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OPTIMISATION METHODS FOR ASSISTING POLICY DECISIONS ON ENDEMIC DISEASES

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SUMMARY

Endemic disease of animals is an economic problem as it deprives humans of scarce resources that might otherwise satisfy human wants. Optimisation methods identify the strategies that minimise this economic problem. Given the potentially vast extent of the deprivation, not only in terms of lost wealth but also in terms of animal welfare, human health and environmental damage, this subject offers great benefits to decision-makers from the individual farm to the global level.

This paper uses examples to illustrate the basic economic principles concerned. It shows how these principles may be extended to deal with current limitations in theory and practice. Lack of data is a common problem that may be dealt with by using computer simulation, theoretical approaches or the experiential knowledge of the decision-makers themselves. The latter method has the added advantage of greatly assisting with the difficult problem of effectively communicating the results of decision analysis to the decision-maker. In most situations the decision-maker will need to strike a balance between conflicting objectives such as short term profit and long term environmental damage (sustainability). This problem will require a wider perspective, which is greatly facilitated by collaboration between economists and scientists. The paper illustrates ways in which this has been done by using decision analysis methods to focus on the decision rather than the disease.

The conclusions highlight prirority areas for future research and development in this area. Topics include the contribution of endemic disease control to sustainable development, endemic disease eradication, capturing wider implications such as animal welfare and food safety, accounting for variation in rational decision making and dealing with risk.

Keywords:Economics, decision analysis, optimisation, modelling, endemic disease, knowledge transfer

INTRODUCTION

Why optimise?

If we are to achieve the vision set out in the Animal Health and Welfare Strategy for Great Britain (AHWS) (Defra et al., 2004) then all concerned must engage as appropriate in a coherent network of policies. Assisting policy decisions therefore ranges from individual farm health planning right through to international agreements designed to combat global pandemics. At all levels, it will be necessary to allocate scarce resources between competing activities in order to achieve the most appropriate objectives in the best way. In other words, economics is at the heart of this decision support process and optimisation the guiding principle.

McInerney et. al. (1992) highlighted the importance of this point using a loss-expenditure frontier as explained below. Their approach clearly demonstrated the role of economics in animal health to non-economists and paved the way for the interdisiciplinary team work needed for effective policy decision support. Establishing the optimal endemic disease control option provides a benchmark with which to judge all alternatives. It also indicates the relative potential for extra investment in specific endemic diseases in competition for resources with other diseases and with alternative opportunities open to the decision-maker. This is important given the temptation to use average total disease costs as an indicator of relative importance even though most of the total cost of endemic disease will be unavoidable and the marginal cost of improvements subject to the law of diminishing returns (McInerney, 1996, Figure 1).

Unfortunately, the loss-expenditure frontier approach demands considerable data that are rarely available (Bennett, 2003). However, by teaming up with scientists, systems modellers and epidemiological modellers, the data required by economists can often be obtained by computer simulation (e.g. Gunn et al., 2004, Stott et al., 2003, Santarossa et al., 2005). Some applications have also been based on field data (e.g. Yalcin et al., 1999 and Chi et al., 2002).

Decision analysis

The analysis of McInerney et al. (1992) assumes complete information and unimpeded optimising behaviour, assumptions that are not likely to be satisfied in practice (Tisdell, 1995). Tisdell (1995) therefore extends the special case of McInerney et al. (1992) in a number of ways including dealing with multiple diseases and situations where disease control funds are in short supply (see Figure 2). An alternative approach is to focus on decision making rather than on disease and so draw on the wide range of generic decision analysis (DA) techniques available (Ngategize et al., 1986). The original and best known DA technique is linear programming (LP) (Jalvingh et al., 1997). Although little used in animal health economics, LP captures the essence of decision support i.e. it addresses the resource allocation problem. For example, Stott et al. (2003) used it to incorporate biosecurity options into whole farm planning in order to achieve a farm income target at minimum risk. This approach demonstrated the impact that endemic disease could have on whole farm management and on risk management. A more common application in animal health economics is the decision tree (Marsh, 1999). Competing decision choices such as when and with what to dip sheep for external parasites (Milne, 2005) are represented as branches on the tree. Possible outcomes flowing from each decision choice are represented by further branches, each with a probability of occurrence and a financial outcome. The 'optimal' decision is usually considered to be the one that gives the highest expected (probability weighted average) net cashflow from its branches.

Decision trees provide a visual representation of the decision choices faced. The decision-maker can get directly involved, drawing on his/her experience to estimate likely outcomes and risks (Boehlje and Eidman, 1984) and thus overcoming some of the data problems mentioned previously. These features are of real benefit in practical decision support and are far more likely to result in progress at farm level than more sophisticated 'black box' methods. However, once sufficient branches have been added to capture the full impact of a present decision over the many cycles of animal production likely to be affected, including future decisions and chance outcomes, decision trees become very difficult to handle. This is where dynamic programming (DP) (Bellman, 1957) steps in. It finds the optimum route through a decision tree in a computationally efficient way. The approach is explained in Stott et al. (2005a) where it is used to explore the relationship between the cow replacement decision and Johne's disease in dairy herds.

Wider perspectives

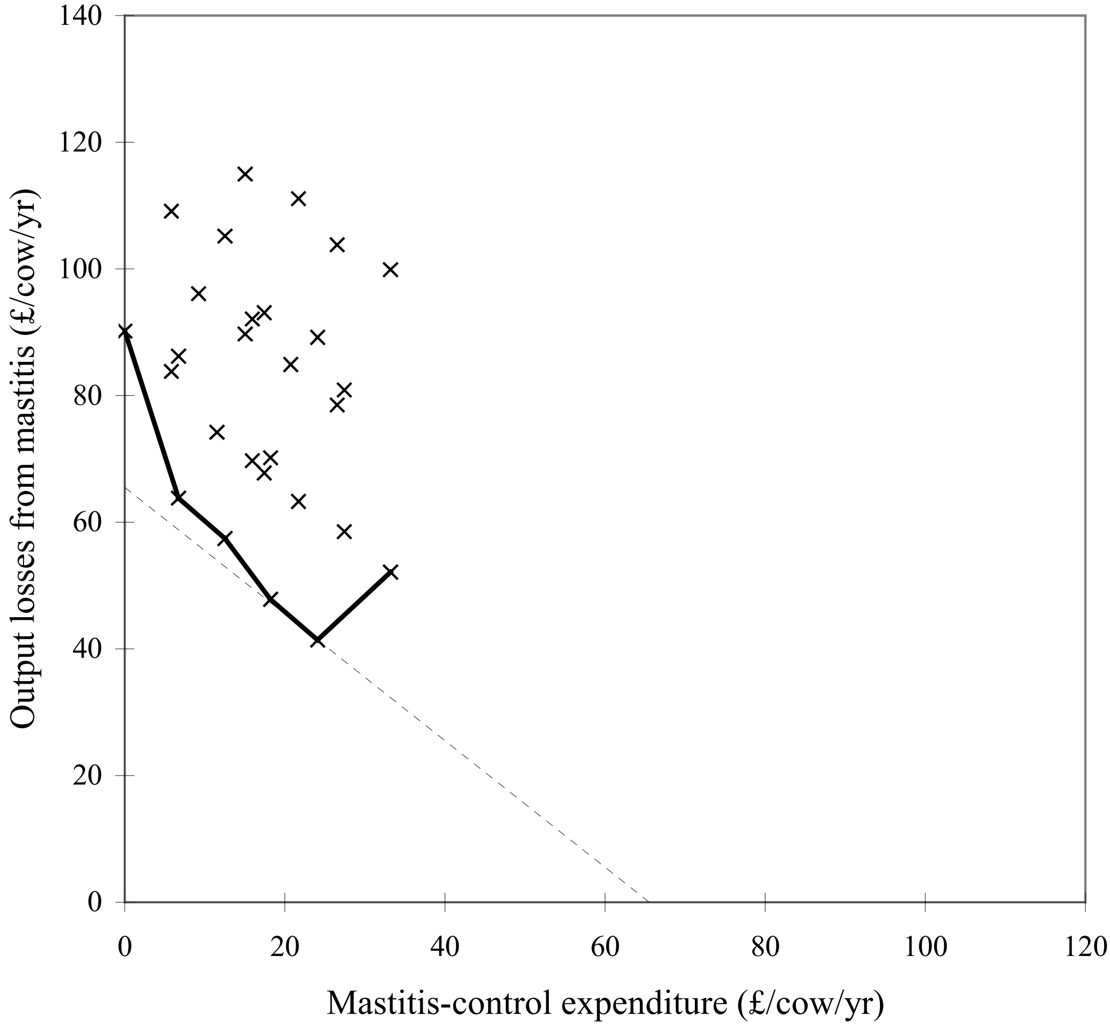
Because the world is complex, simplified models are needed to help us understand it (Tisdell, 1995). These models frequently involve reductionism. The scientific approach may be to focus on a specific disease or pathogen. As a consequence we may know for example the biochemical composition of a pathogen but have little information about its prevalence in the field or other information vital for economic analysis and decision support. Focusing on the economics of a specific endemic disease or analysing a particular decision are other examples of reductionism. Although such approaches are essential for progress in their respective disciplines, assisting policy decisions, including those on endemic disease may require a wider perspective. Economics can widen the perspective and so add great value to scientific knowledge. For example, when dealt with at the farm level (GB), there are benefits from optimised policy advice to individual farmers on controlling Johne's disease (Stott et al., 2005a). However, from the wider national perspective (USA), Losinger (2005) found that consumers may stand to benefit more than producers from eliminating Johne's disease in dairy cows, given the transfer in economic surplus from producers to consumers that would result from increased milk production. This transfer is caused by the increase in milk supply following disease eradication, which is accompanied by a reduction in milk price, of benefit to consumers. Similar studies following the 2001 foot-and-mouth crisis in the UK (e.g. Thompson et al., 2003) established the considerable impact on various sectors of the economy such as tourism, the food industry and ancillary industries as well as agriculture. Although such wider perspectives are rare in studies of endemic disease, their importance will grow as agricultural policy shifts away from 'cheap' food production in the West towards globally sustainable systems that address wider considerations such as adequate food for all, environmental protection, animal welfare, food safety and rural development (Hodges, 2005). These concerns are implicit in the AHWS as it calls for the distribution of the costs of animal health to better reflect where the balance of responsibilities lies for managing the risks from animal disease. The distribution of costs should also take account of those who benefit from measures to manage these risks. The concerns are also reflected in Defra's aim of sustainable development and its objectives, particularly objective 5 to promote sustainable management and prudent use of natural resources domestically and internationally (Defra, 2005). Optimisation methods to assist policy decisions on endemic disease will make an important contribution to this aim and objective. This paper therefore gives a brief overview of some of the techniques involved.

KEY TOOLS AND CASE STUDIES

The loss-expenditure frontier

Figure 1 drawn from Yalcin et al. (1999) provides an example of the approach of McInerney et al. (1992). Each cross on the graph represents the average performance of farms in the sample using the same approach to controlling subclinical mastitis. Those with the highest control expenditure tend to have the lowest losses from the disease. The solid line is the loss expenditure frontier, joining the most efficient treatment strategies at each level of control expenditure. The optimal strategy is on the iso-cost (hatched) line tangential to the frontier. It has the lowest total cost (output loss+control expenditure), in this case £66/cow per year. Average total cost in this sample was £100/cow/year. This gave an avoidable loss (true cost) of £34/cow/year.

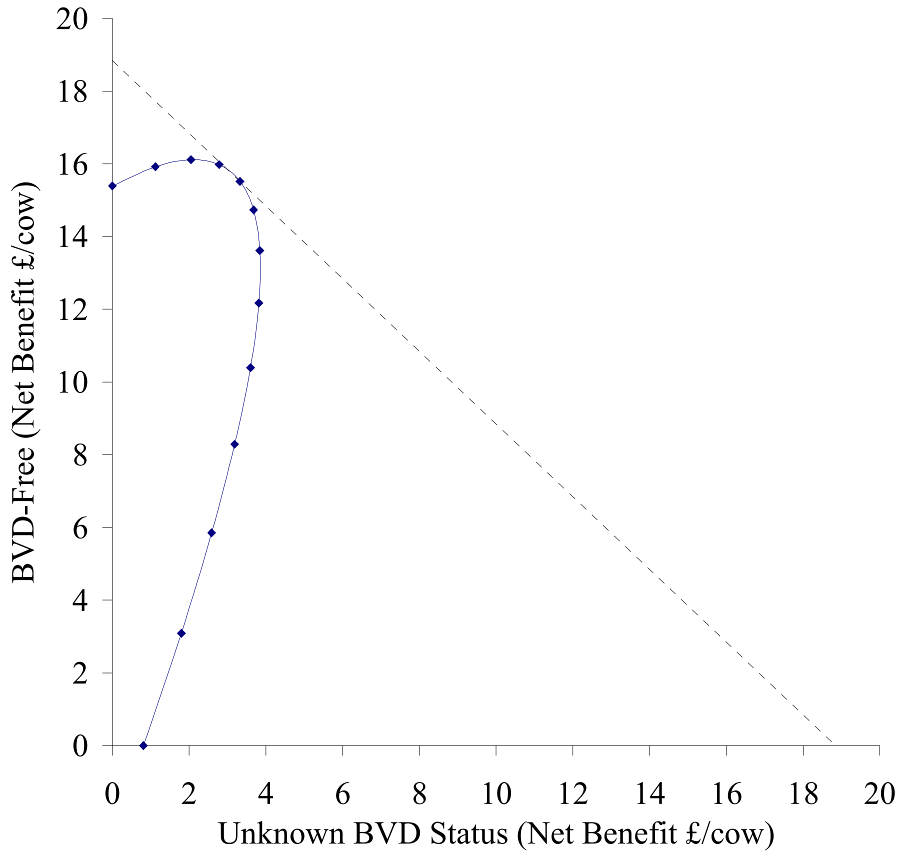
Figure 1. Loss-expenditure frontier for subclinical mastitis in a sample of 750 dairy herds



Dealing with multiple diseases and restricted control funds

Figure 2 shows an example of the method of Tisdell (1995) based on data for bovine viral diarrhoea (BVD) in beef suckler herds generated by the model of Gunn et al. (2004) and using the function for biosecurity costs set out by Stott et al. (2003). The graph deals with a hypothetical allocation of expenditure on biosecurity between beef suckler farms that are either free of BVD or of unknown BVD status but otherwise identical. Expenditure is fixed at £12/cow/year. If this entire sum is given to the BVD-free herds the net benefit (output loss avoided less cost of biosecurity) will be just over £15/cow/year. If given to the herds of unknown BVD status the net benefit is just £1/cow/year. The iso-net benefit (hatched) line shows that giving £8/cow/year and £4/cow/year to the BVD-free and BVD-unknown herds respectively yields the highest net benefit (£19/cow/year).

Figure 2. Alternative allocations of £12/cow/year biosecurity expenditure between beef suckler herds of different BVD status

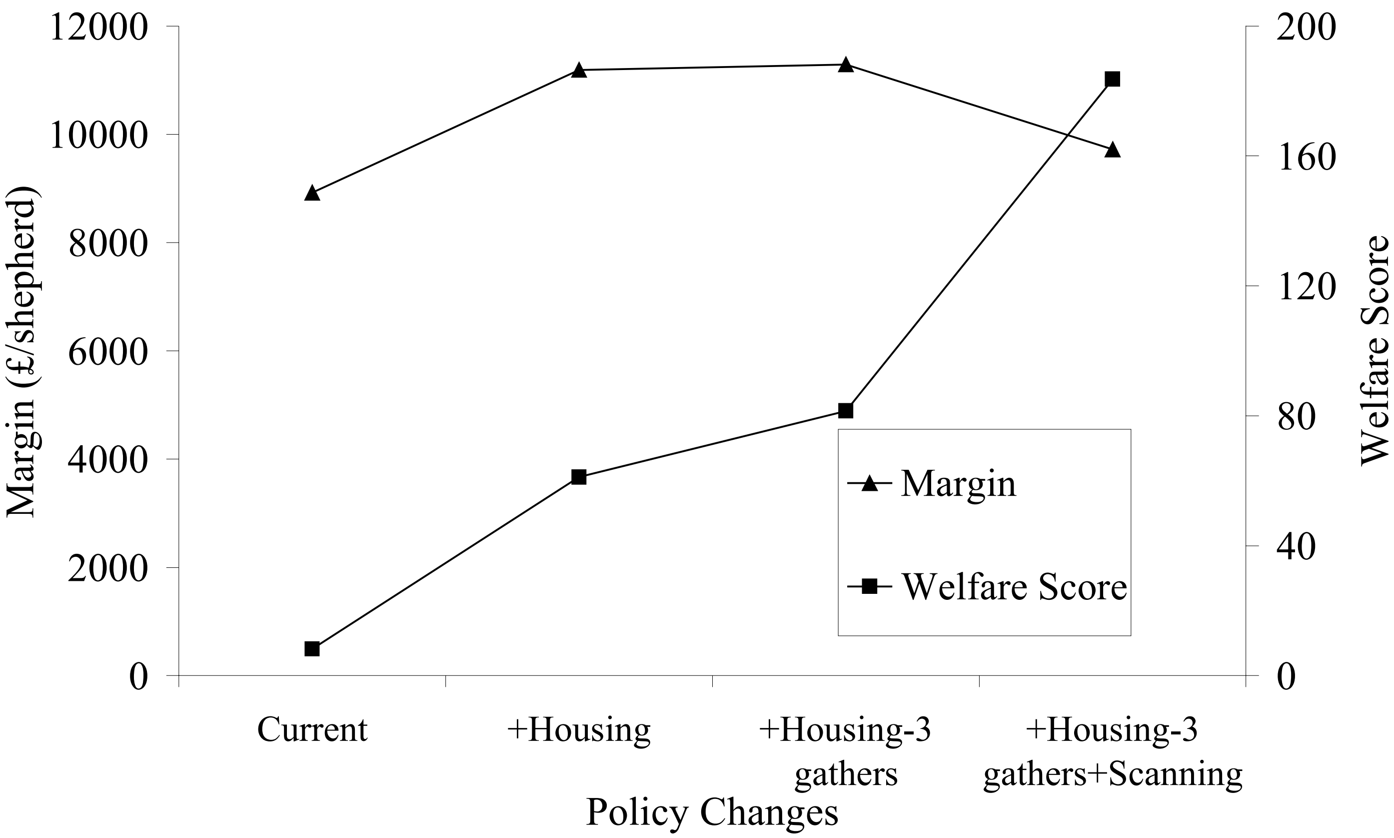


The above example is intended to illustrate the potential of the technique. Instead of different BVD status on different farms, the technique could deal with different diseases competing for fixed control resources on the same farm. However, the BVD example does widen the perspective to regional level. Although not attempted here, the interaction between farms, i.e. the benefit that BVD-unknown farms get from BVD-free neighbours could be built into the analysis. Notice the considerable cost of getting the decision wrong (giving all the incentive to BVD-unknown farms). Also notice the value attached to knowledge of BVD status. Reflecting that value by offering twice as much support to farms free of BVD would not only deliver the best regional outcome but would also act as a considerably incentive to those would-be 'free-riders' (Holden, 1999) that might otherwise be tempted to opt out of an eradication programme from which they will benefit while others carry the costs.

Communicating results of DA

The world of computer simulation models and mathematical programming techniques is so far removed from the practical realities of coping with disease in livestock that special effort is needed to bridge the gulf and extract real benefits in terms of improved animal health and welfare. One way to do this is through direct participation of farmers in the research effort. This was the approach taken in Defra funded project AW1012 (Improving sheep welfare on extensively managed flocks by understanding the economic and husbandry influences on flock welfare). Figure 3 gives an example output for a farm in the Peak District participating in the project. It shows the changes needed in the set of husbandry activities ('policy') used on a farm to maximise animal welfare. The farmer was already using the best disease prevention strategy for animal welfare and had plenty of labour to meet welfare needs. By housing ewes at lambing time he could improve welfare and gross margin. By reorganising his system he could reduce the number of gatherings required with further benefit to animal welfare. The final step is to scan the ewes and feed accordingly with considerable marginal improvement in animal welfare but at some expense in terms of gross margin.

Figure 3. Path to the welfare-maximising policy for an extensive hill sheep farm

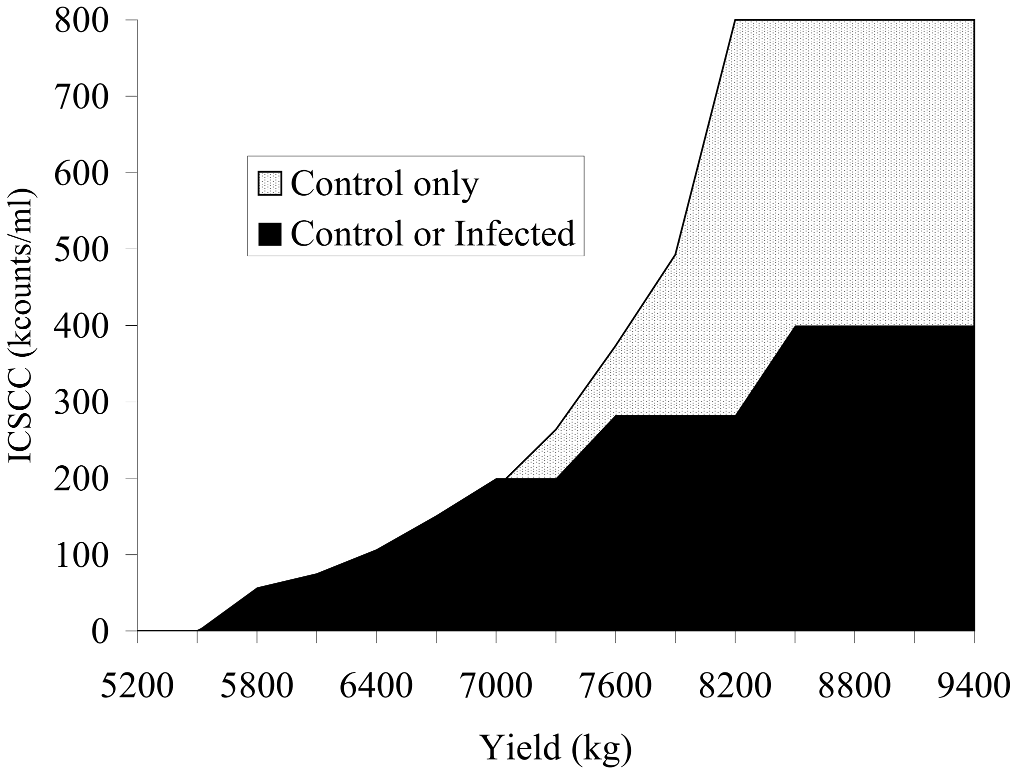


Welfare score in this study was based on farmers' perceptions corroborated by welfare specialists as explained in Stott et al. (2005b). The gross margins were determined using LP. This was not to provide the farmers with optimal solutions but to ensure that each gross margin was best suited to the policy under test. This is like using the DA technique to simulate the actions of the rational decision-maker in the system. It provides a useful way to drive biological simulation models and highlights another fertile ground for interdisciplinary collaboration between economists and scientists/modellers. The approach is familiar to animal breeders who have been using such bio-economic models for many years to provide economics weights for selection indices used in national breeding programmes (see for example Stott et al., 2005c and Santarossa et al., 2004).

Note that the aim of this analysis was not to use DA to dictate an optimal solution but to use it to assist provision of a hierarchy of suggested improvements to farm policy that will indicate priorities for welfare in order of affordability. In so doing it acknowledges the constraints that bind practical decision making and highlights the trade-offs that often have to be made in practice but cannot always be included in a DA. These features ensure that the decision is supported by the system, the aim being to improve the decision-making process rather than identify the best decision. This approach is more likely to result in practical benefits in terms of animal health and welfare. Involvement of farmers throughout improves the chances of success still further, provides data for the analysis and a validation procedure that is unlikely to be obtained in other ways (Defra, 2005b).

Figure 4 illustrates an alternative approach for transferring knowledge (KT) gained by DA to the decision-maker. It is based on the output of a DP exercise to determine optimal culling strategies for cows in a herd suffering from *S.Aureus* mastitis compared to a control herd. (Stott et al., 2002).

Figure 4. Culling guide for controlling mastitis in dairy cows in lactation 5. S.Aureus infected herd vs control herd



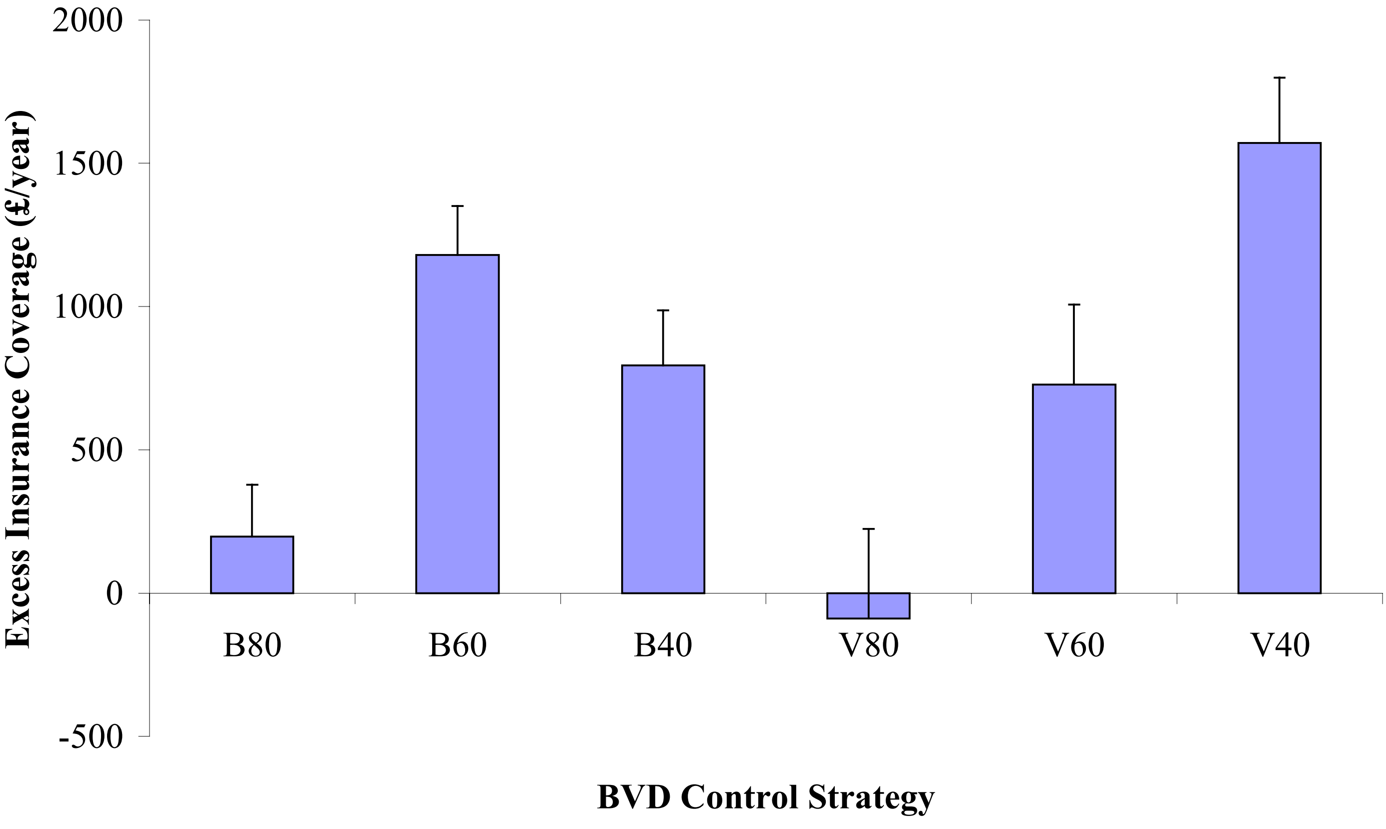
The graph shows the trade-off between ICSCC (individual cow somatic cell count, a measure of mastitis infection) and milk yield as culling criteria. Cows in the shaded area should be considered for retention, while those in the unshaded area should be considered for culling. Note the additional culling pressure required in infected herds, which will be compounded by the greater proportion of cows outside the shaded area as a result of *S.Aureus* infection. Figure 4 is for cows in lactation 5. Similar graphs were produced for other lactation numbers. These culling guides were tested by specialist SAC advisers with Scottish dairy farming clients and found to be in line with best practice and trends observed in the field (Logue et al., 2000).

Multiple objectives

Most DA techniques seek to maximise financial gain to the decision-maker. It is often argued that this is not always the primary objective of decision-makers and if followed may prejudice the interests of other stakeholders. In the case of endemic disease prevention, motives such as improved animal welfare, human welfare and environmental gain need to be considered. These are not easily expressed in monetary terms and are therefore liable to be neglected in a DA that emphasises private cost-benefit. However, although rare in this context, some DA techniques can handle multiple objectives. Milne (2005) for example used a multi-criteria analysis to highlight the conflicts that can arise between farm profitability, animal welfare, human health and the environment in the control of ectoparasites of sheep. Santarossa et al. (2004) examined the trade off between the short-run productivity of natural assets and their long-run value (sustainability) in dairy farming.

At farm level, the trade off between risk and profit is of particular concern. This concern may grow as European farmers are gradually weaned off protectionist agricultural policies and become more exposed to the vagaries of global commodity markets. Stott et al. (2003) demonstrated that the least-cost BVD control option is not necessarily the risk-minimising option. They concluded that risk and decision-maker's attitude towards risk are important considerations when choosing the optimum BVD prevention strategy. The same conclusion is likely to apply to other endemic disease control decisions. Santarossa et al. (2005) therefore developed the idea by incorporating risk reduction and decision-makers' attitude towards risk into the BVD control choice decision. They did this by using a contingent claim analysis (CCA) method (Stinespring, 2002) to assess alternative BVD prevention strategies. A representation of their results is shown in Figure 5.

Figure 5. Excess insurance coverage needed to offset risk from BVD under alternative control options*



*B80/B60/B40 assumes that biosecurity strategies have a 0.8/0.6/0.4 probability of avoiding virus introduction in any one year. V80/V60/V40 assumes that vaccine ensures that 0.8/0.6/0.4 of all adult cattle are effectively immunised each year. Strategies are hypothetical. Results are mean and SE of 100 Monte Carlo simulations in each case using the model of Gunn et al. (2004).

The CCA method calculates the level of (hypothetical) insurance cover necessary to maximise the decision-makers' expected utility of wealth (psychological satisfaction of holding wealth) under risk. The more effective the BVD control strategy, the less the risk and the lower the excess insurance cover required. For example, in Figure 5, the excess insurance for B80 and V80 was not significantly different from zero i.e. these options provided adequate protection from the risks of BVD while the others did not. Hypothetical insurance requirements therefore become a proxy for measuring the relative value of alternative endemic disease prevention options in terms of the trade-offs between profit and risk as perceived by the decision-maker. The main point to emphasise here is that the results depend on the decision-maker's attitude towards risk, which is affected by income and wealth. For the values for these parameters used to derive Figure 5 see Santarossa et al. (2005). Another decision-maker with different values would have a different Figure 5 and make different disease control choices. This point is relevant to the AHWS, which emphasises understanding of the costs and benefits of animal owner's own actions so that best practice is understood, accepted and adopted. With such understanding animal owners will be able to act in their own best interest but they may not all act in the same way and their actions may not always be in the best interests of other stakeholders. For example, Santarossa et al. (2005) showed that the utility maximising BVD control option was not an optimal solution in terms of animal welfare under the assumptions used.

DISCUSSION AND CONCLUSIONS

The aim of sustainable development that under pins all Defra policy including the AHWS, dictates that the resources required to implement policy are allocated as efficiently as possible. This means that optimisation methods for assisting policy decisions on endemic diseases are obligatory not an optional extra. Such obligation extends from the international policy-maker ensuring value for public money through to the private business that must remain competitive to survive. However, for the reasons highlighted above, optimisation methods should rarely if ever be used to determine policy decisions. The dangers of over-reliance on economic optimisation techniques are all too evident in the history of the financial markets of the world (MacKenzie, 2004). This paper therefore highlights more pragmatic approaches to the use of optimisation methods in the context of endemic disease decision support.

Data are rarely available to realise the full potential of economic optimisation methods in support of endemic disease policy decisions (McInerney, 1996). This problem can be alleviated by closer collaboration between scientists, modellers and economists. However, even with perfect knowledge, problems will almost invariably involve reconciliation of competing objectives rather than optimisation of independent objectives. The concept of sustainability itself is a question of reconciling current with future demands on finite resources. Improved animal health through better endemic disease policy decisions will play an important role in this balancing act. For example, Garnsworthy (2004) using DA methods developed by Stott et al. (1999) estimated that improved fertility in dairy cows (much affected by endemic disease) could reduce greenhouse gas emissions such as methane by up to 24%. Clearly wider perspectives on endemic disease to tackle issues such as this are urgently required.

The predominance of multiple objectives in endemic disease decision problems does not reduce the value of optimisation methods in decision support. Multiple objectives can be handled as shown in the above examples based on Tisdell (1995), Stott et al. (2002), Stott et al. (2005b) and Santarossa et al. (2005). Cost minimisation methods based on sound economics also have vital roles to play. They establish bench marks against which to measure the opportunity cost of alternatives to the optimum solution. Perhaps more importantly, they demonstrate clearly to decision-makers the vital role that economics can play in this field. They highlight the cost of complacency and question traditional assumptions about an issue that has important implications for us all.

It is also important to appreciate that optimisation methods for endemic disease control can play a wider role in decision support than their name implies. For example, DA techniques focus on decisions rather than on disease. By doing this they can widen the perspective and draw in decisions not normally associated with disease prevention but potentially vital to it. For example, better support for the replacement decision in dairy cows may allow us to better control endemic diseases such as *S.Aureus* mastitis which is unresponsive to antibiotics and/or reduce the use of antibiotics in agriculture with less risk to animal welfare (Stott et al., 2002). The wider perspective therefore captures some of the externalities of conventional approaches to animal disease thus providing another means to contribute to sustainability.

Eradication of some endemic diseases is a potential policy objective that will require a wider perspective. Some competitor countries have or are eradicating diseases that are still endemic in the UK (Stott, 2005). Decision support is needed at regional and/or national level to ensure that this problem is dealt with in the best way. The example above based on Tisdell (1995) raises some of the issues and responses involved. This is an issue where public-private partnership mentioned in the AHWS needs to be effectively developed.

From the endemic disease policy maker's perspective, the greatest contribution optimisation methods will make in future is probably in risk communication. Increasing risks at farm level due to CAP reform etc. have already been mentioned. Other policy makers need no reminding about the difficulties of communicating relative risks associated with endemic diseases of livestock. As ever, the main problem is lack of data. Purely scientific approaches may breakdown at this point but economic models can still provide insights based on appropriate theoretical principles (Harvey, 1990). Issues of public safety must in any case deal equally with the emotional aspects of risk perception and public concerns as with the scientific facts (Peddie et al., 2005). Getting stakeholders involved and using DA techniques to aid communication and/or model decision-maker behaviour as illustrated above is likely to be most important. Greater collaboration between disciplines, such as the use of the insurance industry approaches described by Santarossa et al. (2005) need to be encouraged. Realising that different stakeholders will make different decisions, i.e. there can be no uniform collective response to endemic disease risks is fundamental. Using DA techniques to predict these decision sets will be the first step towards effective policy making.

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