The Use of Bayesian Updating in Estimating the Impact of Highly Pathogenic Avian Influenza in Asia.

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ABSTRACT

Bayesian updating is used to demonstrate the value of good information when estimating the economic impact of various control methods during animal disease emergencies. Various states of highly pathogenic avian influenza (HPAI) disease emergency, various control methods including vaccination and stamping out, and their economic impact on farm production systems are estimated using prior and likelihood probabilities of farm infection (prevalence of HPAI). For individual producers, vaccination is shown to be the option resulting in least economic damage when expectation of local prevalence is high. Following Bayesian updating, a Bayesian strategy is developed that allows estimation of the value of vaccination to an individual producer (what a producer should be willing to pay), and the expected utilities of vaccination and stamping out under alternate disease scenarios.

INTRODUCTION

Highly pathogenic avian influenza (HPAI) has resulted in the deaths of more than 100 humans and more than 300 million birds over three continents, causing billions of dollars in economic damage. The zoonosis continues to spread westward across Europe threatening to land in North America. Concern remains that the global avian epidemic may enter a new phase involving human to human transmission. Control and eradication of HPAI outbreaks are of urgent importance in countries experiencing new and continued outbreaks. Accurate and current information is highly important to this process.

This paper presents the basics of an approach using Bayesian updating to estimate the economic impact of control methods during an HPAI emergency response. The approach is equally applicable to other animal disease emergencies. Bayesian updating generates a Bayesian strategy with which one can estimate the value of a control method. This example estimates the expected utilities of vaccination and stamping out under alternate HPAI disease scenarios. Data are simulated based on observations in South East Asia. Further refinement and application of the process is in progress.

STATES AND BENEFIT COST RATIOS

Sample data were generated using a combination of simulation and economic surplus calculations, based on field observations of farm revenues, costs, and impact during the HPAI crisis in Vietnam and Thailand. The primary field data were gathered in 2004 from more than 2400 producers and industry stakeholders using a questionnaire procedure; the results are summarized by Dolberg (2005).

Three control options are considered: 1) do nothing; 2) stamping out (slaughter and eradication); and 3) broad pre-outbreak vaccination. Four states of nature are considered which express conditions at some point in time. For this example, the states of nature express the pathogenicity of the HPAI strain, ranging from a severe highly pathogenic strain that spreads rapidly and causes high mortality (E1) to a mild strain that spreads slowly and can be brought under control quickly (E4). A 100 bird farm with low bio-security is assumed. Benefit-cost ratios (BCRs) are used as the economic instrument with which to express value of the different options. Thus, monetary units are irrelevant but can be assumed to be USD.

BCRs were calculated using estimates of farm costs and returns from the country studies outlined in Dolberg (2005). Estimates were adjusted upwards or downwards to reflect hypothesized impact of the various states of nature. In practice this information should ideally be available and fairly accurate although a high degree of variation is sure to exist given the uncertainty of the natural processes of disease. The BCRs are summarized in table 1. Pre-vaccination results in highest BCRs for states of nature E1, E2, and E3; doing nothing yielded the highest BCR under state of nature E4, the least pathogenic strain of the four.

Table 1 Benefit cost ratios under four different HPAI states in South East Asia

	Benefit Cost Ratios		
State of Nature (Ei)	Do Nothing	Stamping Out	Pre-Vaccinate
E1	0.1	0.2	1.5
E2	0.2	0.3	2.1
E3	1.2	0.8	2.4
E4	3.1	1.3	2.9

PRIOR AND LIKELIHOOD PROBABILITIES

Prior probabilities (the probability of the occurrence of Ei, or prevalence) are assumed known or are collected from seroprevalence survey data. Likelihood probabilities (P(Zk|Ei)) represent expert opinion as to the severity of upcoming epidemics; this information would be collected by elicitation of expert opinion and past observation. Likelihood probabilities range from quickly contained epidemics (Z1) to rapidly wide spread and slow to contain epidemics (Z3). Sample data for likelihood probabilities are indicated in table 2.

Table 2 Prior (P(Ei)) and likelihood (P(Zk|Ei)) probabilities

		Likelihood probabilities		
State of Nature (Ei)	Prior P(Ei)	Z1	Z2	Z3
E1	0.40	0.4	0.3	0.3
E2	0.25	0.3	0.2	0.5
E3	0.25	0.4	0.1	0.5
E4	0.10	0.1	0.4	0.3

BEST OPTION BASED ON PRIOR INFORMATION

Based on prior information, the expectation of BCRs for the various scenarios can be estimated where E(BCRi) = P(Ei)*BCR(Ei). Individual calculations are not shown for brevity. Summary calculations are: BCR(Do Nothing) = 1.57, BCR(Stamping Out) = 0.85, BCR(Pre-Vaccinate) = 2.44. So the best option based on priors is to pre-vaccinate which yields an expected BCR of 2.44. Stamping out appears to be the worst option based on priors, yielding an expected BCR of 0.85.

JOINT, POSTERIOR, AND MARGINAL PROBABILITIES

The next step is to calculate the updated Bayesian strategy. First, we need to calculate the expected BCRs based on updated beliefs (the posterior distributions) associated with each Zk forecasted distribution, based on the joint and marginal distributions where: posterior probability = joint probability / marginal probability = [P(Ei)*P(Zk|Ei)]/[sum of joint for Zk]. These intermediate step tables are not shown for brevity, but the results are displayed in table 3 which displays the updated Bayesian strategy.

Table 3 Bayesian BCR distributions based on updated posterior probabilities

	Do Nothing			Stamping Out			Pre-Vaccination		
Ei	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3
E1	0.02	0.03	0.02	0.09	0.10	0.06	0.68	0.75	0.44
E2	0.04	0.04	0.05	0.07	0.07	0.11	0.45	0.44	0.65
E3	0.34	0.13	0.37	0.24	0.09	0.26	0.71	0.26	0.76
E4	0.09	0.52	0.23	0.04	0.23	0.10	0.08	0.50	0.22
SUM	0.49	0.71	0.67	0.45	0.49	0.53	1.92	1.95	2.07

From table 3 the updated Bayesian strategy, assuming producers are risk neutral and given strategies Z1-Z3, is to pre-vaccinate for all three scenarios. This will not always be the case, as sensitivity analysis can reveal. Sensitivity analysis is made more difficult by the high degree of uncertainty of the variables and the multidimensionality of the problem. Only one option under one scenario is plotted in figure 1 for illustration; there are eight more to consider, as well as the input variables (price, production costs, etc.)

RISK AVERSION, UTILITY, AND CERTAINTY EQUIVALENTS

Figure 2 demonstrates the concept of accepting a cash payment for a risky proposition of equal expected value. Producer wealth (W) is plotted against producer utility (U). Given that producers are risk averse, where U(Wc) = E[U(W)], the certainty equivalent wealth value can be determined which indicates the point of indifference between a cash payment and accepting production under risky (forecasted) conditions. In figure

2, the CE is E(W)-Wc. From this we can calculate the value of information, or in the case of an HPAI control program, the value of reasonable investment in a control/prevention animal health program. This is calculated in the next step.

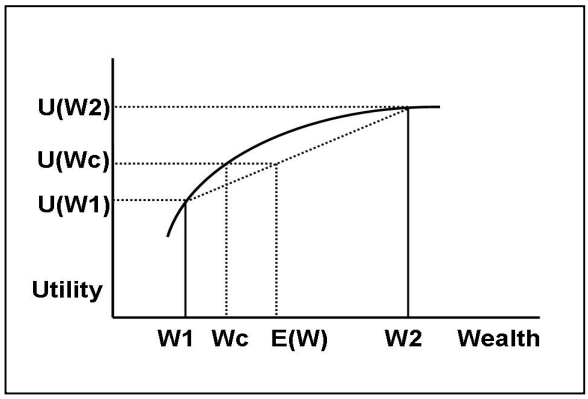

Figure 1 Distribution of pre-vaccination BCRs given Z1. Figure 2 Certainty equivalence given risk aversion.

EXPECTED UTLITY OF THE UPDATED BAYESIAN STRATEGY

Finally in table 4 the expected utility of the Bayesian updated strategy is displayed. This has been calculated assuming producers are risk averse, and using the equation CE = { ln(-SUM EUi)/ -r }. The risk coefficient, r, is needed to capture the conditions of risk aversion and its derivation is beyond the scope of this paper. For this exercise, r is set to 0.0001. More details on this topic can be found in Pratt (1964).

Table 4 Expected utility of the Bayesian updated strategy

	Expected utility		
Forecast	Do Nothing	Stamping Out	Pre-Vaccination
Z1	456.0	717.0	2464.1
Z2	581.2	721.9	2491.0
Z3	590.8	784.3	2551.8

Utility is a unitless concept; that is, it is not expressed in terms of dollars or birds or any other tangible item. The larger the number, the greater the supposed satisfaction of the producer. In this example, table 4 indicates the expected utility of the Pre-vaccination strategy far outweighs that of the Stamping Out strategy. Stamping Out is in turn considered preferable to the Do Nothing strategy. This is a different conclusion than that of the initial optimal priors in which BCR(Do Nothing) = 1.57 and BCR(Stamping Out) = 0.85. Part of the reason is the nature of the utility function and the weighting of Zi.

The difference {CE(Bayesian strategy) – CE(Prior optimal)} is the potential cost (or value) of the forecasted information to a control program. For this example the calculated values are (2708-2520) = 189. As stated, currency units are neither indicated nor necessary; 189 is about 2% of total revenues (not shown).

CONCLUSIONS

Pre-vaccination provided the most favourable BCR values under prior and under posterior distributions for all levels of prevalence. Stamping Out appeared to be the least favourable option when measured by BCR. However, the updated Bayesian strategy indicated that Stamping Out provides higher utility to producers than Do Nothing; Pre-Vaccination remained the best option under all forecasts. Bayesian updating also provided a framework for calculating the value (Certainty Equivalent) of the updated information.

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