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Winners and losers from Johne's disease eradication from the Scottish dairy herd: a Markov-Chain simulation

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Abstract: In this paper, we evaluated the welfare effects of a hypothetical programme of Johne's disease eradication from the Scottish dairy herd on different stakeholders in the domestic milk market. We undertook the evaluation using a Markov-Chain simulation and applying an economic welfare analysis which takes into consideration the effects of an eradication programme on product price, on output quantity, on cost and on milk yield for given levels of supply and demand elasticities. We found that, following the eradication of the disease, milk yield per cow increased for all herd sizes in Scotland whereas price and unit cost of milk production fell. Consequently, milk consumers gained around £14.3 million in discounted economic surplus and producers with infected herds around £13.4 million whereas producers with un-infected herds lost around £10.7 million in discounted surplus. The gain in surplus made by consumers and owners of infected herds, however, more than made up for the loss in surplus made by owners of un-infected herds. Therefore, on balance, Scotland gained a net economic surplus of £17 million from the programme.

Keywords: Johne's; eradication programme; economic welfare effects; economic surplus;

JEL Classification: I180

1 Introduction

Johne's disease is a chronic bacterial infection that is widespread in domesticated and wild ruminants. The infection is caused by *Mycobacterium avium* subsp. *paratuberculosis (Mptb).* The disease manifests itself as a chronic enteritis resulting in reduced production, weight loss, and eventually death. The clinical signs of the disease do not show easily and it might take years before they are detected (Begg et al., 2005). In the UK, the herd and individual level prevalence rates are not known for certain. But from the small scale preliminary surveys that have been carried out, the prevalence rate within the dairy herd is estimated to be 17.5 % ±10% (Caldow and Gunn, 1999.

The full economic cost of the disease in the UK dairy and beef herds is not very well known. This is not surprising given the difficulty involved in detecting the disease among dairy and beef herds. Bennett (1999), however, puts the cost of prevention and control of the disease in the range of £28.6 - £ 30.7 million. Caldow and Gunn (1999) estimate the annual losses due to paratuberculosis to be in the range of £4.2 to £15.4 million for the dairy herd and in the range of £1.33 to £4.88 million for the beef herd.

To date, no one has made an attempt to estimate the benefits accruing to producers and consumers of dairy products in the UK as a result of Johne's eradication. The study by Stott et al (2005) is an exception in that it estimates the benefit accruing to individual dairy farmers in the wake of Johne's eradication from the dairy herd. However, in essence, the study is a herd level analysis. As such, its focus is the farm and not the national level. Against this background, our paper is the first attempt at estimating the implications of Johne's eradication from the dairy herd for the economic welfare of consumers and producers at the national level in Scotland.

The paper is outlined as follows. Section 2 describes the aim and methodology. Section 3 describes the data used in the analysis. Section 4 discusses major results and their implications for policy. Finally, section 5 concludes.

2 Aim and Methodology

2.1 Economic model

In the manner of other similar works (Forsythe and Corso, 1994; Ebel et al; Lichtenberg et al, 1988; and Andersson et al., 1997), the paper aims to achieve three objectives. Firstly, it calculates changes in the price and quantity of milk which result from Johne's eradication. At the conceptual level, these can be thought of as changes which result from improvements in epidemiological risk factors that contribute to the spread of Johne's disease (Losinger, 2006). Secondly, it estimates changes in producers' surplus for a category of farmers indirectly affected by the eradication programme. These are farmers whose herds are free of the disease prior to the implementation of the programme. Thirdly, it estimates changes in producers' surplus for a category of farmers whose herds are infected with Johne's disease before the implementation of the programme. Finally, it estimates changes in consumers' surplus. All through the analysis, the supply and demand functions are assumed to be approximately linear around the pre-eradication equilibrium where the price and quantity changes are thought to be miniscule (Lichtenberg et al., 1988). By making this assumption, however we do not intend to ignore the importance of non linear demand and supply curves (Miller et al., 1988).

Lichtenberg et al. (1988) are the first to offer a formal treatment of the theoretical model on which this analysis is based. In their treatment, they first describe the equilibrium marginal cost functions for producers with infected herds and for those with un-infected herds, the equilibrium market demand function, and the market equilibrium quantity assuming that the market is perfectly competitive. They then describe changes in market price and in quantity following the introduction of a disease eradication programme assuming that the impact of such a programme on marginal cost is known. On the basis of estimates of changes in market price and in quantity, they then estimate the effects of such a programme on changes in consumers' and producers' surpluses for given demand and supply functions.

Following Forsythe and Corso (1994), given a reduction in price and an increase in quantity which result from disease eradication, changes in producers' surplus (ΔPS) and in consumers' surplus (ΔCS) are calculated as:

$$\Delta PS = (P + dP)(Q + dQ) - PQ - \frac{dC}{Y}(Q + dQ) - PdQ - \frac{P(dQ)^2}{2\varepsilon Q} \quad (1)$$

$$\Delta CS = -dP(2Q_d - dQ_d)/2 \quad (2)$$

In (1), the term *(P+dP)* refers to the new equilibrium price of milk after eradication with *dP* denoting the reduction in price. The term *(Q+dQ)* represents the new equilibrium quantity of milk after eradication with *dQ* being the increase in quantity. The term (*PQ*) denotes revenue before eradication with *P* and *Q* being the base price and quantity supplied respectively. The term *dC/Y* is the reduction in cost (*dC*) per unit of output (*Y*) resulting from disease eradication. The term ε is the elasticity of supply. The terms PdQ and $P(dQ)^2/2\varepsilon Q$ denote the increase in the cost of production due to output expansion. The term, Q_d, in (2) denotes the quantity of the product domestic consumers are willing to purchase at the given price.

2.2 Empirical implementation

2.2.1 Estimating price and quantity changes

In order to calculate changes in the price and quantity of milk over a twenty-year horizon of the eradication program, the paper implemented an iterative procedure that takes account of base quantity demanded (or supplied), of demand and supply elasticities and of changes in supply as a result of a small shift in marginal cost. This is a procedure pioneered by Muth (1964) and later applied by Pinstrup-Andersen (1977) and by Alston and Scobie (1983), among others, to the analysis of agricultural research benefits. The equations implemented in this procedure are as follows:

$$P^k = P^{k-1}\{1-[B/(\varepsilon-\eta)]\} \tag{3}$$

$$Q^k = Q^{k-1}\{1+B/[(\varepsilon-\eta)]\} \tag{4}$$

where k=1, 2,..., 10 denotes year of eradication and $B= \Delta S/Q^{k-1}$ is the change in quantity supplied, S, as a proportion of initial quantity in the previous period, Q^{k-1} . The term ε is as defined earlier whereas η denotes the elasticity of demand in absolute value.

The change in supply was calculated as the gain in milk yield per infected cow aggregated over the total number of infected cows in Scotland. This is calculated based on a Markov-Chain model developed from Stott et al (2005a). Base year milk quantity was calculated by first calculating the number of cows infected with the disease and then expressing this in terms of milk in litres based on yield generated from the aforementioned model. Quantity aggregation for the infected herd at the national level was carried out assuming that the yield gain from the hypothetical programme of eradication is uniform across the herd size distribution in Scotland. The implicit assumption is that herd size is not an important epidemiological risk factor in the spread of the disease. This assumption was based on a survey of veterinary experts in the field in Scotland (Stott et al., 2005b) and additional personal communication with experts in Europe. However, a minority of experts in the Scottish survey did rank herd size as an important risk factor in line with the position taken in the US where herd size distribution was identified as an epidemiological risk factor that impacts significantly on the spread of the disease (Losinger, 2006). However, in the absence of a clear indication of the extent of any herd size effect in Scotland, we maintained the implicit assumption of no size effect. The yield gains which result from the eradication programme are calculated as the difference between yield per cow for the disease-free herd and that for the infected herd.

2.2.2 Estimating cost changes

The model based on Stott et al (2005a) was used to generate separate cost estimates for the infected and for the un-infected herds. These are estimates of variable costs associated with yield loss, with a longer calving interval, with lost future income, with culling, and with the treatment of clinical cases. On the basis of these cost estimates, the saving in unit cost of production per litre for the infected herd which resulted from the eradication programme was calculated. This was done by calculating the difference between unit variable cost for the infected herd and unit variable cost for the un-infected herd. We found that relative to a cow in a disease-free herd, a cow infected with Johne's cost £53/year more to maintain. This suggests that a programme aimed at eradicating the disease will increase the annuity which accrues to owners of the infected herd by this amount. In this calculation, the value of milk yield gained following Johne’s eradication was assumed to be one component of the cost that would otherwise have been incurred in the presence of the disease. However, in order to comply with the dictates of the economic model which we described in section 2.1, we treated the cost associated with milk yield loss saved following the programme of eradication as revenue gained rather than as a cost saved. This was done with no loss of generality to the analysis. In the following, the procedures used to calculate each of the cost components are detailed.

Loss of milk yield: this was estimated assuming a Poisson distribution for the number of clinical cows in a herd and a Poisson or binomial distribution for the number of subclinical cows. The yield loss was converted to a 'cost' using the method of Benedictus et al (1987) which deducts 50% of concentrates saved from the proceeds of milk sale assuming that clinical cases continue to eat normally but eat less concentrate as the yield drive to eat is reduced.

Opportunity cost within lactation: this was estimated using a Markov Chain. The major assumption in the calculation of this cost component was that the proportion of cows in each stage of the lactation curve and in the dry period were affected by Johne's. The Calving Interval (CI) was split into 4 equal periods (early, mid, late and dry). Using the assumed culling rates, the steady-state proportion of the herd in each period was estimated for clean and infected herds. Using a standard Woods curve (Wood, 1967) the effect of Johne's on the proportion of cows in each part of the curve over a CI was estimated. This was considered a herd level effect on milk yield (uninfected herd average) which was additional to the losses due to individual clinical and subclinical cows. Using a given CI, the result was expressed per year. Note that differential CIs for infected and uninfected herds was not currently allowed as CI was only used as a divisor to annualise results which would otherwise be calculated on a CI basis. Having a larger divisor for infected herds might result in a smaller annualised cost than for clean herds. Effects of Johne's disease on fertility were therefore not accounted for except as increased replacements. This seemed a reasonable assumption to make as all clinical cows were culled under default assumptions so their fertility was irrelevant and subclinical cows have 11% higher culling than normal (Benedictus et al., 1987). Additional allowances run the risk of double counting.

Opportunity cost of prolonged dry period: idle production factors due to prolonged dry period were difficult to estimate using the methodology suggested by Benedictus et al. (1987). However, the relatively longer period of time an infected herd spent dry could be taken to be a lost opportunity. By calculating (for infected and for clean herds) the average yield opportunity lost per CI due to cows being dry and converting this to a lost yield per year and then to a lost gross margin, a comparison of the dry cow opportunity costs could be made. The use of a gross margin allowed that the lost production was offset by saved variable costs.

Lost future income (between lactation opportunity cost): premature culling due to Johne's alters the herd age structure and hence the production potential of the herd due to the effect of lactation number on yield. Dynamic programming (DP) adjusts voluntary replacement to minimise this effect. However, replacement decisions are not confined to milk yield and expected future Johne's risk. Farmers are therefore unlikely to follow such a policy even if they had the information. If they had a good test to detect Johne's, they would remove infected animals for their effect on herd mates even if the DP decision based on individual cow prospects was to keep. The alternative here is to predict long-run steady state herd age structures under fixed voluntary and involuntary culling proportions/probabilities for infected and clean herds (another Markov Chain) and use these to see the effect of age structure on clean herd average milk yield. The difference in gross margin based on this herd average milk yield difference was then the lost future income potential due to Johne's.

Extra Involuntary culling costs: these were estimated based on the age structure of infected and clean herds from the Markov Chain used to calculate lost future income and based on involuntary culling rates by lactation number and by reasons for culling from the Kingshay Longevity report (Forbes et al., 1999). These data were converted into a number of cows culled in each lactation by reason for culling. Cows culled for infertility were sold at their maximum weight for age as predicted by the cow growth model of Van Arendonk (1985). Other reasons for culling yielded average weights for age as culled cows are not assured of completing lactation and so gaining weight before sale. For infected herds, extra cows were culled due to additional involuntary culling of clinical and subclinical cows. Subclinical cows were culled at average weight for age, whereas clinical cows were culled at minimum. This gave an average weight loss for clinical cows over subclinical cows of 79kg (compared to 100kg in Benedictus et al., 1987).

Extra Voluntary culling costs: these were calculated based on age structure as for involuntary culling. Any costs in the default settings were due solely to differences in age structure of the herd as voluntary culling rates and values of culls were identical.

Veterinary costs of clinical cases were assumed to be £100 per clinical case by default as in Stott et al (2005a).

3 Data description

The cost data used in this analysis were estimates of the cost of a standard Johne's epidemic in dairy herds generated by a Markov Chain model as described above for a 100-cow dairy herd in Scotland. An all-year farm-gate milk price of 17.58 pence per litre (ppl) was used as a base price (SAC, 2006, p.133). A long run milk supply elasticity of 1.8 was used (Colman et al., 2005). A milk demand elasticity of -0.17 was used (National Food Survey, 2000). A herd prevalence rate of 0.27 for Johne's was used to calculate the proportion of infected herds in Scotland (Stott et al., 2005a). This represented the proportion of herds with clinical (0.02) and sub-clinical cases (0.25). A discount rate of 3.5% used to calculate the net present value of benefits was obtained from the Government Green Book (HM Treasury, 2007).

4 Results and discussion

4.1 Price and quantity effects

As a consequence of Johne's eradication, the price of milk steadily declined at the rate of 0.7% per annum whereas aggregate quantity of milk produced increased at the rate of 1.9% per annum. Yield among infected herds increased by 187 litres per cow per annum whereas unit cost declined by 0.35 pence per litre per annum (Table 1).

Table 1
Parameter values and their distribution between herd types, Scottish dairy in the presence of Johne's disease

Parameter	Infected	Uninfected	Difference
Yield (in litres/cow)	6015.00	6202.00	187
Unit cost (pence/litre)			-0.36
Herd size (Number of cows per farm)	100.00	100.00	0.00
Scottish dairy herd ('000 cows and heifers in milk)*	46.38	171.77	125.39

*SEERAD,2006

4.2 Distributional consequences of Johne's eradication

Following the eradication of Johne's disease from the Scottish dairy herd, consumers gained around £ £14.3 million in discounted surplus whereas owners of the infected herd gained around £13.4 million in such surplus. Owners of the uninfected herd, on the other hand, lost £10.7 million in discounted surplus. On net, the eradication programme generated around £17 million in net economic gain for Scotland (Table 3). In a similar exercise, Losinger (2006) finds similar results for the US dairy sector except that he is not conclusive about whether Johne's positive operations gain from an eradication program. In the light of our analysis, the reason his model does not come up with a positive economic gain for Johne's positive operations is because he does not take account of the cost saving which such operations make following eradication.

Table 3 also presents the sensitivity of net economic surplus to changes in supply and demand elasticities. The major result is that net economic benefits decline as demand becomes more inelastic and supply more elastic.

Table 2
The sensitivity of net economic surplus changes for the Scottish dairy herd assuming ranges of values for the demand elasticity (-0.2 to 0.8) and for the supply elasticity (2 to10)) (million £)

ε	*η=0.2*	*η =0.4*	*η =0.6*	*η =0.8*
1.8	17.00	17.40	17.90	18.50
2	16.58	16.86	17.20	17.70
3	15.81	15.92	16.00	16.20
4	15.43	15.49	15.60	15.60
5	15.21	15.25	15.29	15.30
6	15.07	15.09	15.11	15.15
7	14.96	14.98	15.00	15.02
8	14.89	14.90	14.91	14.93
9	14.83	14.84	14.85	14.86
10	14.78	14.79	14.80	14.81

4.3 Discussion of results

The reason producers with infected herds gain in surplus is that a programme of Johne's eradication brings about a unit cost saving which is greater than the unit price reduction which the same programme brings about. The reason producers with un-infected herds lose in surplus over the said period is that, for a given unit cost of production, quantity of milk increases with the result that price of milk per litre falls.

The reason consumers gain in surplus can be explained as follows. On the one hand, the eradication programme results in a unit cost reduction for the affected farmers. On the other hand, such a programme increases the quantity of milk produced. Both effects push the price of milk down. Consequently, consumers benefit from an increase in surplus relative to their position prior to Johne's eradication.

On balance, the eradication programme has a positive impact on net economic surplus for Scotland. This is because the increase in combined economic surpluses accruing to consumers and to producers of the infected herd more than offset the reduction in producers’ surplus for the un-infected herd.

The above results need to be treated with caution taking account of the model's restrictive assumptions. Firstly, it assumes that demand and supply elasticities remain constant throughout the eradication period. Secondly, it assumes away international trade effects. In other words, it assumes that not only will the level of imported milk supply remain unchanged but increased domestic supply of milk will affect only domestic milk price and not international milk price. Thirdly, it does not take account of other epidemiological effects. For instance, it does not allow for the possibility of another disease filling the vacuum left by Johne's. Finally, it does not take account of the on-going costs of keeping the disease out, the cost of getting rid of the disease in the first place and of increasing marginal costs of eradication as the eradication programme progresses. Despite the restriction they place on the model, nevertheless, these assumptions are essential in order to carry out analysis of this type as they isolate the particular impact of eradication on price and quantity. Our analysis assesses the *ceteris paribus* position as a necessary starting point for further evaluation. For example, it gives an idea of the opportunity cost to the nation of failure to instigate an eradication programme. This can then be compared with the expected costs of carrying out such a programme.

Our hypothetical Johne's eradication programme in the Scottish dairy herd is assumed to be carried out independently of a similar programme in the Scottish beef herd. Given that, geographically, the two systems exist in close proximity to each other it would not be long before the disease made its way back from the beef herd to the dairy herd if no programme were implemented in the beef herd. This may render the now free and naive dairy herd more susceptible to re-infection. With the view to controlling for such effects, we assumed that the aforementioned eradication programme was implemented in both the dairy and beef systems simultaneously.

Thus far, the implicit assumption has been that the eradication programme eliminates the epidemiological risk-factors which contribute to the spread of Johne’s disease all at once. Such risk factors might include size of dairy herd per farm, geographical location of a farm, percentage of cows not born on the operation, multiple-cow-maternity housing used in a previous year and multiple-preweaned-calf housing used in previous year to name just a few (Losinger, 2006, 2005). Given that some risk factors are easier to eliminate than others it is unrealistic to assume that all of them will be eliminated at once. A more meaningful approach to an evaluation of a programme of Johne's disease eradication from the Scottish dairy herd is therefore to calculate "the fraction of Johne's disease that can be prevented by eliminating exposure of the herd to a specific categorical risk factor from a population, while the distribution of other risk factors in the population remains constant" (Losinger, 2006, p.33).

In epidemiology parlance, the aforementioned fraction is called the population-attributable-fraction (PAF) (Bruzzi, et al., 1985; Rockhill et al, 1988). It has been in wide use in human medicine and is calculated from a logistic-regression model which calculates categorical risk factors associated with Johne's disease on dairy operations as:

$$PAF_i = p_i\left(\frac{e^{\beta_i - 1}}{e^{\beta_i}}\right)$$

where PAF_i is the population-attributable fraction, β_i is the coefficient derived from the logistic-regression model, and p_i is the proportion of cases for the *i-th* category of a categorical risk factor. The logistic-regression model coefficients, and the associated proportion of Johne's-positive operations are parameters that are supplied by epidemiologists based on data generated by scientists working in the field. For the base category, (i=1), β_1=0, $e^{\beta}{}_1$=1 and the PAF_i=0. For categories other than the base category, PAF_i indicates the fraction of disease that can be prevented by shifting everyone in a particular category to the base category of the risk factor.

Once the fraction for each categorical variable is known, then the benefits and costs of a Johne's eradication programme that can be attributed to each categorical variable are easy to reckon. This involves multiplying changes in consumers' and producers' surpluses by the PAF corresponding to each particular risk factor. To our knowledge no one has made an attempt to estimate the economic welfare impact of Johne's eradication resulting from eliminating exposure of the dairy herd to a particular epidemiological risk factor. At the moment, however, we have found no such PAFs published for Johne's in the UK.

4.4 Policy implications

As the above analysis showed, a programme of Johne's eradication favoured consumers and milk producers with infected herds at the expense of producers with un-infected herds. Clearly, on consideration of the favourable economic implications of the programme, it is reasonable to expect that it will be popular among dairy farmers whose herds are currently being affected by Johne's. However, the programme might not garner support among producers whose herds are currently free of the disease as they stand to lose their comparative advantage. But given that living with Johne's (or any endemic disease) involves the risk of a financial loss considerably greater than expected losses, farmers who are currently disease-free might prefer eradication even if the expected net benefits are inferior to living with the disease to the extent that eradication reduces production risks (Oglethorpe, 1995). There are, however, several other non-economic considerations which can be used to elicit farmers' support for such an eradication programme.

Firstly, the ethics of good farming requires that farmers rear a disease-free stock able to produce milk which consumers trust.

Secondly, animal welfare policies require that animals be treated as humanely as possible and that they do not suffer the avoidable effects of any disease. For instance, one of the "Five Freedoms", which underlie the basic principles of the Farm Animal Welfare Council (FAWC) of Britain, stipulates that "animals be free from pain, injury and disease through prevention, rapid diagnosis and treatment". At the moment the Five Freedoms are serving as a benchmark for evaluating animal welfare standards only for such limited farm schemes as Farm Assurance and Organic Certification. However, it is only a matter of time before they permeate through all other schemes of farming.

Thirdly, food retailers and consumers are becoming more critical of the welfare dimension of animal products when making their purchase decisions. On the face of this, producers of primary products cannot afford to be lax in the health and welfare standard expected of their stock. It suffices to invoke the recent crisis related to BSE to realize how much the breakout of a health scare anywhere in the food supply chain can lessen consumers’ trust in the safety of the food they eat.

Fourthly, if competitor countries make more progress in reducing or eliminating Johne’s disease Scottish dairy products traded in the world market may earn a negative image particularly if Scotland does not show as strong commitment to eradication. Given the potential negative impact that this image can have on Scotland’s dairy trade with other European countries, Scottish farmers’ participation in a Johne's eradication programme works to their own long term advantage even if the cost of the eradication programme is borne by themselves.

To this stage, the paper has brushed aside the issue of who pays for the cost of the proposed Johne's eradication programme. The most recent government policy on animal health (Defra et al., 2004) seems to advocate that the cost burden of disease prevention and control be borne more by owners of farm animals themselves rather than by taxpayers. As this analysis has shown, however, most of the benefits of Johne's disease eradication in Scotland accrue to consumers and to owners of infected herds in Scotland. It may therefore be argued that the cost of such an eradication programme be shared between consumers and owners of infected dairy herds rather than be borne fully by all farmers. If results regarding the distribution of benefits were to provide a rough guide as to the amount domestic actors involved need to contribute to Johne's eradication, it appears that consumers and producers with infected herds should pay the greater proportion of the cost of eradication. This is in keeping with the "beneficiary pays principle" being advocated by the Government (Defra, 2007).

5 Conclusions

In this paper, we attempted to estimate changes in consumers' and producers' surpluses in the Scottish dairy herd following Johne's eradication assuming a 20-year Johne's eradication programme. We found that as a result of the eradication programme, consumers and farmers with infected herds made a positive gain in surplus whereas farmers with un-infected herds made a loss in surplus. However, the economic surplus gained by consumers and farmers with infected herds more than made up for the loss in surplus made by producers with un-infected herds. On balance, therefore, the eradication programme generated a net positive economic surplus for Scotland.

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