japan)	Nin Pratt A., Falconi C (2007)	Assumes variation in impact between both scenarios based on estimates from previous studies. For instance, it is assumed that demand for poultry drops by 20% in the first scenario and by 8% in the second. Assumed that migratory bird flyway is the only mode of transmission for disease outbreak and spread.	Vaccination, compensation to farmers and, surveillance	Assesses (and highlights) the importance of institutional response to HPAI. Allocates country-specific costs and probabilities for each scenario based on unique country characteristics. Employs sensitivity analysis to justify use of some of the assumptions that were made.

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
Linear programming approach (MOTAD) to estimate the economic impact of bovine viral diarrhea (BVD) in Scotland by minimizing decision makers' risk subject to a set of farm-business constraints.	Stott A.W., Llloyd J., Humphry R.W., Gunn G.J. (2003)	Farms are assumed to have limited resources for animal health activities for which they must compete and farmers are constrained by certain regulations Probabilities of finding a given number of infected animals were adopted based on an ideal distribution – the truncated geometric distribution.	Investment in greater bio security measures such as double fencing on the perimeter of the farm, vermin control and protective clothing and boots for farm workers.	Models probabilities of infection and risk reduction in the context of whole-farm business management to determine the marginal benefits that disease prevention can have on a farm enterprise as a whole. Compares the benefits associated with risk minimization against cost minimization, for disease prevention and control. Analyzes bio security measures as possible disease prevention and control strategies as opposed to the conventional control mechanisms (e.g. culling).
Mathematical and spatial spread 'transmission kernel' model for *between-farm* transmission of HPAI, focusing on transmission that remains after regulatory interventions have taken place.	Meuwissen M.P.M., Van Boven M., Hagenaars T.J., Boender G.J., Nodelijk G., De Jong M.C.M.,	The models which estimate the possible impact of an HPAI epidemic are based on the assumption that an introduction of the HPAI virus has actually	EU strategy: culling of infected and contact farms and establishing surveillance (3 km) and protection zones (10 km) around infected farms; and a combination of EU strategy and culling in a 1	Models the probability of transmission from one farm to another (from infected to susceptible farm) by assuming transmission probability is a function of distance between two

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
Transmission kernel is estimated from actual epidemic data using maximum likelihood estimation. Direct costs are simulated using Monte Carlo simulation model.	Huirne R.B.M. (2006)	occurred on a particular farm.	km radius.	farms. Had available data from an actual HPAI epidemic (which occurred in 2003) that aided in development of a sound theoretical framework upon which the simulated models were based. Allowed different distributions for each subcomponent of the Monte Carlo simulations: (1) Poisson distribution to reflect uncertainty in the number of epidemics that occur, (2) discrete probability distribution for the region in which the epidemic occurs and (3) cumulative probability distribution to estimate direct costs.
Dynamic simulation model to estimate transmission and control of TB from badgers to cattle; deterministic model to calculate control costs	Smith G.C., Bennett R., Wilkinson D., Cooke R. (2007)	Assumes herd breakdowns are caused by infection from badgers to cattle, and can therefore only be inferred to culling herd breakdown (CHB)	Culling of badgers by trapping and gassing	Estimates costs and benefits associated with *both* reactive (local badger culling within a certain distance from an actual CHB) and proactive (predefined monitoring and culling of badgers in badger-dense areas within a

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
		populations in which the proportion of CHBs caused by badgers is known. Also, the study assumes a period of six months between initial infection and detection.		specified km^2 area from CHBs) badger culling scenarios.
Spatial stochastic simulation model to simulate day-to-day disease spread from infected farms through local spread and three contact types, for Classical Swine Fever in the Netherlands; direct costs and consequential losses were estimated using a financial model based on partial budgeting. Combines an epidemiological and economic model to quantify the relative consequences of adopting two possible emergency-vaccination campaigns.	Mangen M.J.J., Jalvingh A.W., Nielen M., Mourits M.C.M., Klinkenberg D., Dijkhuizen A.A. (2001)	Modeling is carried out under several assumptions. For example, an infectious period of 1 month was enforced and, only 'vaccinated-and-later-infected' farms were assumed to show a reduction in virus spread. Two kinds of infected farms were also distinguished: (1) infected farms that were never vaccinated and farms that were first infected-and-later-vaccinated and, (2)	Emergency vaccination	Imposed assumptions were supported with sensitivity analyses in most cases. The model acknowledges and incorporates three potential spread pathways, i.e. animals, vehicles and persons.

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
		farms that were vaccinated and later became infected. Although vaccination is the main control strategy being dealt with in this study, the model presumes no relaxation of other control measures.		
Bio-economic model to quantify the costs and benefits of controlling plant quarantine disease (Brown rot of potato) and potential export losses as prescribed by the Dutch brown rot control policy.	Breukers A., Mourits M., van der Werf W., Lansink A.O. (2008)	Epidemiological parameters (policy, sector, exogenous, farm and field) used were based on estimates from expert panels.	Model is developed for estimation of costs and benefits for various Dutch potato rot control strategies including a ban on irrigation of seed potatoes with surface water, destroying of lots which are found to be infected and, quarantine of infected lots for three years.	The approach allows for *ex ante* evaluation of control strategies for their cost-effectiveness. It also has two appealing attributes: In relation to the effectiveness of control, it is able to quantify the costs of controlling a disease, and the benefits associated with avoiding export losses.
Stochastic epidemiological model and deterministic economic model to estimate the effectiveness and total costs of decontamination	Ahmadi V., Velthuis A.G.J., Hogeveen H., Huirne R.B.M.	For Monte Carlo simulations modeling elimination probabilities of each method, they assumed a specific	Decontamination methods include: trimming, hide wash with ethanol, hot water wash, steam pasteurization, steam-vacuum, lactic acid	Combines an epidemiological and economic model.

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
measures in beef carcass against E.Coli O157:H7 by using and ranking cost-effectiveness ratios. Two Monte Carlo simulations were used to: (1) Estimate the number of contaminated beef quarters at the end of the quartering stage and, (2) model the elimination probabilities of each decontamination method.	(2006)	surface area for each beef carcass, with a corresponding number of bacteria on each surface. Used a binomial process for Monte Carlo simulations for contamination and a beta distribution to describe carcass contamination.	rinse, gamma irradiation; and different combinations of the aforementioned decontamination methods.	Assesses 7 different decontamination methods both individually and as different combination sets.
Probabilistic Risk Assessment (PRA) model linked with a decision model to evaluate the cost effectiveness of various combinations of pathogen reducing technologies to reduce the prevalence of food borne pathogens (*E.coli)* in the beef production process. Incorporates the probability of contamination associated at each step (4 steps in all) of the	Malcolm S.A., Narrod C.A., Ollinger M., Roberts T. (2004)	In line with economic theory, assumes that firms (production plants) adopt the least-cost combination of technologies to achieve pathogen reduction. Also assumes that the plants do not have improved technology in place.	Decontamination methods include: dehiding, steam vacuuming, hot water final carcass wash, steam pasteurization and irradiation.	Integrates risk analysis with a decision making model of effective decontamination strategies.

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
production process.				
Total Cost Minimization Approach; Two-stage stochastic economic programming model to examine the tradeoffs between pre and post outbreak strategies for controlling FMD.	Elbakidzie L., MC Carl B. (2005)	Wealth utility was assumed to be maximized (or affected) by minimizing damages and costs associated with possible disease outbreaks and severity of attacks.	Pre-outbreak measures include surveillance and detection costs while post-outbreak costs include vaccination and/or slaughter.	Examines tradeoffs between pre and post outbreak control strategies taking into consideration outbreak probability, speed of disease spread, magnitude of disease introduced damages and costs of mitigation strategies
Dynamic optimization model to evaluate alternative FMD control strategies.	Kobayashi M., Carpenter T.E., Dickey B.F., Howitt R.E. (2007a;2007b)	A daily discrete-time specification was assumed with the following assumptions at the beginning of the day: (i) set prevalence variables representing the number of herds in each status at the beginning of the day, (ii) herd's transition in disease status, (iii) latent incidence, and (iv) implementation of depopulation and vaccination controls.	Depopulation of FMD infected herds (baseline depopulation), preemptive depopulation of potentially infected herds, vaccination of infected herds, and movement restrictions on animals, vehicles and personnel.	The optimization model allows for simultaneous consideration of all control strategies and chooses the most efficient one endogenously. Validates its findings by using sensitivity analysis to compare results to that of an epidemic simulation model carried out in the same region (Bates et al., 2003).

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
		Assumptions were made about the dynamics of vaccinated herds; e.g. vaccination was assumed to be effectively immediately after administration. Only commercial herds were included in cost estimation. Backyard herds were assumed to have no monetary value.		
Uses prevalence data and Geographical Information System (GIS) data to develop risk maps. Based on these, it estimates the total population at risk of contracting malaria and then estimates the costs associated with controlling these risks based on a costing exercise carried out in 2006.	Teklehaimanot A., McCord G.C., Sachs J.D. (2007)	Assumes a ramp-up of coverage by 2008, which is then projected through to 2015 to give a year-to-year cost of meeting the MDGs for reducing the burden of malaria.	Provision of bed nets, indoor residual spraying, training of community health workers, other information and education.	Estimation of risk and incidence by location using GIS data serves as a new and appealing method as opposed to traditional survey methods which have been employed for cost estimation in the past.
Spatial simulation model to examine the spread and management of two invasive	Wadsworth R.A., Collingham Y.C., Willis S.G.,	Model assumes that a single introduction of species occurs only in	Management strategies include: (1) Random - random visits of cells until	Model explores six representative strategies and uses realistic demographic

Methods applied	Authors	Assumptions	Control Measure(s)	Strengths
weeds of riparian habitats, and the circumstances under which control programs may reduce the range of spread. Does not calculate direct costs or benefits but assesses strategies at different intensities of management, at varying efficiencies in terms of proportion of plants destroyed and, timeliness of implementations.	Huntley B., Hulme P.E. (2000)	the primary contact location	the maximum number of sites were found and treated; (2) Social – treating of infested cells with the highest human population density; (3) Population – focus on areas where that were population-dense; (4) two 'Age' strategies – one for cells that had been occupied longest and another for newly targeted cells that had been recently colonized.	parameters and multiple dispersal mechanisms.
Stochastic, state transition susceptible-latent-infected-recovered (SLIR) model which operates within a GIS framework to estimate the rate of spread and assess the impact of a potential introduction of FMD by calculating costs resulting from incurred losses from an outbreak, and costs of implementing a management program.	Ward M., Norby B., McCarl B., Elbakidzie L., Srinivasan R., Highfield L., Summer L., Jacobs J. (2007)	Assumptions were made on: direct and indirect contacts, herd type allocation, composition of herds by animal type proportions, values and daily revenues for herd types, saleyards, slaughter, disposal time, ring vaccination, surveillance, windborne spread for certain herd types and, quarantine and other costs	Slaughter (culling), vaccination	Combines an epidemiological, economic and GIS model. Examines different possible avenues of disease spread simultaneously. Considers 13 different herd composition types as well as different species.

5. Proposed Methodology for this Project

The models used in evaluating effectiveness of various control strategies presented above vary from relatively simple deterministic mathematical models to complex stochastic simulations. These models have been used to 1) predict the future based on baseline scenario and known behavior; 2) explore effects of various conditions based on known dynamics; and 3) simulate various scenarios to test outbreak conditions and control measures.[5] In order to address the project's objective, we use three approaches. First, with the national partner we will do a simple CBA to capture the global effects following the Glauber and Narrod approach (see Narrod, 2008). Second, we will combine the results of this CBA with the results of the quantitative risk assessment to do a simple CEA (see Narrod, 2008). Lastly, we will adapt the bio-economic framework developed by Breukers et al. (2008) to simulate the effect of various risk management options on biological efficacy of disease, economic efficiency, social desirability, and political feasibility. We believe that the Breukers et al'sr framework would be useful to also capture the uncertainty and variability surrounding the nature of HPAI virus. As shown in Figure 1, specific control measures identified such as depopulation of infected and possibly exposed birds, vaccination, compensation, and improved biosecurity practices (including no mitigation measures implemented) will be evaluated and compared in terms of both the cost-benefit ratio of the measure and the cost-effectiveness of the measure (see Table 2 for prevention and control measures currently being used in the five countries). Disease risk and economic outcomes will be simulated under each control strategy and then cost-benefit and cost-effectiveness analyses of control strategies will be conducted.

The disease risk output will be producing disease risk maps, qualitative, and quantitative risk assessments, and stochastic and spatial disease risk models. Economy-wide modeling (CGE and multi-market type of models) will be conducted using specific scenarios identified in the disease risk modeling results to look at the potential macro-economic impact of the spatial spread of HPAI on the economy. The macro-economic effects will include the impacts on production, price changes, trade patterns, and national economic welfare, and the impact on other sectors such as industry, and non-market impacts in the economy. The CGE and multi-market analyses approach is detailed in Roy (2008). In determining the magnitude of the economic impact, factors such as rate of spread of the disease, control, mitigation, reaction of trading partners and multiplier effects will be taken into consideration.

[5] HPAI disease control measures include culling and proper disposal of infected and possibly exposed birds, vaccination, border controls, zoning/compartmentalization, movement controls, and cleaning/closing wet markets, disease surveillance, compensation, poultry sector restructuring, and improved biosecurity practices.

Table 2. Control measures and responses of governments and private sectors to HPAI outbreaks in the five study countries

	Responses of Governments	Responses of private sectors	Control Measures
ETHIOPIA	Established a national task force, which set up technical committees Drafted a US $43 million budget for possible control measures Set up crisis management team for avian flu and developed the national preparedness plan Outbreak investigations and surveillance on poultry and wild birds	Individuals importing the food are responsible for ensuring compliance with food safety from the country of origin. Exporters are also responsible for ensuring compliance of goods with food safety standards, quality and nutrition.	Banned all poultry imports and poultry machinery from countries with HPAI outbreaks Strengthened controls on cross border trade
GHANA	Public declaration of outbreaks by Minister of Food and Agriculture Intensification of public awareness campaign to highlight the roles of migratory birds, movement of infected poultry and importation of contaminated poultry products in the spread of AI Sero-surveillance/epidemio-surveillance (active and passive search for the disease in the infected area and beyond) established	Anecdotal information suggests that some farmers folded up their businesses due to inability to market products because of the ban on the sale of poultry and poultry products	Quarantine of infected farms and standstill measures as required Ban on the movement of poultry and poultry products in and out of the infected area. Culling of affected and in-contact animals Paid compensation to owners of destroyed animals; rates vary between 70% and 90% of the market price Decontamination and disinfection of premises, vehicles, etc. infected by the virus Closure of wet poultry markets in the area

INDONESIA	Established a national committee, Komnas FBP, on Avian Influenza to ensure AHI strategy implementation Engaged non-government organizations and civil society in planning Komnas FBP, with support from UNICEF in coordination with FAO and AED, and the Ministries of Health, Agriculture and Information launched a separate national public awareness campaign to promote behavior change and to raise awareness to reduce the risk of human exposure to HPAI A US$15 million World Bank grant to control avian flu and provide preventive vaccines and compensation for culling Implemented standard procedures and systems for communicating outbreak observations and reporting between the government and technical agencies and hospitals Implementation of compensation policy for culled poultry	Implemented standard procedures and systems for communicating outbreak observations and reporting between the government and technical agencies and hospitals Launched a national public awareness campaign to promote behavior change and to raise awareness to reduce the risk of human exposure to HPAI	Selective Stamping out Vaccination Surveillance Compensation to layer farms with less than 10,000 hens and broiler farms with less than 15,000 bird per cycle Credit schemes for farms that have been infected with HPAI Increased biosecurity to prevent contact or spread; targets: commercial and backyard farms Control movement of live poultry, poultry products, and farm waste
KENYA	Completed a national action plan Strengthened surveillance Launched awareness programs Placed veterinary personnel at entry points on alert Training of veterinarians and para-	Farmers reduced the size of their poultry flock for fear of the avian flu, lack of market for their products and low demand and prices for broilers Loss of revenue due to panic and premature selling of poultry in an	Epidemio-surveillance (includes both active and passive surveillance) Import ban Banned import of poultry and poultry

	veterinarians to strengthen the surveillance system Strengthened laboratory diagnostic capacity Established strategy for possible destruction of birds and disposal of carcasses Engaged the private sector with the coordinating committee for effective mobilization Increase awareness among small-scale farmers and poultry producers	attempt to get rid of stock and reduce chances of poultry to contract avian flu. Sector 1 and 2 suffered losses as a result of cancellation and reduced booking for day-old chicks. Peoples' attitudes towards chicken were greatly affected by the initial announcements about avian flu from the media. However, after a short period, they recovered from the shocks through public awareness campaigns aimed to enlighten individuals about the spread and nature of the disease	products from all affected countries Quarantine; delineation/zoning Culling Disinfection of persons, materials, equipment and vehicles infected by the virus Movement control
NIGERIA	Putting plan in place for restocking poultry once bird flu outbreak is confirmed The UNCT established a national task force and committees at the state level to assist government in preparedness and response Government established a Crisis Center to link with affected areas Teams from FAO, WHO and US Centers for Disease Control and Prevention training Nigerian health and veterinary workers in controlling the virus Engaged non-government organizations and civil society in preparedness and planning Conducted socio-economic impact studies of HPAI	Through the Community Dialogue System (CDS), community leaders were trained in identifying risky behaviors, attitudes, perceptions and beliefs, before, during and after the outbreaks	Quarantine Eradication Restocking poultry once bird flu outbreak is confirmed Compensation to farmers whose birds were destroyed, at 30-40% of the market value

Sources: United Nations Office for Coordination of Humanitarian Efforts (2006). http://www.irinnews.org/frontpage.asp; IFPRI-ILRI Synthesis Background Paper 2008.

In the cost minimization approach, we adapt the model suggested by Beach et al. (2006). In this model, only HPAI risk is considered; other risks such as production and price risks are not being considered. Also, the model only focuses on poultry production activity and does not consider other non-poultry production activities.

The optimal levels of control measures would be those where the marginal benefits in terms of avoided impacts of HPAI are just equal to the marginal costs for providing the control measures. The marginal benefits can be calculated from the first-order conditions of a profit maximization function. Thus, the goal is to maximize profit, which is equal to revenue less a priori costs plus expected cost of disease:

$$\max_{\mathrm{T_p,T_{si},N_{pi},a_i,b_i}} \text{Profit} = \text{Pp}\ Q_i - \left[w_pX_p + p_mC_m + w_{pN}N_{pi} + w\left(T_p + T_{si}\right) + p_aa_i + p_bb_i\right] - \pi_\mathrm{i}(a,b) * C_d$$

where the parameters are defined as follows:

Q_i = poultry output, which is a function of farm and hired labor, flock size of the farm, and other fixed and variable inputs

Pp = poultry output price

wp = vector of farm input prices other than household labor and birds

Xp = farm inputs other than household labor and birds

pm = price vector for consumption goods

Cm = vector of consumption goods

w_{pN} = input price for poultry

N pi = flock size of the farm

w = wage rate

Tp = amount of time working on farm to produce poultry

Tsi = amount of time spent for on-farm disease surveillance

pa = price of HPAI vaccine

pb = price vector for biosecurity inputs

and the decision variables are defined as follows:

ai= takes a value of 0 if without vaccine, and 1 with vaccine

bi = vector of biosecurity measures

π_i = probability of an outbreak

C_d = cost of disease including financial compensation for culling as a control measure

Note that *i* above refers to a single class of operator and different classes are likely to have different costs and maybe sets of control options. In addition, the probability of an outbreak is determined by what the individual operator does and what other operators do, and will differ between farms and along the value chain.[6] Institutional costs for monitoring control measures and training will be covering costs both at the farm level and along the value chain.

In the case of costs incurred at the institutional level, direct expenses related to the control strategy including cleaning/disinfection and carcass disposal, value of poultry depopulated, daily operational costs during the preparation of an outbreak or during the epidemic, direct and indirect costs of disease control, and costs if the government provides compensation for lost poultry assets are included in the model (see Table 3 for list of data needs). Direct costs of control strategies are relatively easy to identify and can easily be quantified as they can be equated with resource expenditures incurred by relevant government authorities. Indirect costs are more difficult to quantify since they theoretically extend to other sectors of the economy. For purpose of simplicity, we mentioned earlier that we will adapt the deterministic model suggested by Bennett et al. (2003) to measure direct costs. To do this, we first identify the poultry population at risk and the production systems (commercial, semi-commercial, or backyard) affected by HPAI virus. The incidence of HPAI outbreaks in these populations is also important; information with respect to the incidence of outbreaks can be found in the background papers of the study countries. Then we try to estimate the value of production loss by production systems affected to identify the range of the physical effects of HPAI infection, compared to what might be the expected production without HPAI. Finally, we identify the different control and prevention measures undertaken such as depopulation, provision of information and technical assistance, and a combination of these control measures, and estimate the costs incurred.

The benefits of controlling HPAI at the farm level are the changes in costs in preventing infection or avoiding outright death of animals like investment in biosecurity to improve the physical condition of the farm, and reduce probability of HPAI introduction on the farm. However, these benefits are difficult to quantify. If consumers are not willing to pay off for additional efforts made by the producers, the benefit and income of the producers would decrease. We could look at direct benefits as higher production efficiency, reduced production costs or economic savings when the number of animals culled decreases. Indirect benefits could include extra profit for increased sales or higher prices due to improved consumers' perception. Increases in profits will significantly improve the livelihoods particularly of rural poultry farmers.

Once the costs and benefits have been quantified, the next step is to calculate for the marginal costs and marginal benefits and set these two equal to each other to obtain the efficient level of control strategy. A decision maker chooses a control strategy that maximizes net benefits, where the expected value marginal of costs equals the expected value of marginal benefits (see Narrod (2008) for details). For each of the control measure, there are actually two decision choices: to apply or not to apply; each decision will have the same chances of events: no infestation, infestation controlled, and infestation not controlled with the assigned probability of occurrence of HPAI virus in a farm/village/country i, π_i, based on existing knowledge (from the disease risk assessment findings). The probability would depend on the situation of the outbreak, such as no outbreak, or initial

[6] According to Beach et al. (2006), the probability of primary HPAI introduction into poultry flocks in an area is a function of both farms' behaviors, locational characteristics, and production systems, including the prevalence of the virus among live bird markets and the contact rate between these flocks, which depends primarily on the number of poultry (N_p).

discovery, or a major outbreak has occurred. So a change in probability would affect the change in net benefits in controlling the disease.

Data needs

The CBA framework has basically four components table of parameters or variables used to calculate costs and benefits, incremental-effects model that sets out expected events (which are subject to uncertainty) and its consequences over time, table of costs and benefits over time, and expected outcomes of investment, and a statistical and graphical analysis of net present values and investment risk.

The data needed to identify disease risk factors can be grouped into four parameters: policy, exogenous, epidemiological, sector. Policy parameters include HPAI control policy that is implemented or to be implemented; exogenous parameters include social and climatic circumstances; epidemiological parameters include prevalence or incidence of HPAI outbreak,[7] severity of the outbreak, probabilities of introduction/occurrence and transmission of HPAI, and duration of the outbreak; and sector parameters include characteristics and structure of different poultry production systems and players along the poultry chain including slaughterhouses and processing plants. In the absence of exact values for each of these parameters, information from experts' consultation can be considered, and sensitivity analyses could be performed based on different assumptions to indicate which uncertain input parameter would most likely influence the results of the model. The output of the epidemiological model feeds into the economic model.

Data needed for the economic analyses include supply and demand for poultry and poultry products including prices, and price elasticities, and cost and benefits of implementing various control measures and alternatives which are listed in Table 3. A more comprehensive list of data needs is available in Narrod (2008). A simple spreadsheet model accounting for these costs can be estimated adapting the approach standardized by Bennett (2003) using expenditures on prevention and control for each control measure instead of total costs. Information is also needed on the incidence of infection by HPAI virus in the poultry population at risk (measured by a certain probability), and the severity of the effects on production at the time the disease is introduced and in the course of an epidemic (in the absence of data, estimates of low, medium, and high values can be used to capture both the variations over time and uncertainties related to the incidence and effects of the disease). For example, expected losses can be calculated as the product of the probability of an outbreak and estimated production losses (mortality). To value the expected production loss is calculated as the product of the number of poultry (by species) affected by production system and the appropriate market price for the poultry.

[7] Prevalence is a proportion (P) indicating the number of cases of a disease (D) within a population (N) at a specific time (P=D/N).

Table 3. Summary of data needed for the costs and benefit analysis to controlling HPAI

Types of costs (expenditures)	Items
Direct costs(expenditures)	
Prevention and control costs per head of poultry (for example, culling, vaccination, surveillance, biosecurity)	Number of poultry lost (died from the disease or culled), by production system as much as possible; Average market value per head of poultry (pre-outbreak); costs of equipment, facilities; transportation, and veterinary service fees, drugs and vaccine costs, cost for surveillance and diagnostic tests, compensation costs + eradication estimates (could be based on compensation paid to producers); or costs of other preventive and control measures where appropriate;
Labor costs to manage the outbreak	hired labor costs, opportunity costs; overtime costs
Transport and disposal costs	On-farm disposal costs, license/permit fees,
Cleaning and disinfection	Disinfectant used in cleaning infected premises
Consequential on-farm losses (for example, costs due to fall in stock, movement restrictions etc.);	Farm income from activity per head of poultry; Duration of farm business disrupted due to the outbreak; labor productivity loss in terms of work-year lost; output elasticity of labor; prices of farm inputs, farm gate prices for different poultry products, changes of inputs and costs.
Costs incurred by governments during 'normal' times (for example, emergency preparedness plans and coordination)	Costs on strengthening the capacity of Veterinary services and animal public health services—number of veterinarians, diagnostic laboratories, etc., public disease control measure, and public regulations; surveillance networks, laboratory costs and cost of training staff capable of doing lab tests, and lab testing and diagnose costs; and border controls; early warning, development of animal health strategies.
Indirect costs (expenditures)	
Ripple effects (on product prices, trade, and on upstream/downstream activities along the livestock value chain)	Changes in domestic and world poultry price; change in domestic sales; volume and value of export losses which may be induced by large number of outbreaks or reported cases in a particular year or a relatively number of reported cases in several successive years—could be temporary reduction on export volume following an incident; volume and value of imports, i.e. revenue foregone as a result of denied access to markets or idle production capacity; production losses as a consequence of control; costs related to extra preventive measures undertaken.

Spill-over effects	Loss in world tourism income value; impact on agricultural input and services sectors; net impact of outbreak on consumer demand and price levels and proportion of producers/ production affected on domestic and international markets: depends on impact; effect on the non-agricultural sector.
Incidence of infection	Probability of incidence and severity of infection by HPAI H5N1 virus in the poultry population at risk

Other data needs related to livelihood and income include poultry production, prices of inputs and outputs, revenues, costs of production including labor and transport costs, and capital investments and how HPAI alters that—this means looking at different scenarios or HPAI situation: from no infection, to sporadic, to endemic.

6. Examples of CBA of Control Measures Done in the Five Countries

The following examples for Nigeria and Indonesia were mostly taken from the work on economic analysis of prevention and outbreak costs conducted by Civic Consulting - Agra CEAS Consulting in 2007. They used global estimates from available literatures and experts interviews to estimate prevention and control costs. It is not surprising that there are relatively few examples of CBA studies found in the literature associated with prevention and control strategies for HPAI. This could be due to difficulties in terms of acquiring data required for the analysis and the dependence of the analysis on basic assumptions and scenarios. For example, costs of control methods may differ in terms of the nature of the disease spread, whether locally (contract with infected animals in wet markets) or long distance (through migratory birds, sale of inputs or illegal trading of birds), or in terms of timeframe, whether short-run or long-run when disease is acute or endemic. Moreover, there might also be differences in economic impacts between production arrangements and income groups.

Table 3 presents the different control measures to HPAI outbreaks and actions taken by the government in the five countries covered in this project. The control measures are based on the Global Strategy for the Progressive Control of Highly Pathogenic Avian Influenza developed by FAO/WHO/OIE, which were adopted in the formulation of National Action Plans to Control AI of each of the study countries.[8] Depending on data availability, ex-ante or ex-post CBA will be conducted in five country studies,wherever appropriate.

[8] The key components of the Global Strategy for the Progressive Control of HPAI are: 1) *Control at Source in Birds*—this means improving veterinary services, emergency preparedness plans and control campaigns (including culling, compensation, quarantine and movement restrictions and vaccination); 2) *Surveillance*—this involves strengthening early warning, detection and rapid response systems for animal and human influenza; building and strengthening laboratory capacity rapid confirmation; rapid and transparent notification; 3) *Rapid Containment*—this means support and training for the investigation of animal and human cases and clusters, and planning and testing rapid containment activities; 4) *Pandemic Preparedness*—this involves building and testing national and global pandemic preparedness plans; strengthening health system capacity, training clinicians and health managers; 5) *Integrated Country Plans*—this includes developing integrated national plans across all sectors to provide the basis for coordinated technical and financial support; 6) *Communications*—

7. Ghana: selected direct and indirect impacts of AI outbreaks

After detection of the first H5N1 strain of avian influenza in April 2007, culling of infected domestic poultry was implemented. The Ghanaian government was transparent about the reported infection, both to the national and international community. It is said that the Ministry of Food and Agriculture is responsible for the compensation to farmers 50-90% of the market value for their destroyed birds. To stop further spread of the virus, exporting of birds was temporarily banned. Other actions taken by the government were quarantine of affected area and temporary closure of live-birds market.

The cost of prevention and containment for domestic animal populations is estimated at USD 1,218,878 (AI Working Group 2006).

(Note: No CBA for Ghana was found in the literatures reviewed)

8. Ethiopia: selected direct and indirect impacts of AI outbreaks

In the case of Ethiopia where there is no HPAI outbreak yet, CBA can be done to predict the future costs of HPAI epidemic and assess the social and economic impact of an HPAI outbreak. The introduction and spread of the disease could result to losses of income and therefore negative effect on the livelihoods and nutrition particularly of rural smallholders. Poultry occupies a unique position in terms of its contribution to the provision of high quality protein food to rural smallholder farming families in Ethiopia. It is estimated that spread of the disease could result in flock mortalities of up to 100 percent in the case of the H5N1 subtype, resulting in losses of income and a negative impact on the livelihoods of millions of smallholder farmers (FAO). Free-range chickens kept as scavengers or in backyards increase the risk of infection through the transmission of the disease from wild birds to domestic chickens.

FAO developed a manual of standard operation procedures (SOPs) for HPAI prevention and control in Ethiopia. The manual covers the animal health component: biosecurity, movement control, surveillance and diagnosis of avian influenza, culling of poultry, disposal of carcasses and potentially infective materials, vaccination of poultry and compensation. Based on the SOPs, two training manuals were prepared for use by personnel who would be involved in poultry vaccination, culling and disposal of carcasses and contaminated materials. A livelihoods assessment of the social and economic implications of an outbreak of HPAI was commissioned. The results of this study were valuable in the development of a compensation policy, designed to address the commercial and backyard poultry production sectors. This policy was approved by the National Avian and Human Influenza Coordination Committee. Detailed guidelines for the implementation of the compensation policy were developed.

(Note: No CBA for Ethiopia was found in the literatures reviewed)

because factual and transparent communications, in particular risk communication, is vital (Source: Global, OIE/ FAO/WHO, March 2007).

9. Kenya: selected direct and indirect impacts of AI outbreaks

Kenya's national preparedness plan includes epidemiology and surveillance, disease control strategies, laboratory diagnosis and research, information, education and communication. The main objectives of the plan are to strengthen the influenza surveillance network, assess the impact of influenza and benefits of prevention and control, generate a national action plan for avian and human pandemic influenza preparedness and develop policies for influenza vaccine and anti-viral usage during influenza pandemics. A summary of the contents of this plan is found in Omiti et al (2008).

(Note: No CBA for Kenya was found in the literatures reviewed)

10. Nigeria: selected direct and indirect impacts of AI outbreaks

Right after the confirmation of HPAI infection in Nigeria in February 2006, FAO, OIE and AU-IBAR launched a countrywide active surveillance programme and identified the programme's priorities. These include surveillance of live-bird markets, training and capacity building, socioeconomics, biosecurity and communication.

Nigeria's poultry population is estimated at 140 million, with backyard farmers accounting for 60 percent of poultry producers. A dose of chicken vaccine costs between 5 and 20 US cents (United Nations Office for Coordination of Humanitarian Efforts 2006).

The HPAI outbreaks created general panic among the public that led to an initial boycott of poultry products, resulting in a sharp decline in sales and prices. Egg and chicken sales declined by almost 81% within 2 weeks following the announcement of avian influenza outbreaks in Nigeria. Additionally, poultry feed sales dropped by 82% as a result of the first outbreak. AI outbreaks thus have a direct impact on the livelihoods of poor households particularly in the rural areas, where many depend on poultry to meet their economic and dietary needs.

You and Diao (2007) found that in Nigeria, depending on the size of the affected areas, the direct impact of the spread of AI along the two major migratory bird flyways would be the loss of about 4% of national chicken production. The indirect (ripple) effects of consumers' reluctance to consume poultry if AI is detected, causing a decline in chicken prices, are generally found to be larger than the direct effect. It is estimated that, if the worst-case scenario occurred (AI spreads >20km along the two major flyways), Nigerian chicken production would fall by 21%, prices by 12% and the combined result could mean that poultry farmers would lose up to US$250 million of revenue. In the best case scenario where AI is confined in a narrow zone within the flyway, You and Diao estimated the total loss to farmers to be US$ 48-52 million.

Fasina et al. (2007) worked on an estimation procedure of possible costs associated with a specific control strategy—vaccination—and a combination of other control measures (such as culling) to confine the spread of HPAI H5N1 virus infection. A decision tree and cost benefit analysis was used to analyze control options used in Nigeria and in developing countries with similar veterinary infrastructures, biosecurity and farming systems as that of Nigeria. The final cost of vaccination was based on the total animals to be vaccinated, frequency of the vaccination, labor, distribution and administration costs. Benefits include reduced compensation per year, prevention of egg production losses, regaining of regional trade in poultry meat, normalization of egg prices, evaluation of culled birds and prevention of redundancy of poultry facilities. Results showed that vaccination of poultry is much cheaper control strategy for HPAI and reduce the chances of human zoonoses in Nigeria. Vaccination combined with other control measures turned out to be more effective means of controlling HPAI in most developing countries.

Estimates on the direct costs and losses

Production losses: As at mid-June 2006, the HPAI outbreak caused a loss of approximately 890,000 birds through deaths and stamping out. At an average farm gate price of about N700 per bird, the farm gate value of the birds lost was about N 617 million (or US$ 4.8 million). These figures are based on official estimates, and are believed to under-estimate reality, because the actual poultry population wiped out in rural areas remains unknown. Culling teams were organised on an ad hoc basis and culling costs were estimated to reach about US$ 1.00 per bird, if the team culled 1,000 birds within a day (culling and disposal costs).

Re-stocking costs: The cost of restoring the affected poultry units back to pre-outbreak levels is estimated at about N889 million (or $6.95 million). In addition, there was a 45% drop in the flock size of the non-affected farms, mainly because of lack of funds to feed the birds which forced many farmers to reduce flocks, and it is unclear whether these farms will recover.

Consequential on-farm losses: The UNDP rapid assessment survey revealed that 80% of workers in the affected farms and 45% of those working in non-affected farms have lost their jobs as a result of the HPAI outbreak.

Estimates on the indirect impact: ripple effects

Poultry sales: Egg and chicken sales declined by 80% within 2 weeks following the announcement of HPAI outbreaks in Nigeria in February 2006 (UNDP data and Nigerian Poultry Association –PAN). Up to 4 months after, the recovery rate was still below 50%.

Feed industry: Following the HPAI outbreaks in Nigeria in early 2006, poultry feed sales dropped by 82%, and only 43% recovery (to pre-outbreak levels) had been attained by May 2006 (by 2008, recovery rate has gone up to 70% due to entry of new players in the industry (based on personal communication with large feedmiller, October 2008)). Even in non-affected farms, following a 45% drop in the flock size (as farmers were cutting down flocks due to lack if funds to feed the birds), the level of feed usage declined by 55%. The loss to feed mills is estimated at about N 60.5 million ($0.5 million), on the basis of average feed consumption per bird (0.135 kg per day) and assuming it takes about seven months for the feed mills to fully recover from the shock at a constant rate; this translates to a 3.5 month volume of feeds (the average price per ton of feed is about N 48,000).

Traders/markets: Associated businesses such as those trading in poultry products are estimated to have lost close to N 61.7 million ($0.5 million): this is estimated as the 10% of the farm gate price of the number of birds that were either culled or dead as a result of the HPAI. One live chicken sellers' association (Abubakar Rimi Market in Kano, reputed to be the largest local chicken market in Nigeria), claimed that their sales dropped from 10,000 birds to only 1,000 birds per day in

February/March 2006. The price per bird also crashed during the crisis. Similar experiences were reported in other markets.

Catering industry: A sharp drop by 81% was reported in sales in restaurants, fast food business outlets, roadside roasted chicken sellers and egg sellers within 2 weeks following the announcement of HPAI outbreaks (February 2006), which by May 2006 had only recovered to 67.7% of the pre-outbreak sales.

11. Indonesia: selected direct and indirect impacts of AI outbreaks

Indonesia is one of the countries that have been most severely affected by HPAI in poultry. In 2006, OIE has declared HPAI an endemic disease in Indonesia. The ongoing outbreaks in poultry and sporadic cases in humans are a major global concern. The disease was first recognized in August 2003 and officially declared to the OIE in January 2004. HPAI spread rapidly across Java, into Bali, Kalimantan and Sumatra, and in 2006, infected Papua and much of Sulawesi for the first time. HPAI has now been confirmed in 31 of Indonesia's 33 provinces. Indonesia now has the highest human death toll (107 as of April 2008) in the world caused by the H5N1 avian influenza virus.

HPAI presents a major challenge to Indonesia because of the size and complexity of poultry production, ranging from intensive commercial production to village and backyard production systems, including a range of species, and also because of the considerable logistics required for effective surveillance and response in 33 provinces across an archipelago, with the virus endemic in Java, Sumatra, Bali and southern Sulawesi. Particularly prone to infection is the country's chicken population of 1.4-billion, some 20%t of which are scattered in and around 30 million backyards where people raise poultry for food or income.

The Government of Indonesia's National Strategic Work Plan (NSP) for the Progressive Control of Highly Pathogenic Avian Influenza in Animals contains nine key elements: 1) campaign management; 2) enhancement of HPAI control in animals; 3) surveillance and epidemiology; 4) improved and strengthened laboratory services; 5) national animal quarantine services; 6) legislation and enforcement; 7) communication; 8) research and development; and 9) industry restructuring.

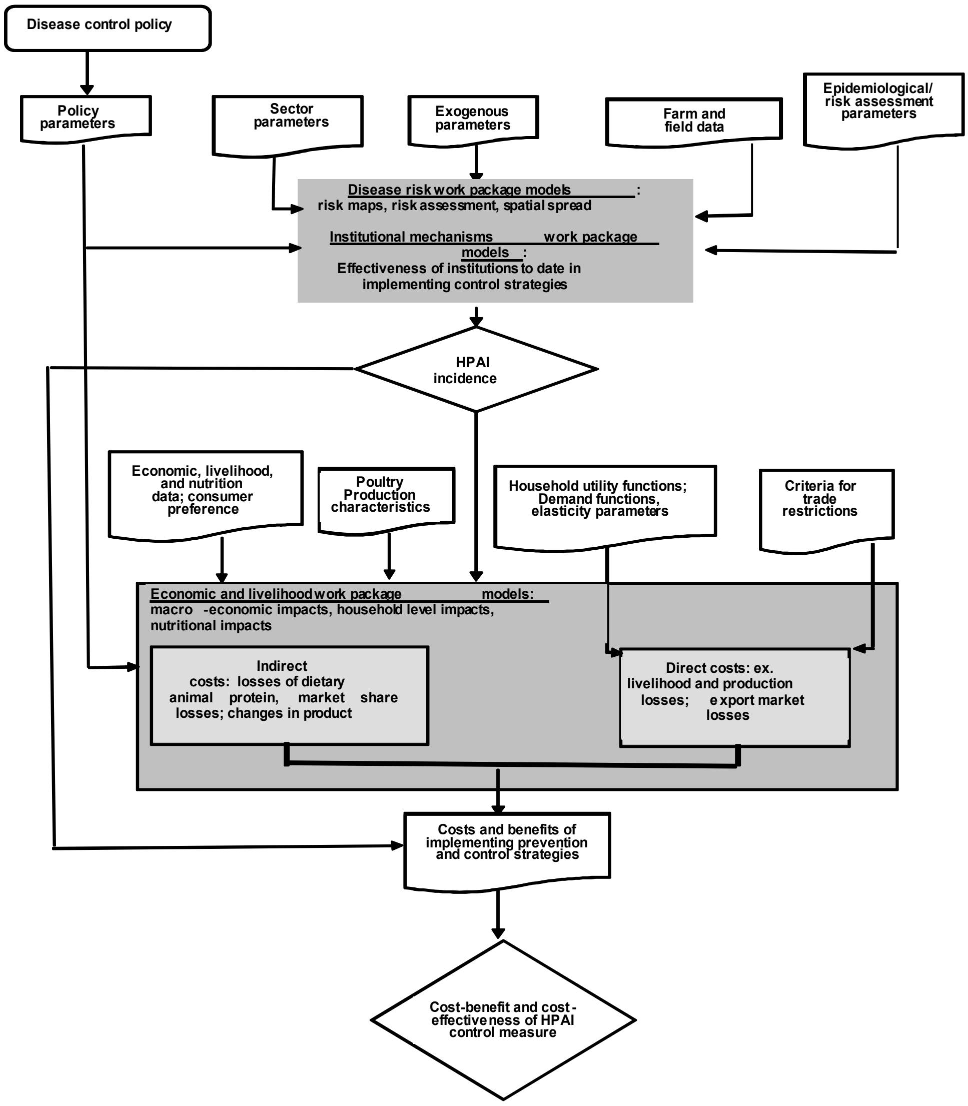
Direct costs and losses

Production losses: In Indonesia, 15 out of 30 provinces were infected with HPAI and 17 million birds (15 million layers and 2 million parent stock) died or were stamped out. The value of birds lost was between US$16.2 and 32.4 million. These estimates are based on a price range of typically US$ 1-2 per bird, subject to weight and type (broiler or layer). The Indonesian Poultry Information Centre estimates the total direct losses of the broiler and layer breeders and producers at US$ 170.9 million. These figures do not account for the loss incurred by village and backyard farmers for which no accurate estimates of total losses are available. It is believed that the greatest loss was among backyard village farmers, estimated at 30 million households keeping 200 million native chickens or 63% of total poultry population.

Ripple effects: According to data from the Indonesian Poultry information Centre, the price of a live broiler fell from around Rupia 8000 per kg in January 2004 to as low as Rupia 4000 in some locations at the end of February, and only recovered to the pre-outbreak level by May. According to other reports, the price fell to Rupia 1200 per kg after the outbreak, but by April it reached Rupia 10000 per kg.

To date, much has been done in assessing costs and benefits of animal and plant diseases performed ex post, but a great deal more needs to be done in the case of ex ante assessment of the cost-effectiveness of a control policy. Studies on cost-benefits and cost-effectiveness of different control strategies that have been reviewed here have used optimization and simulation models to identify an optimal control strategy. In order to arrive at useful and meaningful policy recommendations, one really has to consider the complexity and dynamism of managing a livestock disease such as HPAI. Policy makers would benefit from knowing the epidemic and economic outcomes of alternative HPAI control strategies under existing disease control capacities in order for them to respond effectively to the continuing spread of HPAI and to be prepared to mitigate in the event of a human pandemic.

Figure 1. Schematic linkage of the epidemiological and economic models for evaluating the cost-effectiveness of HPAI control strategy



Source: Adapted from Breukers, A., M. Mourits, W. van der Werf, A. O. Lansink, 2008.

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