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Private Decisions in Livestock Disease Control and the Value of Additional Information about Animal Health

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ABSTRACT

This paper develops a method for estimating the value of additional information to the individual livestock producer. In doing so it considers as part of the decision made by the farmer to vaccinate animals against *B. bovis* the decision to collect information on the health status of his herd using serological sampling. Bayesian decision theory is used in this paper. Bayesian decision theory combines statistical and economic information to assist in identifying optimal management policies. This approach has been used in a number of situations in animal health decision making, for example Williamson, 1975; Elder and Morris, 1986; Fetrow et al., 1985; Parsons et al., 1986.

This paper firstly examines the private use of animal health information then the relationship between the cost of gathering information and the value of the information. This is followed discussion about decisions to gather additional information. A method to determine the optimal sample size is examined and applied.

Keywords: Livestock health, Bayesian decision theory, Animal health information, animal vaccination

JEL Classification: Q12, Q16

Private Decisions in Livestock Disease Control and the Value of Additional Information about Animal Health

1. Introduction

While collecting information is regarded as an essential part of economic analysis, the economics of obtaining additional information is not usually assessed when designing animal health programs.

This paper develops a method for estimating the value of additional information to the individual livestock producer. In doing so it considers as part of the decision made by the farmer to vaccinate animals against *B. bovis* the decision to collect information on the health status of his herd using serological sampling. Bayesian decision theory is used in this paper. Bayesian decision theory combines statistical and economic information to assist in identifying optimal management policies. This approach has been used in a number of situations in animal health decision making, for example Williamson, 1975; Elder and Morris, 1986; Fetrow et al., 1985; Parsons et al., 1986.

The classical statistical approach to the collection of additional information using serology involves the examination of a random sample of serum specimens, with the number of specimens to be examined being determined by the level of statistical precision desired. Inferences are drawn from the sample for the overall population. The Bayesian decision theory can be used to combine the producers subjective or personal probabilities of animal health variables with data acquired from serological examinations. Bayes' formula provides the method to combine the subjective and objective information in a logical way that avoids internal inconsistencies (Anderson et al., 1977; Ngategize et al., 1986). Using Bayesian methods it is also possible to determine the desirability of examining a sample of the population and if so the sample size that should be collected to maximise economic gam (Harrison and Tamaschke, 1984).

This paper firstly examines the private use of animal health information then the relationship between the cost of gathering information and the value of the information. This is followed discussion about decisions to gather additional information. A method to determine the optimal sample size is examined and applied.

2. Inefficiency in Cattle Production Due to Lack of Animal Health Information

There is a great deal of variation in output for similar amounts of capital and labor and for the use of similar techniques (Leibenstein, 1985). This inefficiency has been called X-inefficiency by Leibenstein (1985) and results in a gap in efficiency that can be demonstrated using producer supply curves as illustrated in Figure 1.

In Figure 1 a producer with the function S 10R produces less for the same amount of expenditure as a producer with the function STP. At lower levels of expenditure such as w the gap in the quantity produced is smaller than at higher levels of expenditure such as v.

This variation in efficiency occurs for many reasons including :

- knowledge of the most efficient method of production may not be available, that is the production function is not completely specified nor known. This is especially so for livestock production where large variations in the production function occur between different land types and climates thereby limiting the ability to specify a separate production function for each situation

- knowledge that is available may not be used to capacity; this can occur in the same way as labour and capital can be under-utilised.
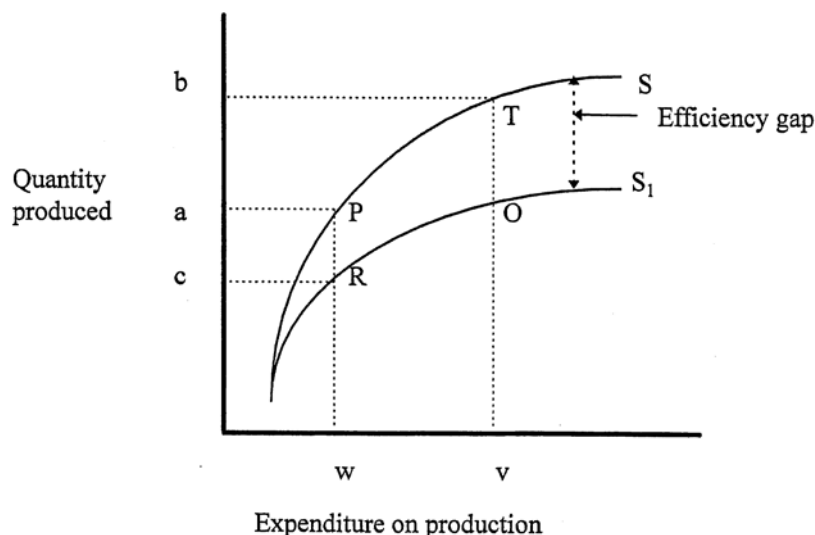

Figure 1: The efficiency gap in production

The collection of additional information will enable some producers to close the efficiency gap by adopting vaccination, technology that is already available but which they are not currently using. Often it is not until additional data are collected and analysed that the presence of a disease problem and the possible benefits of controlling a disease are recognised; that is, the efficiency gap is detected. The value of information will depend on the farmer's attitude to using information and confidence in the accuracy of the information. Disease control is often carried out because a severe disease outbreak in the past has stimulated producers to avoid similar losses in the future. The lack of use of available information on disease control by farmers is referred to by Ellis and James (1979); they comment on the slowness of farmers to take up new disease control measures which have been shown to produce financial rewards. Further, they suggest this is due to farmers being reluctant to spend money and effort to obtain a benefit that they have not previously obtained.

If a producer is already making the most appropriate decisions then the private benefit received from the improved animal health information will be small, and will depend on the value placed on the decreased uncertainty in relation to decisions and the reduction in the cost of maintaining flexible policies due to the decreased uncertainty. It is also possible that additional information will change a decision from the appropriate one to an inappropriate one resulting in a negative payoff from the additional information. It will not be worthwhile for a producer to collect additional information on animal health unless the benefit gained from using that information exceeds the costs of collection.

3. The Private Use of Animal Health Information

This section firstly examines the private use of animal health information then the effects of increasing the level of knowledge and the relationship between the value of information and the cost of gathering that information.

Animal health information provides support for private decision makers. Any decision in livestock disease control involves uncertainty. This is because the aim is to predict what may occur in the absence of a disease control program and the effect that a disease control program may have on disease occurrence. Decisions are therefore made using the imperfect knowledge that is available to the decision maker (in this case knowledge is defined as the sum of available information). However, perfect knowledge is not required for rational decision making and the most economic state for an individual usually involves imperfect

knowledge and hence imperfect information (Baumol and Quandt, 1964).

The collection of additional data that is processed into information, is one to way to decrease uncertainty. However, the production of knowledge requires the use of resources, and hence bears a cost. Because of these costs it is often uneconomic to decrease uncertainty through the gathering of additional information. Alternatively the effects of uncertain events can be reduced by, for example maintaining flexible policies that enable a rapid response to change in the animal health status, such as being prepared to vaccinate immediately if cases of a disease occur in the district, or reducing the hazard as is the case of having a herd of disease-resistant *Bos indicus* cattle where there is a risk of disease caused by *B. bovis* infection. However, maintaining flexible policies may also bear a cost.

The effect of the collection of additional information, leading to increased knowledge, on a decision can be to change the decision, decrease the uncertainty in making the decision, or decrease the need for flexible policies.

Figure 2 the curve ITK describes a relationship between information and the expenditure incurred in obtaining that information.

The benefit that a fanner will gain from collecting additional information will depend on the fanner's current level of knowledge. If using the information currently available the producer's level of knowledge is at a low point such as pointed in Figure 2, then the collection of additional information will most likely bring a large increase in information for a relatively small expenditure. However, if the fanner's level of knowledge is at a higher point such as point e the benefit from collection of additional information is much less per unit of expenditure. A fanner with this level of knowledge would gain less benefit from the same expenditure on information collection than a fanner with a lower level of knowledge. A farmer with a level of knowledge at point f would gain little information from additional expenditure and the expenditure could exceed the value of the information.
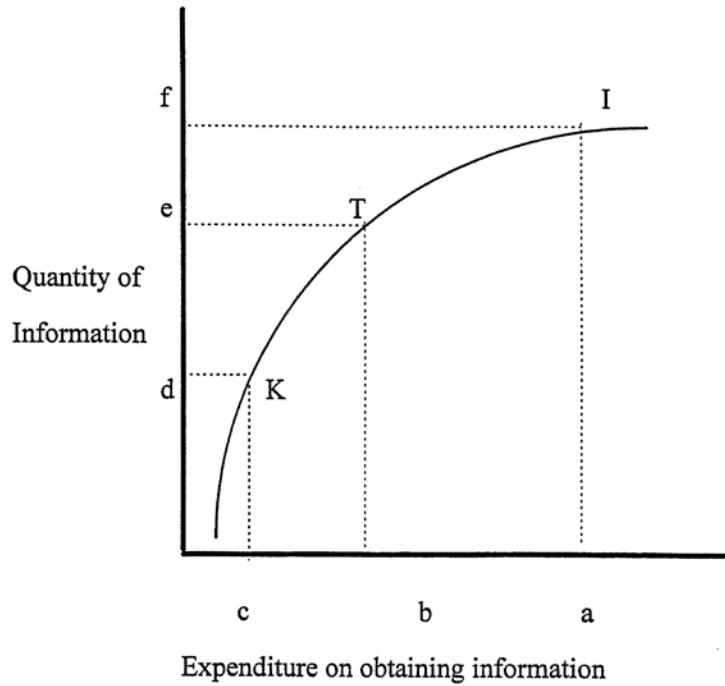
Figure 2:   Cost versus quantity of animal health information

4.   The Relationship Between Cost and Value of Additional Information in Private Decisions

If a farmer decides to gather additional information on the occurrence of disease on her farm there are many ways of collecting that information. While some of those will not be feasible, or will be prohibitively expensive, the farmer will generally have a choice between methods. To select the method to be used the farmer can compare the cost of the method and the value of the information likely to be produced. In most cases the method will not be an ali-or-nothing method and by increasing expenditure the farmer will obtain increasingly accurate information. However, the relationship between the cost of collecting information and the value of that information to a private decision maker is almost certainly not a linear relationship and several possibilities exist for that relationship. The situation examined in this chapter is that in which the data collected are serological data, and the analysis of that data into information is carried out using the models described in Discussion Papers 33 to 36. In the case examined there is a start-up cost associated with the data collection.

4.1 Information collection with start-up costs

Usually in the collection of information there is an initial start-up cost. Before samples are collected on a farm it is necessary that several things are done, including deciding on and obtaining a sampling frame and ensuring that the tests needed to analyse the specimens are available. These must be done each time specimens are collected. In nearly all cases the start-up activities will not produce any information and this is the situation examined in this chapter. The relationship between the cost of collection and the value of the information obtained could follow the relationship shown as curve ARDE in Figure 3.
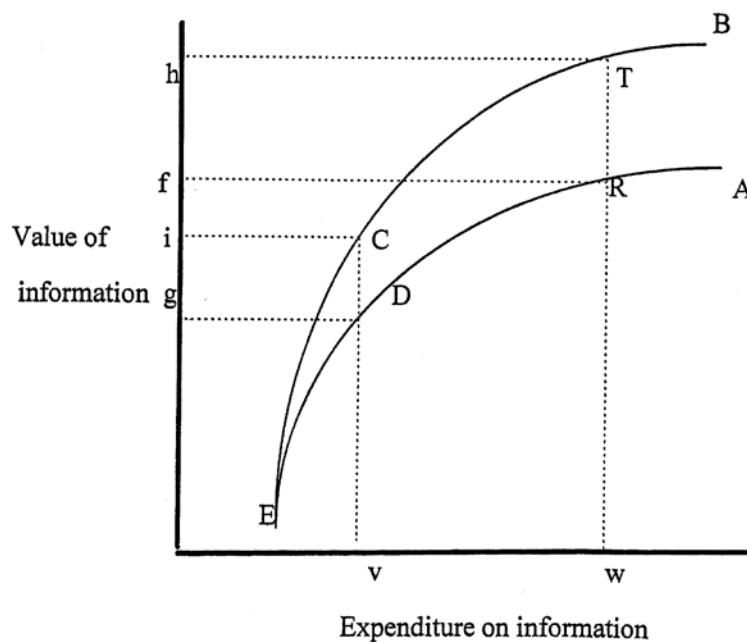
Figure 3: Expenditure versus value for the collection of additional animal health information with start-up costs

Where there is a start-up cost, the overall cost per specimen collected would decrease as the number of specimens collected increases. In addition, if it is possible to test for many diseases from the same specimen then the cost of specimen collection per disease tested for decreases as the number of tests carried out on each specimen increases. If each test carried out increases the value of the information then the curve would be higher as illustrated as curve BTCE in Figure 3.

In Figure 4 the gross value curve is illustrated as curve ARDE while the total cost of information is shown as curve Caa_1F. The break-even expenditure can be determined as the

points at which the gross value of the information equals the cost of collection. These points are demonstrated in Figure 4 as being where the cost curve Caa_1F crosses the value curve ARDE at points a and a_1. The aim of the decision maker collecting the information is to maximise the difference between the two curves. This will occur when information is collected up to the point where marginal cost of collecting information equals its marginal gross value.
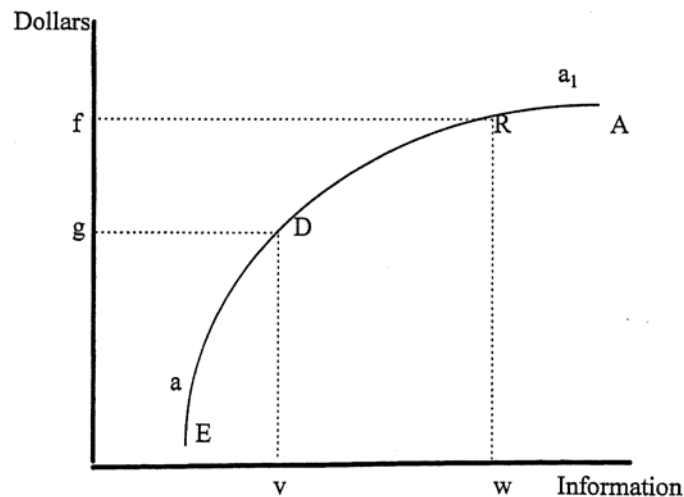
Figure 4: Total cost and gross value of information curves

4.2 Determining the value of data and information

While the cost of collecting data and transforming it into information is relatively simple to determine, the value of that information is more difficult to estimate. The value of the information will depend on the uses to which it can and is put as well as the current disease control actions and level of disease occurring on the property.

The value of additional data collected on individual properties has rarely been estimated in relation to the better decisions which can be made using that additional data. Some attempt has been made in the analysis of herd health schemes which include as part of the scheme a health and production database on which the decisions to examine or treat animals are made (Williamson, 1980).

The curves described in Figures 3 and 4 will vary from farm to farm and from year to year. Standard curves are not available to enable the farmer to determine his optimal level of

8

expenditure on gathering information nor on the type of information that should be gathered. Therefore, while providing a useful framework to examine information gathering in relationship to expenditure the curves do not provide the detail needed by farmers who are deciding whether they should gather more information before deciding on a disease control action.

5. Making Decisions on Gathering Animal Health Information

Currently the information available for private decisions in animal health in Central Queensland is limited and consists mainly of the farmer's own experience and the experience of the farmer's advisers including neighbours, veterinarian, farm adviser, accountant and government officers. Quantified information on the occurrence of disease and the effects of disease control programs is not available.

If a farmer is deciding whether to vaccinate his animals he can make the decision with the information available or he can decide to gather additional information to increase his confidence that the action chosen is the most appropriate one. If the difference between the payoffs for the alternatives is large then it may be worthwhile for the farmer to spend money to learn more. This decision is outlined as a flow chart in Figure 5.

One way of obtaining quantitative information is the use of serological sampling and analysis as has been outlined in earlier chapters. If the farmer decides it may be worthwhile to collect more information by this method, he needs to know that the value of obtaining the information does not exceed the expenditure. Further it would be desirable to know the economically optimal number of serum specimens to collect.

5.1 The decision framework

The decision framework is outlined in Figure 5 and each component of the decision is examined in this section. Several comments can be made about each of the eight steps outlined in Figure 5:

Step 1. The prior information, as outlined in Section 4, consists of the farmer's experience and that of his advisers. This prior information is developed into prior, subjective probabilities. Subjective probabilities refer to the level of belief held by a person about the occurrence of possible events (Spetzler and Stael Von Holstein, 1975; Officer and Dillon,

1968). Because different farmers have had different experience and interpret information and integrate new information into knowledge differently they may have different subjective probabilities for the same event and therefore, make different decisions.

```
                              1. Prior information
                                      │
                                      ▼
                              2. Define problem
                                      │
                                      ▼
                              3. Define objectives
                                      │
Elicit prior                          │
probabilities ─────▶  4. Gather available information
                                      │
                                      ▼
                          5. Analyse that information
                                      │
                                      │
Collect    ◀──── yes ──── 6. Obtain more information?
information                           │
                                      No
                                      │
                                      ▼
                              7. Decision
                                      │
                                      ▼
                          8. Choose optimal action
```
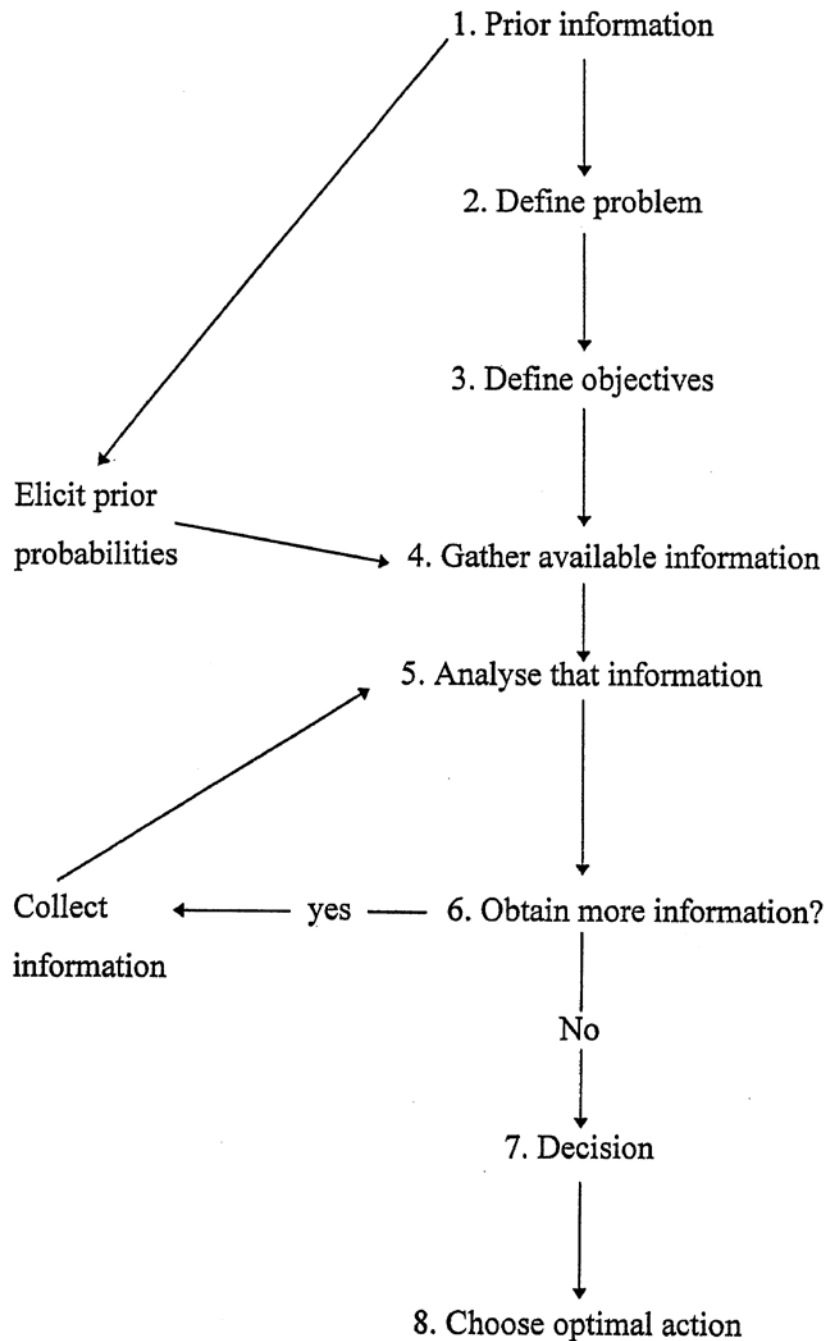
(Modified from Anderson et al. 1977)

Figure 5:   Decision framework for vaccination against *B. bovis*

In this case the event being faced is the incidence risk of infection of cattle with *B. bovis* in the herd (determined from age specific seroprevalence at one year old). This has been divided into five categories, namely very low, low, moderate, high and very high.

Step 2. The problem in the present context is defined as determining whether the farmer should vaccinate his animals against *B. bovis* using either of the vaccination programs Vaccination 1 or Vaccination 2 or not vaccinate at all.

Step 3. The farmer's objective is the maximisation of the expected payoff.

Steps 4 and 5. Available information is gathered and analysed using the models developed in earlier papers so that for each state of nature an expected value is calculated. In these calculations the expected value is the net present value (NPV) at a discount rate of 8%.

It is rational that as new information becomes available a farmer will use this additional information to modify his subjective probabilities of an event occurring. While this is not usually done in a formal manner Bayes' Theorem is used in this analysis to provide a logical framework for the combination of subjective probabilities with the additional information.

Step 6. The farmer then faces the problem of whether it is desirable to gather more information and if so what is the maximum amount that should be spent or preferably the optimal sample size and the benefit that could be gained from gathering the additional information.

Steps 7 & 8. An optimal action is chosen in terms of the assumed objective of maximisation of the expected present value of net revenue.

6. Determining the Value of Additional Information

Two techniques are described in this section. The first involves the calculation of the expected value of perfect information (EVPI) which can be used in association with the cost of sampling to estimate the maximum sample size worth considering. However, this technique does not determine the benefit received from a specific sample size nor does it estimate the optimal sample size. The technique is further developed into a second technique that can be used to calculate the expected net gain from sampling and hence to estimate the optimal sample size (Harrison and Tamaschke, 1984).

Using the methods described in Sections 6.1 to 6.4 a computer spreadsheet model is developed to examine the value of the additional information provided by the serological sampling of the herd and to determine the optimal sample size for a farmer considering vaccination of his herd against *B. bovis*.

6.1 The expected value of perfect information

In the case of animal health information the expected value of perfect information is the increase in expected value (EV) of returns from cattle production, of the decision to vaccinate, that would occur if the decision maker could obtain completely accurate information concerning the event being faced, in this case the disease incidence. That is, the farmer would always know the disease incidence that will occur and therefore always select the most appropriate strategy. To do this it is necessary to calculate the expected value using the information currently available. The EV is calculated for each alternative action and the action with the highest EV is selected. The EV is defined as:

$$EV(A_j) = \sum_i (P_i V_{ij})$$

where

      P_{si} is the probability of the occurrence of state of nature *i*

      V_{ii} is the payoff of action *j* under state *i*

(Harrison and Tamaschke 1984, Ngategize et al. 1986)

The expected value of perfect information (EVPI) is then calculated in the following way:

EVPI = expected revenue with perfect information - expected revenue with current information

In this case because the information collected is not perfect its cost of collection should be less than the expected monetary value of perfect information.

This method provides a useful guideline to determine the maximum amount to be spent on information gathering. This was examined in a veterinary context by Williamson (1975) who used it as a way to determine the maximum amount that should be spent to provide further information as part of a decision analysis evaluating the use of heat mount detectors in dairy

herds. Subsequently the use of decision analysis and the calculation of the EVPI has been expanded on and applied by others in the animal health area (Elder and Morris, 1986; Galligan et al. 1987).

6.2 Calculating maximum sample size

An upper limit on the sample size, the maximum sample size can be set to ensure that:

$$COS \leq EVPI$$

where the cost of sampling (COS) for an individual property is approximated using the function:

$$COS = s + k_n n + k_t n + k_k d + k_m$$

where   s is the start-up cost

k_n is the collection cost per specimen

k_t is the cost of laboratory testing per specimen

n is the number of specimens collected

k_k is the travel cost to the farm per kilometre

d is the number of kilometres travelled to collect the specimens and

k_m is the cost of mustering and handling the cattle for specimen collection then

then

$$s + k_n n + k_t n + k_k d + k_m \leq EVPI$$

$$n \leq (EVPI - (s + k_k d + k_m))/(k_n + k_t)$$

6.3 Calculating expected net gain from sampling

The expected net gain from sampling (ENGS) is the difference between the expected value of sample information and the cost of sampling and is defined as

$$ENGS = EVSI - COS$$

where *EVSI* is the expected value of sampling information which is defined as the difference between the prior and posterior expected opportunity loss (EOL), that is

$$EVSI = prior\ EOL - posterior\ EOL$$

The expected opportunity loss (EOL) of the optimal action is an alternative way to express the expected value of perfect information (that is the benefit forgone from not collecting the information). The EOL also provides an alternative way of expressing the expected value criterion which in this case is the action with the lowest EOL is selected.

The EOL for each action is defined as

$$EOL(A_j) = \sum_i (P_i L_{ij})$$

where L_{ij} is the opportunity loss of action j under state i.

The posterior EOL is an estimate of the EOL using posterior probabilities. The posterior probabilities are calculated from the range of possible outcomes from a given sample size (that is number of specimens collected). An EOL is calculated for each possible action for each possible outcome from the sampling strategy. The posterior EOL is calculated as the sum of the selected strategies for each possible sample outcome weighted by the probability of the different outcomes.

6.4 *Optimising the sample size*

The optimal sample size is defined as the sample size that will maximise the ENGS. A simple formula is not available to determine this value so the EOL and from it the ENGS must be calculated for each sample size with the sample size that maximises the ENGS read from the tabulated results.

7. Determining the Benefits of Collection of Additional Animal Health Information Using Simulation Outputs

The benefit of the collection of additional animal health information is now demonstrated using the spreadsheet outlined in Section 6 and outputs from simulations carried out using the models developed in Papers 33 to 36 as input data. The analysis is based on the standard herd size and structure described in Paper 33. Two representative herds with different types of cattle are examined. The first herd consists of cattle of intermediate disease resistance, cross-bred cattle (*Bos indicus* crossed with *Bos taurus*) and in the second herd the cattle are disease

resistant *Bos indicus*. The pay-off matrices from the simulations are presented as Table 3 for cross- bred cattle and Table 5 for *Bos indicus* cattle. The analysis for cattle of intermediate disease resistance is shown first followed by the analysis for the disease resistant cattle herd.

In the simulations the cost of vaccine is $1.59 per dose and the cost of administering the vaccine is 50 cents per head. Mustering costs are taken as zero because it is assumed that the animals have been mustered for another purpose such as branding when they are vaccinated. The cost parameters used in the calculation of the cost of sampling are set out in Table 1.

Table 1:   Cost parameters used in determining the cost of sampling

Variable	Cost per head
Collection cost (k_n)	$ 5.00
Laboratory testing cost (k_t)	$ 2.40
Travel cost per kilometre (k_k)	$0.80
Distance travelled in kilometres (d)	100
Mustering costs (k_m)	0

The prior probabilities for the different states of nature used in this section were devised in association with Dr Peter Black, a veterinary officer working in Central Queensland, and Dr Bob Dalgliesh, an expert working with disease caused by *B. bovis*. The probabilities were devised to represent the variation in the incidence of *B. bovis* infection that can occur in Central Queensland and the variation in the prior probabilities between different livestock producers in the region. The estimated prior probabilities are shown in Table 2.

Table 2:   Estimated prior probabilities for different states of nature for producers in different parts of Central Queensland

	Prior probabilities					
Incidence of infection	Producer 1	Producer 2	Producer 3	Producer 4	Producer 5	Producer 6
Very low	0.05	0.05	0.5	0.3	0.05	0.1
Low	0.1	0.1	0.2	0.3	0.15	0.2
Moderate	0.15	0.25	0.15	0.25	0.6	0.4
High	0.2	0.3	0.1	0.1	0.15	0.2
Very high	0.5	0.3	0.05	0.05	0.05	0.1

7.1   Sampling estimates for a herd of cattle of intermediate disease resistance

At all levels of incidence of infection for cattle with intermediate disease resistance the payoff was positive for both vaccination programs as shown in Table 3. The payoff for the program Vaccination 2 was higher than for Vaccination 1 where the incidence of infection was very low, low and moderate.

Table 3:   Payoff matrix for disease control alternatives for a herd of cattle of intermediate disease resistance calculated at a discount rate of 8%

Incidence	Payoff (NPV in dollars)		
of infection	Vaccination 1	Vaccination 2	No vaccination
Very low	4164	7144	0
Low	22919	26396	0
Moderate	23416	24913	0
High	11337	11061	0
Very high	1021	334	0

The EVPI and optimal sample size varied with changes in the prior probabilities. As shown in Table 4, in almost all cases for the moderately disease resistant cattle there was little if any net benefit to the producer from obtaining additional information via the collection of serum specimens. This was because in almost all cases Vaccination 2 was the most appropriate action. Where the ENGS was positive and the collection of specimens is expected to produce a net gain for the farmer, the optimal sample size is small (see Table 3) and the ENGS low.

Table 4:   Estimated benefits of sampling for a herd of cattle of intermediate disease resistance with sampling costs of $5 per sample

	Producers with different prior probabilities					
Sample information	Producer 1	Producer 2	Producer 3	Producer 4	Producer 5	Producer 6
EVPI	$ 399	$ 289	$ 62	$ 62	$ 76	$ 123
Maximum sample size	38	23	0	0	0	1
Optimal sample size	8	9	0	0	0	0
ENGS at optimal sample size	$ 148	$ 13	0	0	0	0

When tests for five different diseases are carried out on each specimen, the cost of collection decreases from $5.00 to $1.00 for each test. This causes a small increase in the sample size identified as optimal (Table 5). The ENOS at the optimal sample size increases due to the decreased cost of sampling. However, the decreased cost of sampling does not suggest a sample be collected in cases where sampling is not suggested with the higher cost of sampling.

Table 5: Estimated benefits of sampling for a herd of cattle of intermediate disease resistance with sampling costs of $1 per sample

Sample information	Producers with different prior probabilities					
	Producer 1	Producer 2	Producer 3	Producer 4	Producer 5	Producer 6
EVPI	$ 399	$ 289	$ 62	$ 62	$ 76	$ 123
Maximum sample size	101	68	2	2	6	20
Optimal sample size	11	12	0	0	0	0
ENGS at optimal sample size	$249	$117.34	0	0	0	0

7.2 Sampling estimates for a herd of disease resistant cattle

The disease control option providing the highest payoff for disease resistant cattle varies with the incidence of infection as presented in Table 6.

Table 6: Payoff matrix for disease control alternatives, for a herd of disease resistant cattle calculated at a discount rate of 8%

Incidence of infection	Payoff (NPV in dollars)		
	Vaccination 1	Vaccination 2	No vaccination
Very low	- 1866	-1892	0
Low	2351	2368	0
Moderate	2560	2258	0
High	651	42	0
Very high	-1035	-1729	0

The optimal sample size and EVPI are sensitive to changes in the prior probabilities for the herd of disease resistant cattle. The results for the collection of samples for a farmer with a herd of disease resistant cattle are presented in Table 7. In some cases the ENGS would make the collection of specimens worthwhile.

Table 7:   Estimated benefits of sampling for a herd of disease resistant cattle with sampling costs of $5 per sample

| Sample information | Producers with different prior probabilities | | | | | |
	Producer 1	Producer 2	Producer 3	Producer 4	Producer 5	Producer 6
EVPI	$ 613	$ 406	$ 923	$ 617	$ 148	$ 293
Maximum sample size	67	39	108	67	4	23
Optimal sample size	15	13	24	27	0	0
ENGS at optimal sample size	$ 223	$ 33	$ 414	$ 103	0	0

As is the case for the cross-bred cattle the optimal sample size increases with the reduction in the cost of sampling due to the increase in the number of tests being carried out on each specimen. The ENGS at optimal sample size also increases with reduced sampling costs, however the collection of specimens is not suggested in cases where sampling is not suggested with the higher cost of sampling.

Table 8:   Estimated benefits of sampling for a herd of disease resistant cattle with sampling costs of $1 per sample

| Sample information | Producers with different prior probabilities | | | | | |
	Producer 1	Producer 2	Producer 3	Producer 4	Producer 5	Producer 6
EVPI	$ 613	$ 406	$ 923	$ 617	$ 148	$ 293
Maximum sample size	164	103	255	165		
Optimal sample size	28	27	30	29	0	0
ENGS at optimal sample size	$394	$188	$590	$279.03	0	0

8. Summary

Livestock producers in Central Queensland suffer from a shortage of animal health information. However, a rational decision can be made without perfect information and it will not be worthwhile for a producer to collect additional information on animal health unless the benefit of that information exceeds the cost of collecting that information. This paper develops and demonstrates a technique, using Bayesian decision theory, to determine the net return from sampling and to determine the optimal sample size. The use of this technique would enable the livestock producer to consider the decision to gather additional animal health information systematically and examine the potential returns.

The calculation of the ENGS provides a useful way to examine the benefits from the collection of additional information and to assist in the decision to collect blood specimens for laboratory analysis. It also provides a useful method for the estimation of the optimal number of specimens.

The ENGS and optimal sample size vary with the decision makers prior probabilities and with the susceptibility to disease caused by *B. bovis* of the cattle being considered for vaccination. The ENGS and optimal sample size must, therefore, be calculated for each individual situation.

As part of the decision to collect additional information the farmer needs to determine if the benefit from collecting the information is sufficient to justify the expenditure on its collection. The optimal sample size increases as the costs of sampling decrease. There is not always a net gain from the collection of additional information and in these cases sampling cannot be recommended. When the ENGS at the optimal sample size is small it is possible that the farmer would gain more by using the money elsewhere rather than collecting additional information. In the case of *B. bovis* vaccine is relatively inexpensive in comparison to the cost of the collection of additional information. Therefore, it is possible that money may be more effectively spent on the purchase of vaccine rather than on gathering additional information.

In the situation examined in this chapter the vaccine is inexpensive and provides long- lasting protection. However, where vaccination must be carried out annually and a more expensive vaccine used, the benefit from collecting the information would be expected to be greater.

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