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Measuring the economic benefits and costs of Bluetongue virus outbreak and control strategies in Scotland

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Abstract

This paper provides an *ex-ante* economic analysis, comparing six alternative control strategies for the eradication of Bluetongue virus 8 against five incursion scenarios in cattle and sheep populations. The economic analysis assumes a common baseline unavoidable cost of public and private measures that together contribute to prevention of incursion of BTV8 into Scotland. These costs continue over the five year horizon of this analysis regardless of whether a BTV8 epidemic ensues in Scotland and their total present value was found to be approximately £141m over the 5year period. The benefit of this investment is the costs of a BTV8 outbreak avoided; which depends on the time, location and nature of the incursion, on the control strategies adopted to counter each incursion, on the persistence of the incursion and on the opportunities to mitigate the damage. Specific variations in all these aspects were explored. The benefit-cost ratios were ranked within each incursion scenario to evaluate the efficiency of control outlays. Although the economic model found that benefit-cost ratios were greater than 1 for all interventions strategies examined, the control strategy option with 100% vaccination and protection zone set at Scottish Borders were economically preferable. This implies that if avoided this control option would deliver the greatest benefit from investment in baseline prevention costs. However, in terms of outbreak losses, this vaccination strategy was always most costly. On the other hand, the control strategy with 50% vaccination and all Scotland as a protection zone often provides the lowest benefits in all control options examined.

Key words: bluetongue virus, epidemiology, direct and indirect costs, benefit analysis

1.0 Introduction

Bluetongue virus (BTV) has spread around the world covering much of the Americas, Africa, southern Asia and northern Australia, and during the recent past has extended its range northwards into Europe. The reasons for this last expansion are linked to recent extensions in the distribution of its major Old World vector, *Culicoides imicola*, to the involvement of novel *Culicoides* vectors and to on-going climate change (Purse *et al*. 2005). BTV outbreaks can have severe economic impact on the livestock industry of a country. In 2007, BTV outbreaks in France and the Netherlands were estimated to cost $1.4 billion and $85 million respectively (Tabachnick *et al*. 2008).

The rapid spread of BTV across several European countries, including the southern part of the United Kingdom and countries as far north as Sweden, has increased the likelihood that the virus will also spread into Scotland. There are significant uncertainties about many aspects of the disease including a full understanding of how both the UK livestock (mainly sheep and cattle) and the midge populations will respond to BTV and the effectiveness of existing disease control measures. Such control measures include vector control, vaccination and livestock movement restrictions combined with surveillance for early detection (Defra, 2007*)*. Despite these gaps in knowledge an *ex ante* assessment of control strategies has to be drawn up as a basic prelude to an appraisal of likely control policies.

Because of the public good nature of disease surveillance and control, requisite investments are unlikely to be undertaken privately. Even so, fundamental uncertainties related to stochastic disease outbreaks make surveillance and control policies relatively challenging to design and implement. However, decisions have to be taken in the short term to halt, slow down or manage the spread of BTV in Scotland. This requirement became more urgent in Autumn 2007 when BTV serotype 8 (BTV8) started spreading in England (Tabachnick *et al.* 2008). This work is part of a study commissioned by Scottish Government (SG) in January 2008 to inform development of policy in response to the specific threat of BTV8 incursion into Scotland in 2008/9. A fundamental economic question concerns the level of surveillance investment (cost) that is warranted relative to the likely return that is anticipated in terms of avoided outbreak damages (benefit). As with other public investments for disease control (human or animal) society only requires to outlay resources up to the notional point where the last (or marginal) cost delivers an equal unit of benefit. This cost benefit perspective can be a compelling part of the evidence base for managing disease and developing the associated policy and legislation.

This paper considers the economic impact of BTV8 and undertakes an economic appraisal of options to prevent and manage BTV outbreak in Scotland. Recent studies of potential impacts of BTV (see DEFRA, 2007; Hoogedam, 2007) have not addressed either the detailed costs involved or the economic consequences of the control strategies. This empirical analysis uses an *ex-ante* cost-benefit framework to assess the policy response, comparing the costs of prevention (benefits) with the costs that would ensue if there were an outbreak of BTV8 in Scotland.

2.0 Models and methodology

In theory the optimal level of investment in surveillance is that level where the marginal costs equals the marginal benefits of disease outbreak. In practice establishing this theoretical optimum is somewhat complicated, but it can be approximated. However, to do this we have to identify all costs of surveillance and also the likely costs of outbreaks. The former is relatively straightforward, but the latter is more complicated because one has to simulate counterfactual scenarios that predict the damages from a disease outbreak. It is the damage costs in these scenarios multiplied by the probability of their likely occurrence that gives the expected damages. The expected damages are the benefits of actually preventing an outbreak occurring.

Figure 1 illustrates costs and benefits of a hypothetical BTV8 control measures that maximises net benefits. In the upper panel, costs and benefits are plotted against the vertical axis. The probability of disease incursion is represented along the horizontal axis, and ranges from *Pr (0)* at the left and rises to the maximum *Pr (max)* at the right. The cost of BTV control curve represents the baseline surveillance costs against which the benefits will be judged. They represent the sum of all *ex-ante* investments or passive surveillance costs from both private and public sectors that will reduce the risk of BTV outbreaks or reduce their severity in Scotland. For simplicity it is assumed that to reduce the probability of a BTV incursion, the cost would rise at an increasing rate while the benefit curve is linear and continuous.

The level of risk corresponding with the highest net benefit is shown by *Pr (*)* in the lower panel. The benefits of lowering risks of a BTV outbreak to this level corresponds to costs C* and benefits B* (B*>C*). Notice that the difference between B* and C* is optimum and thus corresponds to maximum net benefit *NB* in the lower panel. It can be seen that at *Pr* (*) both curves have the same slope, which shows that the marginal benefit and marginal cost of disease control are equal. The disease control level that is consistent with *Pr (**) would be the most efficient measure.

Figure 1: Costs and benefits of BTV control at different levels of incursion probabilities (Adapted from Hinchy and Fisher, 1991).

It is evident in the upper panel that at probability levels above *Pr(*)* costs and benefit are increasing but costs are rising at a slower rate as compared with benefits. This gives increasing net benefits at the margin as the level of risk decreases towards *Pr(*)*. However, at risk levels below *Pr (*),* costs are increasing at higher rates than benefits. This causes successive decreases in net benefits at the margin. Thus, control measures not corresponding to *Pr (*)* are not optimal because welfare would not be maximised.

Clearly, the decisions on a control measure that yields optimum social benefits are determined by translating epidemiological impacts of BTV into the economics of damage costing. The following sections describe how our epidemiological model feeds into the economic framework to discern benefits and costs.

2.1 The integrated modelling framework

The basic framework used in the modelling strategy of BTV8 is set out in Figure 2. Due to paucity of data on the relevant biology, the economic and epidemiological modelling approaches used in this paper had to be based on expert derived knowledge about how BTV8 would most likely behave in Scotland. A multidisciplinary expert panel was formed, including BTV and midge experts and disease-control policy makers. The panel agreed a range of feasible BTV8 incursion scenarios and specific control strategies to investigate. Our study utilised data already held by different members of the project team but was predominantly desk based, applying quantitative methodologies with pre-existing epidemiological models.

Figure 2: Schematic representation of the modelling framework

The modelling framework consists of two main model components, which are represented by the broken line boxes. The epidemiological model was used to simulate the spread of disease under selected incursion scenarios and control strategies. The output of the epidemiological model provided inputs for a spreadsheet economic model that was used to estimate BTV8 outbreak costs and benefits. The whole processes of the development of epidemiologic and economic models were based on data inputs from relevant literature or from the project data providers (e.g. EPIC and RADAR). Where information gaps existed in the literature, data inputs based on expert stakeholder were used. Below, the individual model components are briefly described.

2.1 Epidemiological Model

A BTV8 outbreak in Scotland and its spread was assessed using a stochastic, spatial epidemiological model describing both the within- and between-farm transmission of BTV. Transmission between farms was modelled by a generic transmission kernel, which includes both animal and vector movements. Once a farm acquired infection, the within-farm dynamics were simulated based on the number of cattle and sheep kept on the farm and local temperatures (Gubbins *et al*. 2008). An affected farm was assumed to be detected if an animal died due to BTV8 infection or if overt clinical signs appeared.

Epidemiological parameters for the transmission probability between farms were estimated using data on clinically affected holdings in northern Europe in 2006 (Albers *et al*. 2007; EFSA 2007). Parameters for the within-farm dynamics of BTV were derived from the published literature, including temperature dependence wherever possible (Gubbins *et al*. 2008). Species-specific probabilities for an animal showing overt clinical signs were estimated from OIE reports for 2007 (Szmaragd *et al*. 2007). Policy parameters represent the vaccination strategy that should be implemented, with the vaccine assumed to be 100% effective in all animals. The sector parameters were derived from sectoral data such as animal movement data, number and distribution of livestock.

For each scenario described above 100 replicates of the epidemiological model were simulated with the initial conditions specified according to the incursion scenario. Importantly, only a single incursion event was considered. Each replicate was run for two years, starting in January of the year in which the incursion occurred.

2.2 Economic model

The economic model used for estimating the costs and benefits of BTV8 incursion and control strategies in Scotland has been used previously for calculating the direct costs associated with endemic diseases of livestock in Great Britain (Bennett *et al.*, 1999). This spreadsheet model was based on the risk of livestock contracting a disease and associated costs of prevention, treatment and reduced performance. Menzies *et al*. (2002) applied this methodology to estimate the direct costs of cataracts in farmed Norwegian salmon. A spreadsheet model similar to that of Bennett *et al.* (1999) and Menzies *et al.* (2002) was adapted and extended by Moran and Fofana (2007) to account for the cost and benefits of fish disease incursion and control in the UK. A similar spreadsheet model to that developed by Moran and Fofana (2007) was applied here to estimate the costs and benefits of BTV8 outbreaks and control strategies in Scotland.

The costs of presence and control of BTV8 were generally categorised into *direct* and *indirect* costs in the spreadsheet model. *Direct costs* are the sum of the production losses (direct and consequential[1]) and the costs of disease control. *Indirect costs* are costs that results from price effects due to the disruption in markets (Berentsen *et al.*, 1992a). These costs are associated with revenue forgone through loss of markets along the value chain of livestock and livestock products. Bennett (2003) defined direct disease cost (C) by the relation $(L + R) + T + P$ where L denotes the value of the loss in expected output due to the presence of a disease, R the increase in expenditures on non-veterinary resources due to a disease (farm labour, movement restrictions etc.), T the cost of inputs used to treat disease and P is the cost of disease prevention measures. While Bennett (2003) limited P to prophylactic measures to prevent infection occurring, we extended P to cover public disease surveillance costs.

Otte and Chilonda (2000) defined the total cost of disease as a sum of direct and indirect production losses. Bennett *et al.* (1999) model accounts for direct costs but did not include indirect cost of disease. Therefore, the Bennett (2003) model was modified to account for indirect cost as defined by adding another variable thus: $C = (L + R) + T + P + M$, where all variables are as previously defined; and M depicts indirect costs which represent the revenue forgone through loss of markets along the value chain of livestock and products. It was not possible to account for all cost items that should be included in M due to the methodological difficulties and constraints of this type of analysis and lack of the extensive data requirements. The indirect costs included are the business disruption costs at the retail level due to consumer responses and the loss of live animal export revenue due to disease outbreak. There are potentially other losses that would occur along the value chain but to avoid the danger of double counting costs, only potential losses by the final consumer of UK meat and animal products were included. That is the local final consumers and exports that represent external final consumers.

Direct and indirect costs were further classified into *baseline* and *avoided* costs. The evaluation of policies using cost-benefit analysis (CBA) requires the identification of a

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[1] Consequential on-farm losses include losses due to the fall in stock numbers, restrictions of movement when zoning restrictions are put in place and due to the loss in animal value.

baseline cost against which the costs and benefits of alternative BTV control options are evaluated. In this study, strict time frame, financial constraint and data difficulties limit the questions that can be asked with respect to changes in the level of surveillance (baseline costs). Instead, we proposed a simplified analysis that adopts a counterfactual of no surveillance versus the current level of combined public and private surveillance. We assumed that outbreaks incur costs and that the outbreak cost with no surveillance is greater than when surveillance is in place. It therefore makes sense to have some level of surveillance but the optimal level is unknown. Consequently, it becomes pertinent to ask how speculative outbreak costs compare to the current combined public and private costs of surveillance. Assuming that the current level of spending is in some sense suboptimal, we therefore analyse whether it is disproportionate relative to expected damage.

In economic terms, an *avoided cost* from an action is a benefit of that action. In the case of animal disease, the benefits of measures to prevent or reduce the deleterious effects of disease on animals include avoiding costs from the effects of disease, which would otherwise have occurred (Malcolm 2003). The benefits of avoiding BTV8 incursion in Scotland include both the output losses and control costs (e.g. vaccination costs and movement restrictions) of dealing with an incursion. Comparing baseline cost with avoided cost help provide answers to the question of optimal surveillance.

Two levels of BTV8 outbreak persistence and two policy options for licensing of the movement of livestock to slaughter were analysed. BTV outbreak persistence assumes that the disease will persist in year 3 – 5 at year 2 levels and the other disease persistence option assumes that BTV will decline in years 3 – 5. In the case of licensing, we analysed the policy options of securing license to move livestock to slaughter or not**.**

3.0 Scenarios, data and assumptions underlying the model

Scenarios

We explored the most likely distribution of the disease given Scotland’s agricultural systems, unique landscape and climate. We engaged with SG officials and with livestock industry representatives to help inform decision making and prioritisation of disease incursion scenarios and control options should BTV 8 spread to Scotland. Three main routes for potential incursions were identified and a number of approaches were used to determine which of these potential routes posed the greatest level of risk.

- *Wind-borne dispersal of vectors from south-east England, Northern Ireland or continental Europe*: The risk of incursion via wind-borne midges was assessed using ten years worth (1998-2007) of data on wind speed and direction and temperature. These were used to determine the frequency of winds suitable for carrying vectors from potentially infected areas to Scotland.
- *Import of infected animals*: The risk of introduction via the import of infected animals was examined using movement data for 2006 to provide the number of movements to each Scottish county by month.
- *Northwards spread of BTV from south-east England*: The risk of northwards spread was investigated using a model for the transmission of BTV between farms. This was used to predict if and when BTV8 is likely to arrive in Scotland, following expansion from the current infected area in south-east England, assuming that only minimal control measures were applied. Analysis of climatological data (as in (i) above) was also used to assess the risk of incursion if disease foci were to arise near the Scottish border.

More detail on the risk of incursion was added to the analyses by using the relationship between temperature and the extrinsic incubation period (EIP) to predict when and where vectors are likely to pose a transmission risk. This was done by linking an accumulated degree-hour model for the completion of the EIP with temperature data for Scotland. Following this exercise, five hypothetical incursion scenarios were thus drawn up:

(a) South-April 09 Midge (SA09M1): northwards spread of BTV from England arriving in April 2009;
(b) South-July 08 Midge (SJ08M2): northwards spread of BTV from England arriving in July 2008;
(c) South-September 08 Midge (SS08M3): northwards spread of BTV from England arriving in September 2008;
(d) Animal Import April 09 (AI09A 4): import of infected animals in April 2009; and
(e) Animal Import September 08 (AI08S5): import of infected animals in September 2008.

A wide combination of control strategies can be put in place to reduce the incidence and effects of the aforementioned BTV8 incursions. The expert panel selected a range that reflected their judgement of the broad classes of alternative options facing SG at the time of the study. This included a counterfactual (C1) and five control options C2 to C6. Except for C5, all control options were hypothetically applied to all incursion scenarios. Table 1 shows the 26 combinations of control strategies and incursion scenarios evaluated; where an element C_{ij} in the matrix represents the i^{th} control strategy applied to j^{th} incursion scenario.

Table 1: BTV8 Incursion scenarios and control options matrix

	Incursion Scenario(j)				
Control Strategies (i)	**SA09M1**	**SJ08M2**	**SS08M3**	**AI09A 4**	**AI08S5**
C1: No vaccination or Counterfactual	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C2: Control zone options: Border PZ - 100% farms vaccinated	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}
C3: PZ to Highland line – 80% farms vaccinated	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}
C4: PZ all Scotland - 50% farms vaccinated	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}
C5: 100km PZ around incursion above the Highland line - 80% farms vaccinated	…	…	…	…	C_{55}
C6: PZ all Scotland with 80% farms vaccinated	C_{61}	C_{62}	C_{63}	C_{64}	C_{65}

The international acceptance of the concept of zoning in response to an outbreak through the OIE code on zoning and regionalisation (OIE, 2003b) implies that if an outbreak of BTV is successfully contained within a quarantined area, exports of livestock and products from elsewhere in the country may not be affected. Thus it was assumed that zoning regulations will apply in the event of an outbreak of BTV8 in Scotland. The control of an outbreak will be based on movement of animals through a Restriction Zone (RZ). On confirmation of a BTV8 outbreak, a Control Zone (CZ) of at least 20km radius is placed around the infected premises. A Protection Zone (PZ) of at least 100km radius around the infected premises will be declared. A PZ is either the Scottish Border, the Highland line, the whole of Scotland or 100km around an import north of the Highland line (figure 3). An optional Surveillance Zone (SZ) of 50km radius beyond the PZ will also be instituted if there is a need to do so to contain an outbreak.

Figure 3: Definition of PZs to be used for the control scenarios (C2 and C3).
The inside dashed line indicates the contour of a 20km buffer zone around the England/Scotland border, and the second outside dashed line the contour of a 50km buffer zone. Counties indicated in grey-crossing lines will be used to define the tight PZ for vaccination in scenario C2, whereas the grey-filled counties plus the counties with grey-crossing lines pattern will represent the counties to be included within the South-Highlands-line PZ (scenario C3). The islands of Argyll and Bute are not considered with the PZ defined under C3.

Counterfactual (C1) control strategy includes the minimum required control, i.e. movement restrictions but no vaccination. Thus there is no effort to reduce the number of susceptible animals. It was assumed 100%[2] and 50% uptake of vaccine in the rest of the PZ for strategies C2 and C4 respectively and 80% uptake of vaccine for C3 and C6. Where an incursion takes place in April 2009 (i.e. incursions SA09M1 and AI09A4) vaccination is assumed to be administered before incursion (i.e. in January 2009) when animals are likely to be more accessible. For the other incursions vaccination takes place after initial detection of an outbreak. Control strategy C5 is included to cover the special case of incursion AI08S5 where vaccine location depends on place of incursion.

In the case of incursion AI08S5 (import in September 2008) the PZ would be established depending on where the incursion occurs. If the incursion occurs within the border PZ, then C2 control strategy is to be used. If the incursion occurs south of the Highland line (figure 3), control strategy C3 is put in place, and if the incursion takes place north of the Highland line, then a 100km PZ is established around the holding where the incursion occurred, and 80% uptake is assumed within this PZ. In line with the other vaccination options, a 20km CZ will also be established around the incursion with 100% vaccination. Therefore the fifth control strategy C5 will complement options C2 and C3, in the case of a northern import.

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[2] 100% vaccination within a temporary CZ is assumed compulsory.

The different levels of vaccine uptake assumed reflected alternative SG policy options. Where uptake was 50% (C4) this reflected a voluntary vaccination scheme. Higher levels of uptake were thought likely to need a compulsory vaccination programme. For all incursion scenarios we assumed that vaccination is efficient at controlling the spread of BTV8, by reducing the probability of transmission between the midge vector and the ruminant host. In the absence of data for the efficacy of the vaccine to be used, we assumed that it was 100% effective in protecting vaccinated animals against BTV8. Cost relating to the uptake of voluntary and compulsory vaccination was obtained from SG and included a mail shot to all livestock holders in PZ, specialist media (advertising), mail shot to vets, costs related to vet administration and certification of animals for export.[3]

3.1 Assumptions and quantification of costs

The evaluation of BTV surveillance measures in different outbreak scenarios requires a combination of assumptions on economic parameters to derive the costs. As an *ex ante* analysis, the evaluation of costs were based on a set of projections for the production and prices of sheep, cattle, sheepmeat, beef, milk, cheese and wool using autoregressive integrated moving average (ARIMA) over the period to 2013. ARIMA models were used because of their robustness, less data demanding and they have been proved to outperform more sophisticated structural models for short-run forecasting potentials (see Stockton and Glassman, 1987 and Litterman, 1986). The data on production and prices were obtained from various issues of Meat and Livestock Commission (MLC) publications and SG.

3.1.1 Surveillance and control costs

Quantification of surveillance and control cost estimates are substantially more certain than some of the outbreak cost elements (Moran and Fofana, 2007). We identified surveillance costs of BTV8 from those borne by producers (private) and those incurred by the public sector.[4] The surveillance costs presented in this paper are generic costs and not specific to any disease. They represent the various roles carried out by SG agencies in the surveillance and control of all animal diseases. Though there is a passive element in disease surveillance and control, it was viewed as prudent to scale down public sector surveillance costs to avoid the dangers of high overestimates. But by what value to scale these costs down is a matter for conjecture. In consultation with expert stakeholders, we assumed that BTV8 surveillance expenditure in the public sector will be in the order of 2% and 0.5% of total public sector surveillance costs for sheep and cattle respectively. Animal disease surveillance cost data were projected from the data obtained from SG. The data set was obtained in aggregated form and recorded in financial year. To make the cost data compatible with the rest of the data, we took the financial year data to represent calendar years. In the private sector we follow Moran and Fofana (2007) that farmers' interest is to grow healthy stock that would improve their income rather than worry about a specific disease. Therefore we assumed that veterinary treatment of livestock is good husbandry practice and it is meant to keep any form of disease at bay. Consequently, we took all expenditure in the private sector that is geared towards keeping a healthy stock prior to the outbreak of BTV8 as private sector surveillance expenditure.

3.1.2 Reduced milk yield, weight loss, wool loss and reproductive disorders

The expected costs associated with morbidity of sick animals due to BTV8 include weight loss and reduced milk yield due to the inability of animals to feed for several days (Tabachnick *et al.* 2008, Osburn 1994). Such weight loss may influence milk production in dairy livestock. We did not attempt to model the impact of weight loss on milk production.

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[3] Costs of legislation and random monitoring in the case of compulsory vaccination were not included.

[4] Public sector animal disease surveillance cost data received were recorded in financial years. We have taken the financial-year data to represent calendar year for consistency with the rest of the data.

Rather we estimated weight loss separate from milk loss. Output data from the epidemiological model did not differentiate between dairy cows and other cattle, the expected milk losses in dairy cows was therefore estimated by taking the product of: (1) the assumed reduction in milk production due to BTV8 (i.e. 5%[5]); (2) the number of infected cattle (3) the probability of dairy cows in the Scottish livestock; (4) the average production of milk per dairy cow; and (5) the price of milk per litre.

Weight loss was similarly estimated by taking the product of: (1) the assumed reduction in weight for cattle or sheep due to BTV infection; (2) the number of infected animal (cattle and sheep); (3) the assumed number of animal that would suffer a weight loss and (5) price of the animal per head. There is no guidance in the literature on the degree of weight loss in morbid animals. Therefore we assumed that 9% of infected cattle would show 5-10% weight loss and 11% of infected sheep would show 10-15% weight loss[6].

In some sheep flocks, no clinical signs are apparent, whereas in other flocks infected by the same virus up to 30% may develop signs of disease[7]. Sheep that recover from BTV8 infections may render wool fragile and in some cases this can lead to partial or complete shedding of wool[8] which can cause direct economic loss to sheep farmers. In order to quantify this loss, we assumed that an average of 2.5 kg of wool is produced per sheep[9] and wool not sheared from 30% of BTV infected sheep. Multiplying the quantity of wool loss by price of wool gave the cost of wool loss.

Reproductive disorders associated with BTV include abortion, infertility in bulls and rams and malformed lambs or calves. The occurrence of any of these can cause direct economic losses to livestock farmers and some times indirect losses due to export restriction or delays in recovery of animals that survive. In rams and bulls, BTV infection is known to induce infertility, possibly in response to the harmful effect of hyperthermia on spermatogenesis, as well as to the effect of micro-vascular lesions in the reproductive tract (Osburn, 1994). There is no information about the duration of infertility and probability of recovery and this was not incorporated into the spreadsheet model. However, we assumed loss of fertility for beef cows to be £2.7/head (Gunn *et al.* 2004) and loss of fertility for dairy cows to be £2.50/head (Santarossa *et al.* 2004).[10] In the case of sheep we assume infertility to cost £0.60/head. This was based on expert estimates that BTV8 might double the risk of a morbid ewe being barren, that a normal rate of barreners is about 6/100 ewes (Conington te al., 2004), that a barrener costs about £17 loss of net revenue (SAC, 2007) and that morbidty rates in BTV8 infected flocks is about 0.6 (Defra, 2007).

3.1.3 Livestock mortality and carcass disposal cost

We assumed that during an outbreak of BTV8, the disposal options will be limited to incineration or rendering as the only legal methods of disposal of diseased animal carcasses.[11] The disposal of dead animal will be done by appropriate animal disposal contractors such that it fulfils environmental and animal by-products legislations. Carcase disposal cost was computed by taking the product of the number of animal casualties due to BTV8. The costs of incineration of animal carcasses used were £75/head for cattle or

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[5] Johannes Winkelman, personal communication (2008).

[6] A lower and an upper band of weight loss was assumed for sheep and cattle based on personal communications with experts in various EU countries.

[7] http://www.sgm.ac.uk/news/hot_topics/btv.pdf

[8] www.vet.uga.edu/vpp/gray_book02/fad/blt.php

[9] Production of wool per sheep varies considerably from 1.7 kg – 9kg per animal (see Roche, J. 1995).

[10] Note these figures exclude impacts of fertility on production to avoid double counting.

[11] The only exemptions to the ban in the UK are for remote areas of the Highlands and Islands of Scotland (www.allgoats.org.uk/carcase.htm).

£20/head for sheep (Defra 2007). We assumed no compensation to farmers for lost or culled animals.

3.1.4 Palliative and veterinary costs

Palliative care is any form of medical care or treatment that concentrates on reducing the severity of BTV disease symptoms. The goal is to prevent and relieve suffering in that condition. It was assumed that a 600 kg cow would require a dose of (60 ml per 600 kg bodyweight) of *Alamycin la*[12] and *Fluxin*.[13] Since sheep are the most susceptible to BTV8, it was assumed that an 80 kg sheep would require doses of *Alamycin la* and *Fluxin* for five and three days respectively. Costs of extra palliative veterinary care were also included by multiplying the number of infected animals by the cost of the recommended dosage of *Alamycin la* and *Fluxin* for sheep and cattle.

3.1.5 Movement restrictions, labour cost and pre-testing of imported animals

Crucial to the success of control strategies is the placing of high risk holdings and livestock production areas under animal movement restrictions. Effects of animal movement restrictions were incorporated into the spreadsheet model. The cost associated with movement restriction was modelled in the spreadsheet by costing movement restriction at 5% of the value of the animal (Defra, 2007) under each outbreak scenario where zoning regulation applies.

There are labour costs associated with disease outbreak which imposes cost on the livestock farmer. The value of farm labour costs is difficult to estimate. The value of increased labour time by a farm worker will depend on the opportunity cost of the labour time (Bennett 2003) and on the extent and severity of the disease out break. In order to estimate cost in the category we assume that the livestock industry will be reliant upon family-based labour to supplement farm labour at a cost of £1/hour (Gunn *et al*., 2004). The extra labour input was assumed to be two minutes per morbid sheep and seven minutes per morbid cattle per day as indicated by expert opinion.

Pre-testing of imported cattle and sheep is carried out to detect BTV8 which incurs costs. The cost related to this was estimated by assuming that 75% of international imports of live animals are from BTV affected countries which need testing and 100% of imports of live animal from the rest of UK need testing[14]. Using this assumption the number of livestock was multiplied by the price of testing to derive costs.

3.1.6 Consumer reaction and revenue loss at retail

Recent evidence suggests that humans are sero-negative towards BTVs (Jun Hu *et al.* 2008). But when an outbreak of BTV8 occurs this might not be recognised by domestic consumers. Media coverage of the outbreak alone may be sufficient to dissuade consumers from purchasing beef, sheep meat and other related products. The apparent reduction in demand by consumers was modelled using relevant estimates of price elasticity of demand. We anticipated that a disease outbreak would actually increase prices because of the shortages it would cause due to quarantine activities, depopulation and movement restrictions in the industry. We modelled the apparent change in demand by beef and sheep meat and consumers using relevant estimates of price elasticity of demand.

It was envisaged that a BTV8 outbreak will have an instant impact on consumer demand for fresh beef and sheepmeat. This was replicated in the spreadsheet model by assuming

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[12] www.norbrook.co.uk/products/ProductPrintable.cfm/product_Key/441/CatKey/1/Section/Veterinary_Products

[13] www.banamine.com/disclosure/index.html

[14] Based on the international trade statistics of UK.

instantaneous adjustment of consumption of fresh meat products to the news of an outbreak. This assumption may not hold for the industry products like cheese and milk as there may be some time delays in the change of consumer demand for these products. There may be increases in demand for milk and cheese as many consumers will substitute meat and meat products in their diets with dairy products such as cheeses due to disease outbreak (OECD 2002). However, we worked with the normal expectation that a BTV8 outbreak will impact consumer confidence in the purchase of milk and cheese albeit at a lower rate as compared with fresh meat products. As a result of these influences, we found it necessary to incorporate lags in demand change for cheese and milk to mimic consumers' reaction in the demand of these products. The lags were included in the spreadsheet model such that current apparent domestic consumption dependent on the previous period's level of consumption and thus accounts for time delays in purchase as news of a BTV8 outbreak spreads. Estimates of apparent domestic consumption of animal products were derived by adding domestic production to imports and subtracting exports from the resultant. Apparent domestic consumption of animal products was needed to simulate the quantities of animal products consumed locally when such data can not be accessed from secondary sources.

3.1.7 International trade losses

Export trade restrictions imposed on animals and livestock products during disease outbreak usually have the potential to cause major losses to exporters (Schoenbaum and Disney, 2003). The Scottish livestock sector is linked to sectors in the local economy and international trade through a network of input purchases and output sales. The reduction of Scottish exports caused by BTV8 related international trade restrictions will depend upon the livestock and livestock products subject to bans, the duration and the trading regions affected by these bans.

The products which should be subject to export bans are live animal exports and germplasm. OIE and EU rules indicate that export bans are not applicable to livestock products such as milk and cheese. Data could not be found for Scottish germplasm production and we therefore included live animal exports only in our economic model. We used input-output (IO) analysis to simulate the effect of an export ban in Scotland. IO analysis is a technique that has been used in several research papers to simulate the economic effects of export ban due to disease (e.g. see Mahul and Durand 2000).

The equilibrium between total supply and total demand for each sector can be captured in a single set of equations written as *;* where Y is the vector of final demand, A the matrix of input-output coefficients, X the vector of outputs. The final demand equation can be manipulated to yield a multiplier as , where is the Leontief inverse matrix that can be used to simulate overall changes in sectoral outputs, such as the livestock sector, which result from changes in final demand. Following Mahul and Durand (2000) and defining final demand by where *D* is the vector of the domestic demand, *E* the vector of exports and *M* the vector of imports. Therefore, a change in the exports, the imports and the domestic demand being unchanged, will affect sectoral output through the associated multipliers. Input-output multipliers obtained from Scottish, Economy Statistics - Input-Output Tables 2004 were used to measure the magnitude of the effects that export ban have on Scotland.

4.0 Results

4.1 Spreadsheet cost-benefit analysis[15]

In an *ex ante* CBA it would be ideal to have estimates of the relative probability of the incursion scenarios. The probabilities can be used to compute an overall expected benefit and make comparisons between incursion scenarios. Unfortunately given the level of uncertainty

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[15] Spreadsheet is available from the authors upon request.

involved it was very difficult to derive any quantitative estimates for the probability of each incursion scenario as the risks are as yet too poorly understood. Consequently, we confined our analysis within each incursion scenarios by ranking of benefit-cost ratios (BCR).

All present-value equivalents are calculated using a social discount rate from the UK Treasury Green Book[16] (3.5%). We considered net present value (NPV) and the BCR investment indicators. In each scenario all benefits are summed and costs subtracted to arrive at an estimate of Net Present Value (NPV). The BCR is computed as the sum of discounted annual benefits divided by the sum of discounted annual costs. A worthwhile investment in BTV8 prevention in each scenario should generate sufficient benefits to at least cover the investment costs. This implies that the NPV should be positive and the BCR greater than one. In economic terms, the higher the values of NPV and BCR, the more attractive the investment in the baseline surveillance/prevention costs of BTV8. Since there are considerable uncertainties over assumed probabilities, benefit cost ratios were used to rank interventions in terms of economic efficiency. The costs and benefits generated for the diseases from the spreadsheet model are summarised in Table 3 for within incursion scenarios.

Table 3: Within incursion scenario CBA for average values from the epidemiological model

	BTV stay at year 2 values in years 3-5						**BTV dies out gradually after year 2**					
	Control Options						**Control Options**					
Scenarios	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Sum of discounted cost (£m)	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8
SA09M1 (Midge transmission from south in April 2009)												
No license for move-to-slaughter												
Sum of discounted benefits (£m)	344.5	470.5	426.2	340.7	..	350.7	334.7	412.6	384.2	333.6	..	338.7
NPV	203.8	329.8	285.5	200.0	..	209.9	193.9	271.8	243.4	192.8	..	197.9
BCR	2.5	3.3	3.0	2.4	..	2.49	2.4	2.9	2.7	2.4	..	2.4
With license for move-to-slaughter												
Sum of discounted benefits (£m)	335.9	414.9	380.9	340.7	..	350.7	329.6	379.3	356.9	333.6	..	338.7
NPV	195.2	274.1	240.1	200.0	..	209.9	188.8	238.5	216.1	192.8	..	197.9
BCR	2.4	3.0	2.7	2.4	..	2.5	2.3	2.7	2.5	2.4	..	2.4
SJ08M2 (Midge transmission from south in July 2008)												
No license for move-to-slaughter												
Sum of discounted benefits (£m)	344.5	470.5	426.2	340.7	..	350.5	334.7	412.6	384.2	333.6	..	338.5
NPV	203.8	329.8	285.5	200.0	..	209.9	193.9	271.8	243.4	192.8	..	197.9
BCR	2.5	3.3	3.0	2.4	..	2.5	2.4	2.9	2.7	2.4	..	2.4
With license for move-to-slaughter												
Sum of discounted benefits (£m)	335.9	414.9	380.9	340.7	..	350.5	329.6	379.3	356.9	333.6	..	338.5
NPV	195.2	274.1	240.1	200.0	..	209.9	188.8	238.5	216.1	192.8	..	197.9
BCR	2.4	3.0	2.7	2.4	..	2.49	2.3	2.7	2.5	2.4	..	2.4
SS08M3 (Midge transmission from south in September 2008)												
No license for move-to-slaughter												
Sum of discounted benefits (£m)	359.1	453.6	417.2	349.8	..	350.5	341.7	398.9	375.3	337.8	..	338.5
NPV	218.5	313.0	276.6	209.2	..	209.9	201.1	258.3	234.7	197.2	..	197.9
BCR	2.6	3.2	3.0	2.5	..	2.5	2.4	2.8	2.7	2.4	..	2.4
With license for move-to-slaughter												
Sum of discounted benefits	348.4	408.7	376.9	349.8	..	350.5	335.8	374.1	352.9	337.8	..	338.5

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[16] http://greenbook.treasury.gov.uk/annex06.htm

(£m)												
NPV	207.8	268.2	236.3	209.2	..	209.9	195.2	233.6	212.3	197.2	..	197.9
BCR	2.5	2.9	2.7	2.5	..	2.5	2.4	2.7	2.5	2.4	..	2.4
AI09A4 (Animal import April 2009)												
No license for move-to-slaughter												
Sum of discounted benefits(£m)	378.9	499.6	491.2	438.9	..	439.7	355.0	432.3	423.5	391.7	..	392.6
NPV	238.2	358.9	350.4	298.1	..	299.0	214.2	291.6	282.7	251.0	..	251.8
BCR	2.7	3.6	3.5	3.1	..	3.1	2.5	3.1	3.0	2.8	..	2.8
With license for move-to-slaughter												
Sum of discounted benefits (£m)	352.7	428.8	411.9	411.9	..	393.1	339.4	389.8	375.7	363.5	..	364.4
NPV	211.9	288.0	271.1	271.1	..	252.3	198.7	249.0	234.9	222.8	..	223.6
BCR	2.5	3.1	2.9	2.9	..	2.8	2.4	2.8	2.7	2.6	..	2.6
AI08S5 (Animal import September 2008)												
No license for move-to-slaughter												
Sum of discounted benefits (£m)	378.9	478.2	466.5	434.0	414.8	434.8	345.5	414.4	401.8	384.9	373.9	385.7
NPV	238.2	337.5	325.7	293.3	274.2	293.8	204.7	273.7	261.1	244.2	233.4	244.7
BCR	2.7	3.4	3.3	3.1	3.0	3.1	2.5	2.9	2.9	2.7	2.7	2.7
*With license for move-to-*slaughter												
Sum of discounted benefits (£m)	345.5	417.0	397.5	392.0	375.2	392.7	334.3	380.6	363.3	361.3	351.8	362.1
NPV	204.7	276.2	256.7	251.2	234.6	251.8	193.5	239.9	222.6	220.6	211.2	221.1
BCR	2.5	3.0	2.8	2.8	2.7	2.8	2.4	2.7	2.6	2.6	2.5	2.6

In general, total current discounted benefits for all incursions scenario over five years range between £330m to £500m. All the scenarios are economically viable with positive net present values and BCR greater than one. Whether the disease fades out or not, control option C2 (Border PZ - 100% vaccinated) or 100% vaccination with a PZ starting at the Scottish Borders yields the highest discounted benefit and respectable BCRs within incursion scenarios**.** However, as benefits are defined as total disease losses avoided, this control option is associated with the highest disease losses. This means that if this incursion does take place, control option C2 (Border PZ - 100% vaccinated) is associated with the highest outbreak costs.

The lowest returns to baseline surveillance costs depend on obtaining a license for movement to slaughter. Control option C4 (50% vaccination with Scotland as PZ) for incursions SA09M1 (northwards spread of BTV from England arriving in April 2009) and SS08M3 (northwards spread of BTV from England arriving in September 2008) deliver lowest return with no license to slaughter while control option C1 (no vaccination) delivers lowest return with license to slaughter. These options have the lowest benefits and therefore relatively low BCR. Unlike SA09M1, the lowest return to surveillance cost for SJ08M2 (northwards spread of BTV from England arriving in July 2008) depends on the duration of the outbreak or the trajectory by which the disease persists after an outbreak as well as on the license position. Control option C4 (50% vaccination with Scotland as PZ) for SJ08M2 gives lowest disease losses avoided when BTV8 lingers and causes losses equivalent to year 2 levels up to year 5. Control option C1 (no vaccination) for incursion SJ08M2 does the same when BTV8 gradually dies out after year 2 with no licence to slaughter. However, control option C4 (50% vaccination with Scotland as PZ) for incursion scenario SJ08M2 remains the best vaccination strategy as control option C1 (no vaccination) for incursion scenario SJ08M2 is the no vaccination option.

For scenarios AI09A4 (import of infected animals in April 2009) and AI08S5 (import of infected animals in September 2008) the lowest returns on investment also appeared to be control strategy C1 (no vaccination) for all eradication measures; and seemed not to be influenced by either license for move to slaughter or the time trajectory of the disease when an incursion occurs. The vaccination strategy with the lowest return on investment to prevent or to limit the damage caused by BTV8 outbreak is control strategy C4 (50% vaccination with Scotland as PZ) for incursion AI09A4 and control strategy C5 for incursion AI08S.

Under the assumptions of the model, control option C2 (Border PZ with 100% vaccination) is shown to be a worthwhile investment. That is, this scenario achieves an NPV of at least £195 million over the 5-year time horizon considered and respectable BCR of at least 3.0, thereby providing returns of £3.0 for every £1 invested for BTV8 outbreak persisting up to year 5. Even if BTV8 outbreak fades out gradually, control option C2 yields an NPV of at least £192 million over the 5-year time horizon and at least a BCR of 2.7 implying providing £2.7 for every £1 invested.

5.0 Sensitivity analysis

The strength of the conclusions drawn from the CBA will obviously depend upon the quality of the data and rigour of the analysis. An indication of the robustness of the results is provided by conducting sensitivity analyses on the most important parameters to evaluate their impact on benefit –cost ratios. Sensitivity analysis was conducted for the following parameters: weight loss; milk loss; fertility loss; wool loss; export multipliers for cattle and sheep; own-price elasticities for sheep meat, beef and milk.

The sensitivity analysis indicated no change in the CBA ratios for all scenarios when parameters for weight loss, milk loss, fertility loss and wool loss were varied. Again, no change in the CBA ratios when changes of ±2% were applied for export multipliers for cattle and sheep and own-price elasticities for sheep meat, beef and milk. However, the sensitivity analysis showed a change of ±1% in the CBA ratios when export multipliers for cattle and sheep and own-price elasticities for sheep meat, beef and milk were varied by ±5%.

6.0 Conclusions

The most likely incursion scenarios are northwards spread from south-east England or import of infected animals. The risk of direct incursion of infected vectors from affected areas in south-east England or mainland Europe is very low, but not negligible and if a focus of infection were to become established in the north of England or Northern Ireland, this would pose a distinct incursion risk for Scotland. For this economic assessment, five potential incursion scenarios were chosen based on the two most likely routes of incursion.

To see if the benefits of disease being avoided justify the costs of the baseline investment in prevention, it is necessary to know the probability of BTV8 incursion into Scotland. However, it was not possible to establish this probability. Control options were therefore ranked within incursion scenarios. Within each incursion scenario the outbreak losses (average discounted benefits) were minimised with either no vaccination (C1) or a PZ across all Scotland with 50% vaccine uptake (C4). The ranking depended on incursion scenario, disease persistence assumption (declines in years 3 to 5 or persists) and/or mitigation opportunity (license to move to slaughter or not). The vaccination strategy that minimised outbreak losses was therefore C4. The only exception to this was incursion scenario AI08S5 (Imported animal, September 2008) where the vaccination strategy associated with the lowest outbreak losses was control option C5 (localised vaccination according to where the outbreak takes place).

Whether the disease fades out or not, control option C2 (Border PZ - 100% vaccinated) or 100% vaccination with a PZ starting at the Scottish Borders yields the highest discounted benefit and respectable BCRs within incursion scenarios. However, as benefits are defined as total disease losses avoided, this control option is associated with the highest disease losses.

This means that if this incursion does take place, control option C2 (Border PZ - 100% vaccinated) is associated with the highest outbreak costs.

Surprisingly, using the extreme epidemiological outputs made little difference to the economic assessment of alternative incursion control options based on average epidemiological outcomes. This combined with the results of the sensitivity analysis and the consistency between incursion scenarios is reassuring as it suggests that choice of best control option will be more robust to the nature and extent of the incursion than might have been expected. As decisions about control options usually need to be made in advance of any incursion and given the uncertainty that surrounds almost all aspects of this analysis, this is a reassuring outcome.

A major outcome from this study was the lessons learnt from the experience of operating as a team of scientists, economists, other experts and stakeholders. This issue is epitomised by the definition of the CBA framework. This was based from the outset on the assessment of the benefits of avoiding future BTV8 outbreak losses through the current (baseline) surveillance costs. However, the interests of stakeholders and scientists was in the relative costs of alternative vaccination strategies, which would probably need to be ordered and deployed in advance of a BTV8 incursion. Vaccination was therefore considered part of disease prevention costs needed to avoid other outbreak losses. This focused interest on a comparison between outbreak losses with and without vaccination (C1 versus all other strategies). However, lack of any estimates of the relative probabilities of BTV8 incursions into Scotland conditional on each of the alternative control options investigated frustrated such comparisons. Under these circumstances, a clear consistent definition of the CBA framework was a key attribute of success. Within each incursion scenario, a control strategy associated with lowest outbreak losses emerged but still with cost-benefit ratio >1. In most incursion scenarios the same control strategy delivered low or the lowest outbreak losses. This enabled useful decision support to be conveyed to SG despite lack of important information and differences between control strategies in the proportion of vaccination costs devoted to prevention rather than control.

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