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Animal Disease Economics: The Case of Ovine Johne's Disease in New South Wales

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Abstract

Increased surveillance over the last three years has found that the prevalence of ovine Johne's disease (OJD) in Australia is greater than previously believed. Trading restrictions and recent stock movement controls have added to the productivity losses of OJD affected producers in an attempt to minimise further spread of the disease while scientific data to support long term policy decisions is obtained through the National OJD Control and Evaluation Program. The literature on the economics of OJD in Australia is reviewed and a framework for further work in this area developed. Directions for economic research within the National Program are then presented.

1. Introduction

Johne's disease (JD) is a wasting disease of ruminants caused by *Mycobacterium paratuberculosis*. Distinct ovine (OJD) and bovine (BJD) strains have been detected in Australia, with the former now being routinely detected in both sheep and goats. While OJD has been diagnosed in a small number of cattle, it is not known whether infected cattle can pass the disease on to other cattle or back to sheep. Other potentially susceptible animals include alpaca, llamas and deer (Denholm et al 1997).

JD thickens the intestinal wall, reducing the absorption of nutrients. Wasting symptoms do not usually occur for some years after infection, often following a period of managerial, climatic and/or nutritional stress on the animal. Following the onset of the wasting symptoms, the animal progressively loses condition over a number of months until death occurs.

The disease is transmitted by non-infected animals ingesting an infective dose of bacteria when grazing pasture that has been contaminated with the faeces of infected animals. Infected animals do not begin shedding bacteria for some months or even years following infection, but the volume of bacteria shed increases rapidly following the onset of wasting.

It can be shown that *paratuberculosis* bacteria survive longer on pasture in cooler, wetter areas. Soil type and slope may also influence bacterial survival and spread risk whereas higher stocking density probably accelerates disease spread within a flock. It is perhaps for these reasons that OJD is concentrated in the central and southern tablelands of New South Wales and climatically similar areas of Victoria.

Accurately diagnosing the presence of the disease within a flock has proven difficult. Blood testing, which seeks to detect the presence of antibodies to the disease, is expensive and requires large numbers of individual samples to provide a reasonable degree of accuracy regarding the flock's OJD status. The newly developed pooled faecal culture test, which detects the bacteria itself, provides a less expensive flock test, but involves a delay of around three months before results are available. Both tests are less reliable in the early stages of infection. No statistically valid single-animal test exists.

There is no known cure for OJD. Although a one-dose "killed" vaccine has recently become available in Australia, it only delays the onset of wasting. The vaccine does not prevent infection or the shedding of bacteria and often produces lesions in vaccinated animals, thereby reducing the value of the carcase and imposing extra inspection costs on processors. To return to "unassessed" status, an infected

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property essentially needs to be destocked of susceptible animals for a period including two consecutive summers[1].

The National OJD Control and Evaluation Program (National Program) consists of numerous interrelated strategies incorporating increased surveillance of the prevalence of OJD throughout Australia, scientific research into the biology of the disease, and on-farm trials of numerous control and eradication techniques, including vaccination and eradication through destocking. The National Program is scheduled to run for six years and cost $40 million. While there is an economic evaluation component of the destocking trial, the degree to which the economic or financial dimensions of the other National Program components are addressed varies.

2. Financial Effects of OJD on Individual Producers

OJD affects the financial performance of individual producers through its biological effect on production and regulatory restrictions. Anecdotal evidence suggests that OJD adversely affects productivity primarily through increased animal mortality, reduced lambing percentages, reduced wool cut, and possibly decreased fibre quality. Of these, increased mortality is considered the most serious, with annual losses of up to 15% reported, although mortality can vary considerably between infected flocks and rates above 10% are uncommon (Eppleston et al 1999).

For many affected producers, regulatory restrictions impose greater financial costs on their business than do the disease's production effects. Most regulatory restrictions aim to reduce the spread of the disease by limiting trade in infected, or potentially infected, animals. Properties with "infected" or "suspect" status must only sell susceptible animals for slaughter or, subject to approval, to other infected or suspect properties. There are also geographical zones which restrict the flow of susceptible animals between "residual", "control" and "free" areas, with control zones considered to have lower disease prevalence than residual zones. These trading restrictions have imposed significant financial costs on to various classes of sheep producers, particularly those which specialise in the production of store lambs, restocking ewes or wethers and stud rams.

3. Previous Work into OJD in Australia

While some epidemiological work has been undertaken into OJD in Australia, and much more is planned as part of the National Program, Australian work into the economic consequences of OJD is scant. The Australian Bureau of Agricultural and Resource Economics report *Ovine Johne's Disease: Evaluation of control and eradication strategies* (ABARE 1997) is probably the major work to date. Most other work consists of discussion papers based on four to eight financial case studies (see Holmes and Sackett P/L 1996, Australian Animal Health Council 1997, NSW Farmers' Association 1997, and Patterson 1998).

While all of these studies estimate significant individual losses as a direct result of OJD, all suffer from a lack of rigour, both in terms of methodology and sample size and selection. A common shortcoming of these studies is the "accounting" approach taken when estimating losses on a farm, industry or national basis, where the production losses have been estimated by calculating the annual loss in output and multiplying by current prices. Such an approach takes no account of either the enterprise mix response of an individual producer to disease-induced changes in enterprise profitability or price movements flowing from disease-induced changes in supply in the case of aggregate studies (McInerney 1996). In the only "whole farm" approach to date, a 1998 survey of 28 infected properties located in the central and southern tablelands of New South Wales found that the average loss in cash farm income in the year following diagnosis was around $23,000, although there was evidence of continuing enterprise mix adjustment in response to the disease (Webster 2000).

Even if a reasonable estimate of the cost of OJD can be obtained, stating that a producer's farm income, however defined, is $x per year less than it would have been had their flock not been infected is of limited value. This is because the infected outcome is being compared with a state that is

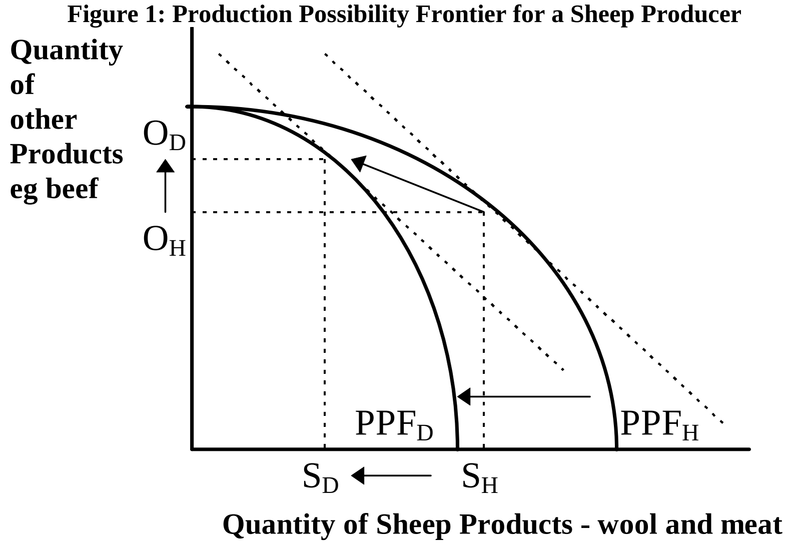
[1] The eradication guidelines are very complex, and a full explanation is not possible due to space restrictions.

unobtainable without cost - a non-infected flock. As McInerney et al (1992) points out, it is not the total cost of a particular disease that is useful, but the avoidable component of that cost.

4. The Animal Disease Loss-Expenditure Frontier

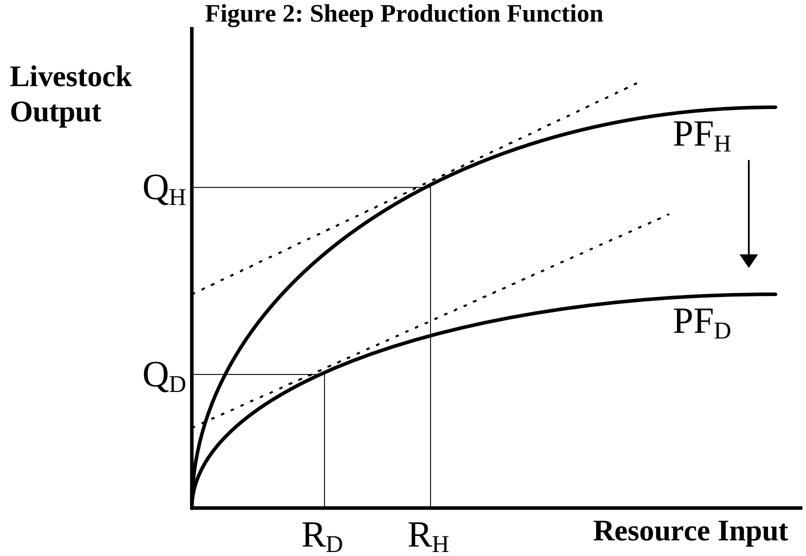
Determining the farm level effects of specific animal diseases and their related optimal control procedure/s is the first step towards developing a coherent state or national animal disease strategy. A concept that will be familiar to all economists is that of the production possibility frontier, as shown in Figure 1. An individual sheep producer whose property is non-infected ("healthy") will have the production possibility frontier PPF_H. The optimal production point will occur at the tangent of PPF_H and the dotted price line, producing S_H of wool and sheepmeat and O_H of "other" products. The introduction of disease shifts the sheep production side of the frontier inwards, resulting in the new frontier PPF_D. Consequently the optimal production point shifts production away from sheep (S_D) and towards other products O_D. The substitution of other, now relatively more profitable, farm enterprises for sheep enterprises after the introduction of OJD is intuitively obvious and has some empirical support (Webster 2000).

Figure 1: Production Possibility Frontier for a Sheep Producer



The commodity supply decisions of an individual sheep producer can be further illustrated by examining the production function for a given commodity, as shown in Figure 2.

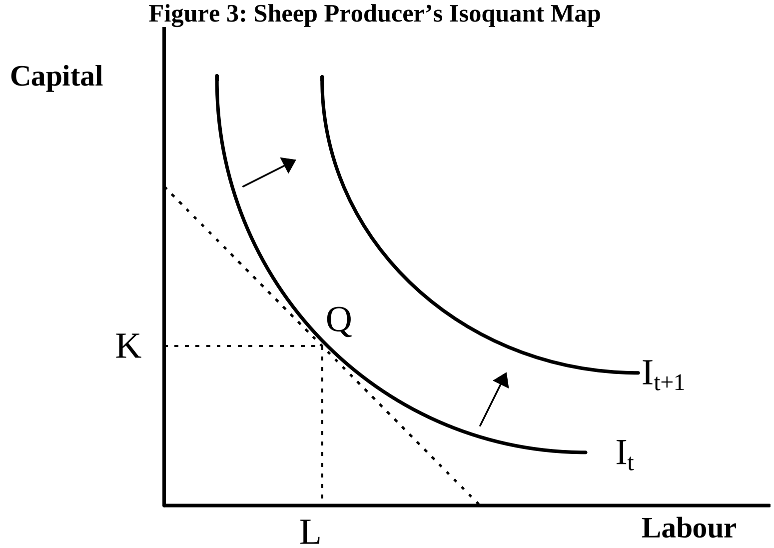
Figure 2: Sheep Production Function



The introduction of disease shifts a producer's production function for wool and/or sheepmeat down from PF_H to PF_D. The level of production under each scenario is represented by the point along the production function where its slope is equal to the relative prices of the resource inputs used in production and the livestock output (P_R/P_Q), again shown as dotted price lines. The introduction of disease therefore reduces the output of the livestock commodity in question from R_H to R_D. This shift away from the given commodity would likely occur in conjunction with a shift towards another, relatively more profitable commodity, thereby minimising the financial cost of the disease. It is this substitution effect that the "accounting" approach to disease loss estimation often fails to take into account.

It can therefore be asserted that the introduction of OJD will generally induce a shift away from sheep enterprises towards alternative enterprises, such as beef cattle or cropping. This shift away from sheep production can be represented at the farm enterprise level by another well-known microeconomic tool, the isoquant map, as shown in Figure 3. The non-infected level of sheep production is represented by Q - the tangent between the highest attainable isoquant (I_t), given the resource constraints K and L, and the dotted price line. The introduction of disease shifts the isoquant map, containing an infinite number of isoquants, upwards. Consequently, I_{t+1} represents the same level of output post-infection as did I_t pre-infection. More labour and capital is therefore required to produce the pre-infection quantity of wool and sheepmeat. If K and L are binding constraints, a quantity lower than the pre-infection optimal will be produced, again represented by Q.

Figure 3: Sheep Producer's Isoquant Map



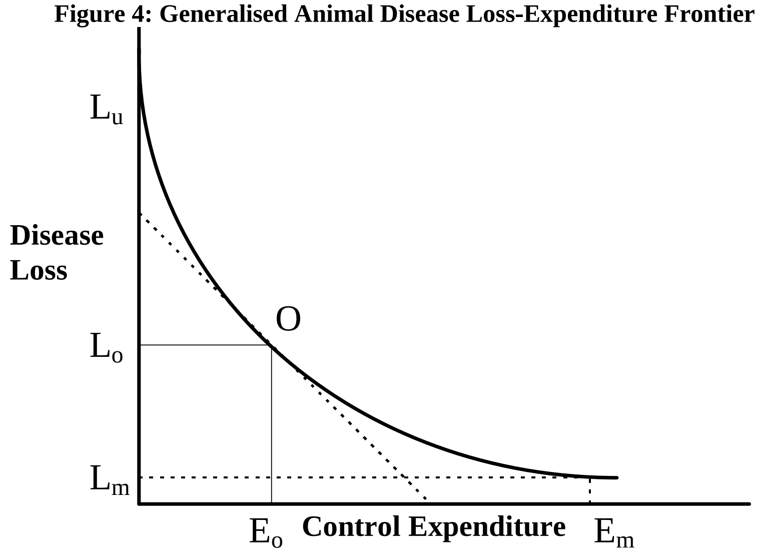
McInerney et al (1992, 1996) has developed a theoretical framework for determining the optimal control procedure for a given disease by adapting the isoquant map concept to represent the trade off faced by producers between disease losses and disease control expenditures, represented by the identity:

Disease Cost (C) = Production Losses (L) + Control Expenditures (E)

The resulting loss-expenditure frontier is shown in Figure 4. Production losses are defined as shortfalls in output arising from the presence of disease. Control expenditures are financial outlays made to reduce production losses. McInerney suggests that the frontier could be considered to represent the cost of a given disease over any period, but in most cases would represent the annual cost.

The frontier is assumed to be downward sloping and concave to account for diminishing marginal returns to control expenditure. Should disease eradication be technically feasible, the frontier would intersect the expenditure axis. If eradication is not feasible, the frontier would eventually become parallel to and above the expenditure axis.

Figure 4: Generalised Animal Disease Loss-Expenditure Frontier



The point of tangency (O) between the loss-expenditure frontier and the dotted price line represents the optimal amount of disease control expenditure (E_o) and consequent production loss (L_o). As both axes are in the same units - dollars - the price line is set at 45 degrees. At point O, a dollar expended on control returns a dollar in disease loss reduction. Control expenditure of less than E_o (where the frontier has a steeper slope than at O) would mean that the producer could achieve more than one dollar in disease loss reduction by expending another dollar - an inefficient outcome. Conversely, more control expenditure than E_o (where the frontier has a flatter slope than at O) would mean that the producer receives less than one dollar in disease loss reduction for each additional dollar spent on control - again an inefficient outcome.

Other features of the loss-expenditure frontier are L_u, which represents the uncontrolled disease loss, and E_m, which is the expenditure required to keep disease losses to the technological minimum L_m. L_uL_m represents the “avoidable cost” of the disease with present technologies.

McInerney et al (1992) present a good example of this methodology applied to mastitis in dairy herds. Using data drawn from a large sample of dairy herds in the UK, each herd was assigned to a particular control strategy. The mean estimated output loss and control expenditure was then calculated for all eighteen control measure combinations and plotted. The lowest set of points (closest to the expenditure axis) were taken to represent the loss-expenditure frontier.

There is at present no suitable farm level survey data relevant to OJD in Australia that would permit the estimation of the OJD loss-expenditure frontier. The following section therefore outlines an alternative method of estimating the frontier using a simulation model for a representative central tablelands sheep producer.

5. OJD Loss-Expenditure Frontier for the Central Tablelands of NSW

The loss-expenditure frontier framework was adapted to represent the loss-expenditure trade off of an OJD infected property in the central tablelands of New South Wales, the area of highest OJD prevalence in Australia. It was assumed that the property had been officially identified as infected and was therefore subject to trading restrictions.

A representative farm simulation spreadsheet model was developed, based on an area of 650 hectares with a carrying capacity of 10 DSE per hectare - for a total carrying capacity of 6500 DSE. The property’s only enterprise was assumed to be a flock of around 2,900 self replacing 19 micron Merino ewes. The model incorporated six OJD control procedures. These control procedures could be implemented individually or in any combination. Destocking, with the aim of eradicating OJD from the property, was also included in the analysis as a control procedure that was exclusive of all other control procedures. The number of ewes joined varied slightly between control strategies as each strategy altered the flock structure, necessitating an adjustment in flock size to ensure that the property's full carrying capacity was used in each scenario.[2]

The primary object of this exercise was to illustrate the potential for using the methodology within the National Program to guide policy and extension decisions. It is not an attempt to deliver a definitive answer as to the optimal control strategy for OJD infected tablelands properties. This initial attempt at estimating the OJD loss-expenditure frontier under Australian conditions has also served to identify existing data limitations, particularly the lack of epidemiological information in relation to a number of control measures.

The OJD control procedures considered in the model were:

1. early culling - where five percent of the "poorest" ewes were culled across all age cohorts of the flock. The ewes culled would be selected on the basis of body weight and condition, with those displaying what could be signs of clinical OJD culled in addition to those culled at the standard age of six and a half years. This control procedure leads to a higher ewe hogget retention rate;
2. feed supplementation - for Winter lambing ewes to reduce nutritional stress;
3. trace element supplementation - the use of annual copper capsules for all breeding stock;
4. water exclusion - fencing dams and streams to exclude stock entry, and providing reticulated watering points where necessary to reduce water contamination and intake of waterborne bacteria;
5. pasture liming - liming pastures every seven years to reduce soil acidity, thereby theoretically increasing the availability of nutrients to stock;
6. vaccination - one-off vaccination of all stock at the beginning of year 1, followed by annual vaccination of all ewe lambs at weaning;
7. destocking - where all sheep are removed from the property for two years, incorporating two consecutive summers, with the goal of allowing ultra-violet light and heat to kill all pasture-borne bacteria on the property. An interim weaner cattle growing enterprise is assumed to be operated during this period. The property is then restocked with sheep (similar in quality to those destocked) from an OJD market assured source. No sheep income is received until year 3.

OJD control procedures such as early culling, water exclusion and vaccination aim to reduce the amount of bacteria shed by infected animals and/or minimise the amount of bacteria ingested by non-infected animals in the flock. Destocking is an extreme example of this strategy. Other control procedures, such as feed and trace element supplementation and pasture liming are aimed at reducing the disease's clinical effects by minimising stress and through nutritional manipulation.

While the cost of each control procedure was not difficult to estimate, the biological benefits arising from each procedure and the interaction between the various control measures was far more problematic. As there has so far been little scientific research conducted into OJD control procedures in Australia, the procedures included in the model cover a wide range of possible control options, both in terms of stock management intensity and proven efficacy. It should be particularly noted that some of the procedures applied to the model, particularly trace element supplementation, water exclusion and pasture liming, are as yet scientifically unproven and theoretical based, and the supporting data was based solely on anecdotal evidence (pers com. Ian Lugton, NSW Agriculture).

It was assumed that the effects of each control measure were manifested in only two ways - a reduction of OJD-related flock mortality and/or changes in the prices received for surplus sheep. Flock mortality effects were implemented by age cohort, with the direction and magnitude of the effects estimated in conjunction with NSW Agriculture OJD veterinarians and epidemiologists.[3] Sheep sale price effects were implemented by animal type, such as wether lambs, ewe hoggets and cast-for-age ewes and rams, and were based primarily on the animal's OJD status and expected body weight/condition at the time of sale.

[2] Examples of the nature of the gross margin budgets and flock structure models employed can be found in Webster (1998).
[3] The authors would particularly like to thank Ian Lugton and Jeff Marshall for their comments and advice regarding the likely effect of each control procedure on flock mortality.

To further simplify the biological aspects of the model, the benefits and costs arising from implementing concurrent control procedures were estimated to be the sum of the individual benefits and costs of each control procedure, although reductions in OJD mortality for any age cohort were constrained at zero. The effects of each control strategy where also assumed to be instant and constant over time.

The estimated effect on flock mortality of each control procedure is shown in Table 1. Vaccination was also assumed to increase the price received for surplus ewe hoggets by $10 to $24 but decrease the price received for cast for age ewes and rams by $3 to $7.40. Destocking was assumed to lead to eradication, and thus the removal of trading restrictions, thereby enabling the producer to receive $40 per surplus ewe hogget and $30 per wether lamb on the restocker market.

Table 1: Simulated OJD Control Measure Effect on Mortality by Age Cohort

Animal Age Cohort	No Control	Early Culling	Feed Suppl.	Trace Element Suppl.	Water Excl.	Liming Pastures	Vaccin -ation	Destocking #
Weaner	2.5%	0.0%	-1.0%	-0.5%	-0.5%	-0.5%	-2.5%	-2.5%
1.5-2.5	16.0%	-2.0%	-3.5%	-4.0%	-4.0%	-4.0%	-15.0%	-16.0%
2.5-3.5	18.0%	-2.5%	-4.5%	-5.0%	-5.0%	-5.0%	-16.0%	-18.0%
3.5-4.5	15.0%	-2.0%	-3.5%	-4.0%	-4.0%	-4.0%	-12.0%	-15.0%
4.5-5.5	5.0%	-0.5%	-2.0%	-1.0%	-1.0%	-1.0%	-3.0%	-5.0%
5.5-6.5	3.0%	N/A	-1.0%	0.0%	0.0%	0.0%	-2.0%	-3.0%
Mean*	10.0%	-1.4%	-2.6%	-2.5%	-2.4%	-2.4%	-8.8%	-10.0%

* Weighted flock average # These figures also represent the "base" rate of (uncontrolled) OJD mortality

To render the various procedures, and combinations of procedures, comparable, the loss-expenditure frontier was calculated on a net present value basis over 15 years. The 15 year horizon was selected for the following reasons:

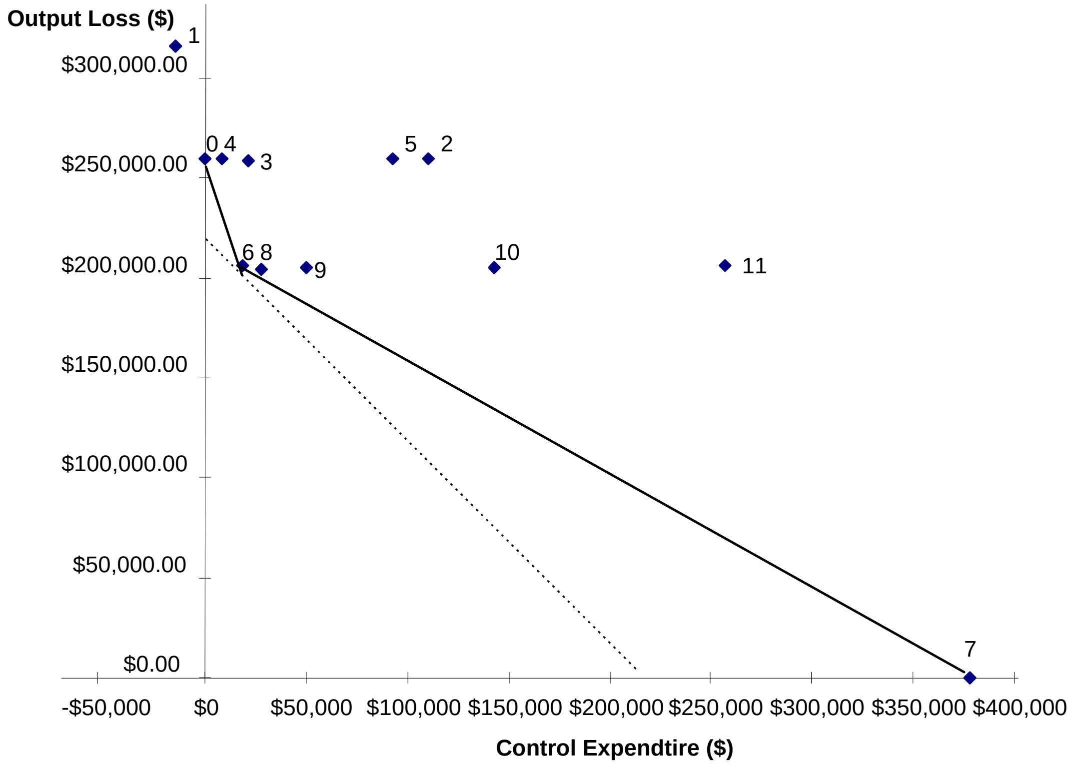
- epidemiologists suggest that a long term vaccination program, in conjunction with other control strategies, might theoretically eradicate the disease in between 10 to 15 years, although this hypothesis is unproven (Denholm 1999);
- liming is based on a seven-year cycle, and it was decided that the completion of two complete cycles was the best way to ensure comparability with other control options; and
- the average age of broadacre owner managers in Australia is presently over 50 years of age (Garnaut et al 1999). It was felt that a 15 year horizon would be a realistic reflection of the working life remaining for many producers.

The estimated loss-expenditure frontier for the representative farm modelled is shown in Figure 5. As with McInerney et al's (1992) mastitis example, each OJD control strategy was plotted as a single point on the loss-expenditure diagram. Output loss was calculated by subtracting the NPV of farm income under each control strategy from the NPV of farm income under a non-infected scenario. Similarly, control expenditure was calculated by subtracting the NPV of total farm expenditure under an uncontrolled infected scenario from the NPV of total farm expenditure under each control strategy. The set of strategies whose position was closest to the expenditure axis was included in the frontier.

The numbered points represent the following scenarios:

0 - no OJD control
1 - early culling
2 - feed supplementation
3 - trace element supplementation
4 - water exclusion
5 - liming
6 - vaccination
7 - destocking
8 - vaccination + water exclusion
9 - vaccination + water exclusion + trace elements
10 - vaccination + water exclusion + trace elements + liming
11 - vaccination + water exclusion + trace elements + liming + feed supplements

Figure 5: Estimated OJD Loss-Expenditure Frontier for a Representative Central Tablelands Merino Ewe Enterprise



Strategy 7 - destocking - has been adjusted for the economic costs of pursuing eradication, namely:

- the changeover cost arising from selling the infected flock for slaughter and paying a market assurance premium when purchasing similar sheep two years later ($99,000);
- foregone income - the difference between weaner cattle income and that which could have been obtained by continuing to run infected sheep during the two year destocked period ($52,000); and
- the difference between the non-infected scenario gross income and the uninfected scenario gross income ($136,000).

The most notable feature of the estimated loss-expenditure frontier shown in Figure 5 is that vaccination and destocking are the only control strategies to lie on the loss-expenditure frontier. All other combinations of control procedures lie above the frontier. Points 8 to 11 represent the next most efficient control strategies. These points would represent the frontier if eradication was not technically feasible. This is a particularly important issue. If eradication is not feasible, which means that there are still high output losses even after destocking, the avoidable costs of OJD are much reduced. As noted above, it is the avoidable costs which should be related to investments in control.

The optimal strategy for this representative producer, shown by the point of tangency between the frontier and the dotted 45 degree price line (point 6), is vaccination. It is also clear that there are numerous other strategies preferable to eradication, such as no control, water exclusion or vaccination + water exclusion. It must be stressed, however, that this preference is from the viewpoint of the individual producer and does not take account of any externalities associated with OJD. If there are significant externalities associated with OJD, as is presently believed by the industry, then the output losses from control strategies other than destocking would be higher from the viewpoint of the industry than from the viewpoint of an individual producer as reflected in this simulation exercise. Note that from an industry viewpoint, control expenditures would include public expenditure on eradication as well as the private costs estimated here. These simulation results for an individual producer based on uncertain biological data cannot be interpreted as recommending that the costs of eradication are too high from the viewpoint of the whole industry.

Another surprising feature of the frontier was that the early culling control procedure was found to reduce total expenditure over the period, but at the expense of income. This is due to its reliance on management change rather than specific expenditure on goods and services. For example, income is reduced under the early culling scenario because replacement hoggets make up a greater proportion of the flock, leading to a decrease in both ewe hogget sales and total wool cut, as hoggets cut considerably less wool than adult ewes. Similarly, annual expenditure falls slightly too because of decreased wool transport and marketing costs.

The model also yielded some more general results. OJD was found to reduce the NPV of total farm profit over the 15 year period by around $260,000, or about $17,300 per year, from a non-infected scenario of about $529,000 to $269,000 for an uncontrolled OJD scenario. The implementation of the vaccination strategy increased total farm profit under an infected scenario to around $307,000, or 14 percent.

While the data used to represent the benefits of water exclusion, trace element and feed supplementation and pasture liming was unreliable, the model does show that the benefits arising from these options would have to be very much greater than that shown in Table 1 for these to be economically viable OJD control strategies. However, as the model took no account of their other non-OJD related benefits, such as a reduction in soil acidity from liming and consequent potential increase in pasture production, the implementation of these strategies within a whole farm management plan may economically contribute to OJD control.

6. Discussion and Future Research

This modelling exercise was intended primarily as a demonstration of the usefulness of the loss-expenditure frontier within a broader program of biological and economic research. The model developed considered only the private output loss and control expenditure trade-off from the viewpoint of an individual sheep producer operating under statutory trading restrictions. There are a number of other scenarios that could be usefully investigated with this model, such as the private cost of trading restrictions and the construction of a community loss-expenditure frontier. The latter exercise would involve estimating the output losses arising from OJD-related externalities, such as the unknown disease status of sale animals or the risk of inter-property infection via bacteria crossing property boundaries. It would also require the calculation of public expenditures on OJD control strategies. Thus, while the construction of a community loss-expenditure frontier is some time off, it can be postulated that it would be located somewhere above and to the right of the private frontier. Its distance from the private frontier provides an indication of the significance of OJD externalities and hence the need for government intervention.

Before these kinds of exercise can be attempted with a reasonable degree of accuracy, better estimates of the output loss reduction arising from OJD under various control strategies and their cost will need to be obtained. This cannot occur until the basic epidemiology of OJD is understood. The most pressing epidemiological data requirements are the quantification of the minimum quantity of bacteria that must be ingested by a non-infected animal for infection to take place and the description of any relationships between age and infective dose. Additionally, many of the biological interactions between *m.paratuberculosis* and the environment, such as soil type, rainfall, ultra-violet light levels and so on, are presently poorly understood.

Research planned as part of the National Program should considerably increase the stock of knowledge in this regard. It is essential, however, that this information be drawn together into epidemiological models of the bacteria’s behaviour in the field, particularly the nature of inter and intra flock disease spread, if the economic implications of OJD are to be accurately determined. If this work does not take place, the ability of the National Program to deliver its scientific results in a context relevant to OJD affected producers will be seriously affected. Unless such producers can identify the financial consequences of the various courses of action identified by the National Program, their production decisions are likely to be inefficient and based on less rigorous sources of information.

Finally, as OJD control decisions in one period affect the quantity of live bacteria on the pasture, and hence the rate of intra-flock disease transmission, in future periods, the disease may be suitable for modelling as a dynamic natural resource problem. This approach has been, and continues to be, successfully applied to other resource problems, such as weed control, water allocation and soil salinity (for an example of this approach relating to weed control, see Jones et al (2000)).

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