Veterinary Record Open

Application of integrated production and economic models to estimate the impact of Schmallenberg virus for various sheep production types in the UK and France

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To cite: Alarcon P, *et al*. Application of integrated production and economic models to estimate the impact of Schmallenberg virus for various sheep production types in the UK and France. *Vet Rec Open* 2014;**0**:e000036. doi:10.1136/vetreco-2014-000036

▸ Prepublication history and additional material is available. To view these files please visit the journal (http://dx.doi.org/10.1136/vetreco-2014-000036).

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Received 14 February 2014
Revised 29 September 2014
Accepted 15 October 2014

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ABSTRACT

Objective: The present study aimed to estimate and compare the economic impact of Schmallenberg virus (SBV) in different sheep production holdings using partial budget and gross margin analyses in combination with production models.

Participants: The sheep production types considered were lowland spring lambing, upland spring lambing and early lambing flocks in the UK, and grass lamb flocks of the Centre and West of France, extensive lambing flocks and dairy sheep flocks in France.

Methodology: Two disease scenarios with distinct input parameters associated with reproductive problems were considered: low and high impact. Sensitivity analyses were performed for the most uncertain input parameters, and the models were run with all of the lowest and highest values to estimate the range of disease impact.

Results: The estimated net SBV disease cost per year and ewe for the UK was £19.65–£20.85 for the high impact scenario and £6.40–£6.58 for the low impact scenario. No major differences were observed between the different production types. For France, the net SBV disease cost per year and ewe for the meat sheep holdings was £15.59–£17.20 for the high impact scenario and £4.75–£5.26 for the low impact scenario. For the dairy sheep, the costs per year and ewe were £29.81 for the high impact scenario and £10.34 for the low impact scenario.

Conclusions: The models represent a useful decision support tool for farmers and veterinarians who are facing decisions regarding disease control measures. They allow estimating disease impact on a farm accounting for differing production practices, which creates the necessary basis for cost effectiveness analysis of intervention strategies, such as vaccination.

INTRODUCTION

Schmallenberg virus (SBV) is a novel orthobunyavirus that was first detected in November 2011 in Germany in cattle with fever and reduced milk yield (Hoffmann and others 2012). SBV affects ruminants and appears to be exclusively transmitted by insect vectors of the *Culicoides* species group and vertically in utero (European Food Safety Authority 2012, Garigliany and others 2012b, Beer and others 2013). The very rapid spread and virus circulation described in spring 2013 (European Food Safety Authority 2013) sparked renewed discussions about SBV transmission patterns. Following expansive spread in various European countries, the virus was officially declared endemic in Belgium, France, Germany, Italy, Luxembourg, The Netherlands, Spain, Switzerland and the UK at the end of May 2012. The virus was detected by reverse transcription PCR in cattle, sheep, goats, alpacas, buffalos, bison, deer and moose, while fallow deer, roe deer and red deer were found to be seropositive (European Food Safety Authority 2013). It is unlikely that SBV causes disease in humans, but the possibility could not be completely excluded (European Centre for Disease Prevention and Control 2011, Reusken and others 2012).

Physiopathology and immunity of SBV remains imprecise. SBV detection in blood was reported to occur up to 15 days after natural infection (Claine and others 2013). Animals infected with SBV could develop immunoprotection which may prevent repeated infection for at least 2 months (Inaba and Matumoto 1990, Elbers and others 2012, Garigliany and others 2012a, Wernike and others 2013).

In ruminants, clinical signs are mainly associated with reproductive disorders. Depending on the time of infection, abortion, stillborn animals, premature deliveries and various intrauterine congenital malformations may occur (Steukers and others 2012, Conraths and others 2013). SBV has been detected in malformed fetuses, stillborn lambs or lambs born at term but with signs of neurological disorders, such as blindness, deafness, recumbency, an inability to suck and convulsions (Lievaart-Peterson and others 2012, Steukers and others 2012). Clinical signs are not observed in adult or growing sheep, although there were some reports of diarrhoea of unknown cause in ewes (Beer and others 2013) and anecdotal evidence of milk drop in milking sheep in The Netherlands (Anonymous 2011). Such acute infections cause production losses in terms of animals and milk lost and require additional expenditures for palliative treatment of affected animals. Additionally, trade or movement regulations may be a further economic cost for farmers, because of immobilisation of infected animals and extra costs due to specific export requirements to SBV free countries (EFSA 2014).

For a farmer to take an informed decision on a potential investment for an intervention on the farm to control a disease like SBV, it is critical to know whether the costs of an intervention are less that the financial losses associated with SBV. To be able to make a judgment on a potential investment for disease control, it is a necessary first step to estimate the impact of disease as a baseline. Interventions may include vaccination, which induces specific neutralising antibodies against the virus in the dam, preventing the virus from reaching the fetus; reduction of exposure to the vector through disruption of vector breeding sites, pesticide use, housing and protection of ruminants by repellents, and management of the timing of service or insemination (Baylis and others 2010, Anonymous 2012, British Cattle Veterinary Association 2012). The latter may prove difficult in many European countries where production and management systems are targeted towards the seasonality of grass growth and market demand.

Because the production type and associated management decisions and husbandry practices impact on the magnitude of losses and expenditures associated with disease (Häsler B. and others, unpublished observations), it is important to take into account the production structure. This allows not only determination of the disease impact with more accuracy, but also allows for investigation of which production factors cause the highest costs related to disease.

The purpose of this study was to estimate the economic impact of SBV at the farm level in the UK and France for the most common sheep production types. The objectives were: (1) to develop sheep production models as a basis for the financial analysis of SBV in sheep farms; (2) to calculate the partial budget for SBV in the UK and France; and (3) to investigate potential differences in model variables and disease estimates between the two countries.

METHODOLOGY

Overview

The SBV disease cost was calculated in three steps. First, the most typical and frequent production types of sheep in the UK and France were identified and modelled in Microsoft Excel. These production models simulated the farm population dynamics for a 1 year cycle using a static model, meaning that animal inputs and outputs (e.g. number of lambs finished or number of ewes bought for replacement) were recorded at the end of the cycle. Secondly, gross margin models were developed based on the production models. This was done by adding price level data and other economic parameters (such as veterinary costs) to the outcome of the production models in order to calculate the annual gross benefit of each system. To validate these models, the annual gross margins obtained for each system were compared with published gross margins. Thirdly, SBV disease effects were included in the production and gross margin models by adjusting respective parameters (e.g. proportion of lambs stillborn) or adding new ones (e.g. disposal costs for lambs that died because of SBV). These models were then run with and without disease, and the differences obtained were used to estimate the extra costs and extra benefits of SBV disease in a partial budget analysis. Two SBV disease scenarios—namely high and low impact scenarios—were investigated. Values for the disease parameters for each scenario were obtained from the existing literature and by expert opinion consultation. Sensitivity analyses were conducted to assess the variability of the disease impact for different combinations of the two most important disease parameter values. The methodology used is based on a concept article available on request (Häsler B. and others, unpublished observations).

Sheep production models

Available benchmarking data and expert opinion were used to identify the most common and representative sheep farm types in the UK and France. In total, three production types were identified for the UK and three for France (Table 1).

For the UK, the farm types were differentiated based on geographic location (upland v lowland) and lambing season (spring v early lambing). Dairy sheep holdings were not considered because their numbers are relatively low in the UK. In France, two meat and one dairy production types were modelled. They differed by area and intensity level, as previously described by the French livestock institute (Institut Elevage Ovin viande 2013). The model 'grass lamb flocks of the Centre and West of France' (GLCW) represents the moderate to high intensive sheep production that takes place in Massif Central and the West of France. The model 'extensive lambing flocks' (EL) represents extensive uplands or low producing areas. The dairy sheep production type modelled is the Massif Central Lacaune breed based system. It accounts for 75 per cent of the sheep milk produced

TABLE 1: Description of the sheep production types in the UK and France considered in this study

Country	Farm types	Description
UK	Lowland spring lambing farms	Sheep and lambs are raised in good grasslands. The ewes are mated in September/October. Lambs are born in April and sold in August/September. Some lambs are fattened and sold in April the following year (store lambs*). Use of crossbreeds. Main breeds are Suffolk, Texel and Dorset. Production of large and muscular lambs for meat. Ewes tend to produce higher number of lambs.
UK	Upland spring lambing farms	Sheep and lambs are raised in relatively poor grasslands and therefore require extra quantity of concentrates in their feed. Breeding cycle similar to lowlands, but with poorer performance. Animals are more resistant to adverse weather conditions. These farms tend to have more pure bred animals and normally replace their ewes with their own lambs.
UK	Lowland early lambing farms	Lambs are born between December and February, when grass is less rich. Therefore, extra concentrates are normally required in the feed. Good housing is required to account for winter conditions. Lambs are sold in the spring when prices are high.
FR	Grass lamb flocks of the Centre and West France (GLCW)	Lambs are mainly finished in barns with high level of concentrates. Several reproduction managements possible: (i) autumn lambing exclusively, (ii) autumns lambing plus spring lambing for first lambing ewe or (iii) three lambings within 2 years. Moderate to high level of productivity. Production of large and muscular lambs for meat. Ewes tend to produce higher number of lambs. High or moderate level of intensification with several breeds possible. Lambs sold are fattened (very few store* lambs).
FR	Extensive lambing flocks	Sheep and lambs are raised in poor grazing lands and therefore have lower productivity and lower selling weight. Breeding cycle is similar to GLCW, but with poorer performance. Animals are more resistant to adverse weather conditions. These farms tend to have more pure breed animals. The proportion of lambs sold fattened is increased compared with GLCW.
FR	Dairy sheep	Central France dairy production (Roquefort). Represents 75% of French dairy sheep production. Lacaune breed. Only one period of lambing per year. Reproduction of adult occurs in June and July (one month later for first lambing ewe). Lambing occurs in November and December for adults, and January and February for first lambing ewes. Lambs are fed with their mother's milk and are weaned at 12–13 kg body weight. They are then sold and fattened in specialised fattening units, to then be slaughtered at 15–19 kg body weight. Milking occurs just after lambing and for 5–8 month.

*Store lambs are lambs that are sold for finishing. Normally smaller lambs are sold in this way so that they have more time to grow and put on weight
FR, France

in France, and is linked to the production of Roquefort cheese. Corse and South-West dairy production types were not included as their farming systems differ highly from the Roquefort one and only represent a small proportion of the dairy sheep production in France.

For the development of the production models, which simulated a 1 year cycle, benchmarking data from different independent sources based on farm surveys and actual expenditures made by farmers were used for both the UK (Scottish Agricultural College 2010, Agro Business Consultants 2012, EBLEX, 2012, Nix 2013) and France (Institut Elevage Ovin lait 2012, Institut Elevage Ovin viande 2013). Some of the available benchmarking data were complemented by other sources, such as the authors' expertise and published statistics on market prices. For example, expenditures in France were available for the whole farm, but not disaggregated by the different classes of animals, and thus needed to be broken down using the authors' professional judgment. The full production models can be found in the online Table 1 in supplement 2.

Estimation of annual gross margins

The production models were used to estimate the annual gross margin for the different production types (Eq. 1):

$$\begin{aligned}\text{Gross margin} = \text{Revenue}\\ &-\text{Replacement costs and breeding depreciation}\\ &-\text{Feed costs} - \text{Veterinary costs} - \text{other variable costs}\end{aligned} \tag{1}$$

The detailed calculations of revenues and costs were done as described elsewhere (Häsler B. and others, unpublished observations) and are given in Table 2. All of the data used for the development of the production

TABLE 2: Revenues and costs calculated in the gross margin analyses for the different sheep production types in the UK and France

Revenues and costs	Equations
Revenues	
UK-FR: Total finished lambs sales	Total young lambs sold×lamb carcase weight (kg) at selling×price per kg carcase weight
UK-FR: Total store lambs sales	Total store lambs sold×price of a store lamb
UK-FR: Total cull ewes sales	Total ewes culled×cull price per ewe
UK: Total wool sales	Total wool sold (kg)×price per kg of wool
FR (dairy): Total female lambs sold for breeding	Total lambs sold for breeding×price per lamb for replacement
FR (dairy): Total milk sales	Total ewes that milked×milk per ewe milked (litre)×duration of milking (days)×price of milk per litre
Replacement costs	
UK-FR: Costs of buying or raising new replacement ewes	Total ewes bought×net value of a replacement ewe or net value of raising an ewe
UK-FR: Depreciation of the ram	((Purchase value of a ram−cull value of a ram)/life of a ram in years)×number of ewes/ewe to ram ratio
Feeding costs	
UK-FR: Costs of feed concentrate for ewes that lamb	Total ewes that lamb×concentrate (kg) per ewe×price per kg concentrate
UK: Costs of feed concentrate for ewes that have aborted	Concentrate (kg) per ewe×number of ewes that have aborted×price per kg concentrate
UK-FR: Costs of feed concentrate for finished lambs	Total finished lambs sold×concentrate (kg) per lamb sold at weaning×price per kg concentrate
UK-FR: Costs of feed concentrate for store lambs	Total store lambs sold×concentrate (kg) per store lamb×price per kg concentrate
UK-FR: Costs of forage for ewes that lamb	(Number of ewes×number of ewes per hectare of land)×forage cost per hectare
Veterinary and medicine costs	
UK-FR: Costs of ewe vaccines	(Cost of chlamydia vaccine+cost of toxoplasma vaccine)×total number of ewes bought+cost of clostridium and pasteurella vaccine×total number of ewes that lamb
UK-FR: Costs of worming ewes	Cost of deworming ewes×total number of ewes that lamb
UK-FR: Costs of lamb vaccines	Total number of lambs sold×cost of lamb vaccines (Note: In upland spring farms the number of lambs kept for replacement is also accounted for)
UK-FR: Costs of lamb worming	Total number of lambs sold×cost of deworming (Note: In upland spring farms the number of lambs kept for replacement is also accounted for)
UK: Costs of disposing dead ewes	Disposal costs per ewe×total ewes that die
UK: Costs of disposing dead fetuses, lambs born dead and lambs that die	Disposal costs per lamb×(total lambs born dead+total lambs that die post partum+total lambs aborted)
UK-FR: Costs of treating ewes with late abortion	Total number of ewes with late abortions×proportion of ewes with late abortion that get treated×cost of treatment per abortion
Other variable costs	
UK-FR: Costs of scanning	Number of ewes×scanning cost per ewe
UK-FR: Costs of tags	Number of ewes×tagging cost per ewe
UK-FR: Costs of bedding	Bedding cost per ewe×(total number of ewes that lamb−total number of ewes that give birth to a lamb stillborn×(1−probability of a ewe with reproductive problems to get culled))×220/365+bedding cost per ewe×(total number of ewes empty+total number of ewes with late abortions)×(1−probability of an ewe with reproductive problems to get culled)
UK : Costs of shearing	Shearing cost per ewe×(total ewes that lamb+(number of ewes empty+number of ewes with abortions)×(1−probability of an ewe with reproductive problems to get culled)
UK-FR: Costs of marketing	Marketing levy transport cost per ewe×total number of ewes that lamb
UK-FR: Costs of minerals and licks	Mineral and lick cost per ewe×total number of ewes that lamb

Input values are specific to each production type. Number and quantities of animals/products indicated in the equations are obtained from the production models (see Table 2 in online supplement 2)
FR, France

models and gross margin analyses are listed in the online supplement 1.

Assessment of SBV disease impact using partial budget models

The scientific literature was screened to identify the biological effects of SBV in sheep. Furthermore, common management practices were discussed with experts (see section 'Software, input values, sensitivity analysis and validation' below) and assumptions made regarding farmers' reactions to disease (Box 1). The generic production and gross margin models were used as the basis for a partial budget analysis. Biological disease effects were integrated into these models by, for example, increasing or decreasing forage use, veterinary costs or lambs born following a partial budget structure (Eq. 2):

$$\text{Net value}_i = (\text{Costs saved}_i + \text{New revenue}_i) - (\text{New costs}_i + \text{Revenue forgone}_i) \quad (2)$$

Net value (or net SBV disease cost) represents the financial impact of disease for a 1 year cycle and i is a defined disease scenario. This net value does not consider non-monetary impacts, such as the opportunity cost of labour spent in treating or caring for diseased animals.

To calculate the values of the PBAs (Partial Budget Analysis), disease parameters were first introduced into the production models. The differences obtained between gross margin parameters of disease and no disease situations were calculated. For example, the proportion of abortions changed the number of lambs born, which then resulted in lower revenues from lambs sold. For new costs items, such as 'treatment of ewes with abortions', new parameters where created in the models as follows:

$$\text{Cost of caesarean} = \text{Total number of ewes with dystocia that require caesarean} \times \text{CostCes} \quad (3)$$

$$\text{Cost of SBV testing in aborted foetuses} = \text{Number of fetuses that will be tested for SBV} \times \text{CostSBVtest} \quad (4)$$

Whereas CostCes is the costs of a caesarean and CostSBVtest is the price of SBV diagnostic of one sample (see online supplement 1).

Data on the within herd SBV incidence, incidence of various disease effects (e.g. rate of abortion, drop in milk yield) and the magnitude of those effects (e.g. proportion of milk loss) are sparse. Consequently, only two scenarios were considered:

- Scenario 1: A high impact in a herd that is highly susceptible to disease, which may, for example, be a management system where the susceptible gestation period falls into a season of high vector activity.
- Scenario 2: A low impact in a herd that is less susceptible to disease, which may, for example, be a management system in an area with low vector density.

Box 1: Assumptions made on general management practices and reactions to Schmallenberg virus (SBV) related disorders in sheep holdings in the UK and France (FR) to estimate the impact of SBV

General management practices (without SBV)
UK-FR (meat): The farmers buy all the replacement stock.
FR (dairy): The replacement stock is raised on the farm, extra female lambs sold for replacement.
Farmers' reaction to clinical disease
UK-FR: A very small proportion (1%) of ewes will receive treatment (anti-inflammatory) to suppress fever.
Reproductive disorders and related management practices
FR: Wool price and price for shearing (not done by farmer) are considered to be the same and therefore not included.
UK-FR: A proportion of ewes will have late abortions or will give birth to stillborn or malformed lambs due to SBV infection. Of all the malformed lambs born, only 1% will survive and the costs related to these lambs are considered negligible.
UK-FR: A proportion of ewes with SBV reproductive problems will be removed from the flock. These will be culled and the meat will be sold (the cull value for the ewe is applied).
UK-FR: A proportion of ewes will die due to SBV reproductive problems (the market value for the ewe is applied).
UK-FR (meat): The proportion of finished lambs and store lambs sold remains the same with SBV infection (while absolute numbers may differ due to disease).
UK-FR: In some cases, the malformations will lead to dystocia and the veterinarian will be called out. In a few cases of dystocia farmers will agree to conduct a caesarean.
UK-FR: When the ewe gives birth to a stillborn or a malformed lamb and there is no dystocia, there will not be any veterinary treatment.
UK-FR: In the case of an abortion, there may be treatment by the farmer. When ≥3% of ewes present abortions, the veterinarian will be called to investigate.
UK: The costs of culling a lamb is negligible (done by the farmer).
FR: The costs of disposing a dead animal is null, since this is paid through a tax at slaughtering of normal animals.
UK-FR: Malformed and/or stillborn lambs are unlikely to be submitted for testing because farmers may already suspect SBV, whereas an aborted lamb may be submitted on rare occasions.
FR: Concentrates are mainly fed 5 weeks before and several weeks after the lambing. Feed concentrate will be saved in case of late abortion.
UK: Concentrates saved considered to be negligible.
FR (dairy): Milk production decreases because of ewes dead or culled and not replaced in the current year and because of a drop in milk production during clinical episodes.
Drop in milk production induces reduced concentrate consumption for ewes with clinical cases.
Note: Unless specified, the assumptions apply both to meat and dairy sheep. These were agreed during the expert workshop

TABLE 3: Parameters and values used for a high impact and low impact Schmallenberg virus disease scenario

Parameter	Scenario 1—high impact	Scenario 2—low impact	Reference	Reasoning
Number of ewes with late abortion due to SBV out of a flock with 100 ewes	1–3.5 most likely=3	1–2 most likely=1.5	(Saegerman and others 2013) and expert opinion	Difference in abortion rate between positive and negative flocks from Saegerman and others 2013 was 3%. This value reflects the mean in the high impact scenario and acts as reference point for the expert estimates.
Number of ewes that will get treated (antibiotics) out of 100 ewes with late abortions	1	1	Expert opinion	The vast majority of farmers do not apply antibiotic treatment after abortion in ewes.
Number of aborted fetuses that will be submitted for SBV testing out of 100 aborted fetuses	0	0	Expert opinion	Because there is no requirement to submit aborted fetuses for testing when numbers are low, farmers are highly unlikely to submit aborted fetuses for testing.
Number of lambs stillborn or malformed and those that die within 1 week after lambing due to SBV out of 100 lambs born	2–12 most likely=7	1–3 most likely=2	(Saegerman and others 2013), (Van den Brom and others 2012), (GDS France, 2012) and expert opinion	Saegerman and others 2013: 23.3% in SBV positive flocks and 11.5% in SBV negative flocks showed stillborn, dead at birth and malformed lambs. Difference 11.8%. GDS France 2012: 13% of lambs aborted, stillborn, dead at birth and 2% malformed lambs. No baseline. Van den Brom and others 2012: 40% of malformed lambs tested after pathology were SBV positive. It was assumed that in the absence of a baseline, half of the observed effects are due to SBV.
Probability of farmers applying insecticide as SBV prevention	0	0	Expert opinion	Given that the vector dynamics are still not fully understood and therefore no evidence is available on the effectiveness of insecticide treatment, farmers are highly unlikely to use this as a measure to prevent SBV. Many farmers will already use insecticides for fly strike, but it is considered highly unlikely that a farmer would start using it particularly for SBV.
Probability of an ewe with reproductive problems to get culled	0.2	0.2	Expert opinion	The majority of ewes with reproductive problems are commonly kept in the flock and mated in the next season. A minor proportion, in particular problem ewes, will be culled and not kept for the next season.
Number of ewes out of 100 animals that suffer from dystocia when they give birth to a stillborn or malformed lamb due to SBV	80	80	(Saegerman and others 2013) and expert opinion	Saegerman and others 2013: flock dystocia rate in positive flocks was significantly higher compared with negative flocks. The ratio of mean dystocia rate/ proportion stillborn and malformed lambs in positive flocks was 0.8. This value was taken as the proportion of malformed or stillborn calves that will cause dystocia in ewes.

Continued

TABLE 3: Continued

Parameter	Scenario 1—high impact	Scenario 2—low impact	Reference	Reasoning
Number of ewes requiring caesarean out of 100 ewes with dystocia	2–10 most likely=5	2–10 most likely=5	(Thorne and Jackson, 2000) and expert opinion	Thorne and Jackson 2000 estimated that 1% of all dystocia problems in the UK required a caesarean. This was based on a survey where fetal abnormalities represented 3% of all dystocia cases. With an increased proportion of malformations causing dystocia, it was assumed that the need for caesareans would also increase.
Number of ewes that die out of 100 ewes with dystocia	50	50	(Scott, 2003) and expert opinion	The number of ewes with dystocia in a survey of 89,000 ewes in the UK was 4313 with a mortality rate of 79.3% for farmer assisted dystocia cases. Only 289 ewes (6.7% of all dystocias) were presented to a veterinary surgeon. It was assumed that the dystocia related mortality rate would be lower, because of increased disease awareness due to SBV. The value in the table corresponds to the mortality rate of ewes that have dystocia and not the absolute mortality rate in a herd due to dystocia. When adjusted to the number of ewes with dystocia, the absolute mortality rate of the herd associated with this condition is 2.6–3.1%.
Number of dairy ewes with clinical episodes out of 100 ewes	3–31 most likely=7.5	0	(Martinelle and others, 2012) and expert opinion	Martinelle and others 2012 report data for cattle, which has been used as a proxy in this study for dairy sheep. Median SBV morbidity rate in cattle was 7.5% which was taken as the most likely value. The minimum reported by Martinelle and others was taken as the lower range value and the median value plus 1 SD as the upper range value.
Duration of clinical episode in a ewe (days)	14–21 most likely=14	14–21 most likely=14	(Martinelle and others, 2012) and expert opinion	Martinelle and others 2012 was also used here as a proxy for the dairy sheep system
Proportion daily milk drop in production in a ewe with a SBV clinical episode (proportion)	0.1	0.1	Expert opinion	Due to lack of evidence on this effect, this figure was derived from dairy cow values (Häsler and others, 2014, unpublished data)

SBV, Schmallenberg virus

For each scenario, input parameters were defined to calculate the partial budget, as outlined in Table 3. To complement the values derived from the scientific literature, the input values for the models were discussed and agreed on in an expert workshop, as described in 'Software, input values, sensitivity analysis and validation' below. For the most variable and uncertain parameters, minimum, most likely and maximum values were agreed upon.

Software, input values, sensitivity analysis and validation

All models were built in Microsoft Excel. Apart from the parameter values derived from the published literature, two workshops were held, with 10 and 20 experts, respectively, representing members of the Schmallenberg surveillance team at the Animal Health Veterinary Laboratories Agency, industry representatives, veterinary clinicians and academic researchers. The first workshop aimed to present and discuss the structure of the production models, input variables and assumptions. Before the meeting, experts were requested to complete table with their opinion on the values of specific disease parameters (Table 3), and their ranges, for the high and low impact scenarios. The different expert estimates obtained and their averages were presented to the experts during the workshop for discussion. For the parameters with major differences and uncertainties, all workshop participants were encouraged to explain why they disagreed, and a discussion was stimulated to get to an agreement on the most appropriate value. Furthermore, the structure of the production models, gross margin and partial budget analysis were presented and discussed until agreement was reached. The second workshop was held at the end of the study, where the models developed and their results were presented. Experts were asked for their opinion on the validity of the results obtained. In addition, gross margin results were compared with literature estimates for validation purposes.

The sensitivity analysis was done by varying two variables: proportions of SBV abortions and proportion of stillborn and malformed lambs. Selection of these variables was done taking into account the uncertainty attached to them and their hierarchical position in the models. Uncertainty was determined considering the range of estimates collated from the literature and experts, and the input from discussions during the first expert workshop. These were also selected because most of the other disease effects in the models depend on these two inputs. The variable percentage of stillborn and malformed lambs due to SBV was varied in steps of 1 per cent between 0 per cent and 12 per cent, and the variable percentage of ewes with late abortions due to SBV was simultaneously varied between 0 per cent and 5 per cent. In addition, the models were run with all of the lowest and highest values to estimate the range of disease impact.

For the purposes of comparison and clarity, all economic results are presented in pounds sterling (1£=1.2303 €, as consulted on 20 May 2014). Further information on the production models is available on request.

RESULTS

Production models and gross margin analyses

The summarised results of the gross margin analyses are shown in Fig 1. The detailed structure and results of the production models and gross margin analyses of non-SBV infected farms are shown in the online supplement 2. For the UK, the model gross margin obtained for lowland spring lambing (LSL), upland spring lambing (USL) and lowland early lambing (LEL) flocks were £38, £23 and £47 per ewe, respectively. The main differences observed between the model gross margins and the industry gross margins (EBLEX 2012) are due to the estimation of replacement and forage costs (see online supplementary Fig 1). Replacement costs also explain some of the differences with the gross margin calculated in the *Budgeting and costing book 2012*.

In France, the model gross margins obtained for GLCW, EL and dairy sheep flocks were £27, £32 and £178 per ewe, respectively (see online supplement

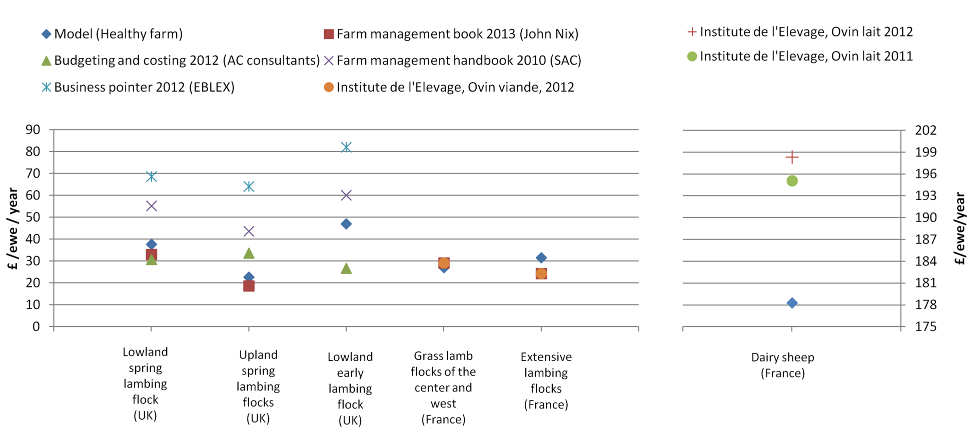

FIG 1: Gross margin results for Schmallenberg virus free sheep farms in the UK and France, and comparison with other gross margin analyses existent in the literature

Fig 2). The higher revenues observed in dairy sheep farms is due to the production of milk (71 per cent of the revenues). The model gross margin estimations for the GLCW and dairy sheep flocks are close to the gross margin available in the literature (within the 7 and 9 per cent difference, respectively). However, the difference for the EL production type is 23 per cent. This is due to the fact that these extensive livestock systems include summer pasturing in farm distant highland areas, and that these areas have particular juridical status for the farms (own property, long term renting, yearly renting), creating substantial variability.

Net SBV disease costs in sheep farms

The results of the net SBV disease costs for sheep farms are shown in Tables 4 and 5.

In the high impact scenario in the UK, the net SBV disease cost per ewe per year obtained in the PBA for an average sheep farm was estimated at £19.65 for LSL farms, £19.68 for USL farms and £20.85 for LEL farms (Table 4). In all three production types, the costs mainly accrued from young lambs not being sold (33–52 per ent of total new costs and revenues foregone) and the replacement of ewes (23–26 per cent of total new costs and revenues foregone). In the low impact scenario in the UK, the net SBV disease cost per ewe and year for an average sheep farm was estimated at £6.40 for LSL and USL farms and £6.58 for LEL farms (Table 4). In all three production types, the costs mainly accrued from young lambs not being sold (36–57 per cent of total new costs and revenues foregone) and the replacement of ewes (23–29 per cent of total new costs and revenues foregone).

In France, the net SBV disease cost per ewe and year for an average sheep farm in the high impact scenario was estimated at £17.20 for GLCW farms, £15.59 for EL farms and £29.81 for dairy sheep farms (Table 5). In the meat sheep production types (GLCW and EL), the costs mainly accrued from young lambs not being sold (50–55 per cent of the sum of costs),

TABLE 4: Schmallenberg virus disease costs (£) for three types of meat sheep farms in the UK considering high impact and low impact disease scenarios

	Lowland spring lambing		Upland spring lambing		Early lambing	
	HI	LI	HI	LI	HI	LI
Additional expenditure						
Treatment and veterinary assistance on ewes with late abortion	100	0	100	0	100	0
Caesareans due to SBV (veterinary visit and labour, drugs)	63	18	63	18	17	5
Disposal of aborted fetuses, stillborn or malformed lambs	38	14	50	17	10	3
Disposal of dead ewes due to SBV (consequence of dystocia)	6	2	6	2	2	0
Replacement of ewes culled or dead due to SBV	2386	761	1883	602	642	205
Chlamydia and toxoplasma vaccination of new ewes bought to replace ewe culled or dead due to SBV	98	31	99	32	26	8
Revenues forgone						
Finished lambs not sold	2710	964	3034	1142	1302	464
Store lambs not sold	1279	455	1530	531	27	10
Wool not sold	60	24	48	20	24	8
Dead ewes due to SBV (not culled and meat not sold)	1372	399	1069	311	369	107
Sum of costs	**8112**	**2668**	**8141**	**2675**	**2516**	**812**
Expenditure saved						
Concentrate feed saved in finished lambs	49	17	93	32	209	74
Concentrate feed saved in store lambs	30	11	60	21	6	2
Lamb vaccines saved	40	14	36	13	10	4
Ewes vaccines saved for clostridium and pasteurella	3	2	3	2	1	0
Deworming saved in culled ewes	3	1	3	1	1	0
Deworming saved in lambs not reared	6	2	5	2	1	0
Bedding saved in ewes culled	7	3	7	3	2	1
Shearing saved in ewes culled	28	9	28	9	8	2
Costs saved in marketing, levy and transport on lambs not reared	208	74	231	80	56	20
Minerals and licks saved	16	8	16	8	4	2
Extra revenues						
Revenues from ewes culled due to SBV	493	176	418	150	133	48
Sum of benefits	**881**	**317**	**900**	**320**	**430**	**154**
Net total disease cost	7231	2352	7242	2355	2085	658
Average flock size (heads)	368	368	368	368	100	100
Net total disease cost/ewe	19.65	6.40	19.68	6.40	20.85	6.58

HI, high impact; LI, low impact; SBV, Schmallenberg virus

TABLE 5: Schmallenberg virus disease costs (£) for three types of sheep farms in France considering high impact and low impact disease scenarios

	Grass lamb flocks of the Centre and West France		Extensive lambing flocks		Dairy sheep	
	HI	LI	HI	LI	HI	LI
Additional expenditure						
Treatment and veterinary assistance on ewes with late abortion	114	0	114	0	114	0
Caesareans due to SBV (veterinary visit and labour, drugs)	11	3	11	3	11	3
Replacement of ewes culled or dead due to SBV	436	139	395	126	73	24
Chlamydia and toxoplasma vaccination of new ewes bought to replace ewe culled or dead due to SBV	35	11	35	11	34	11
Revenues forgone						
Finished lambs not sold	1109	392	899	319	264	93
Store lambs not sold	60	21	100	37	0	0
Replacement lambs not sold	0	0	0	0	1209	411
Milk not produced and sold from dead and culled ewes due to SBV	0	0	0	0	1443	564
Milk not produced by ewes with clinical signs and first lambing and by extra ewes in first lambing	0	0	0	0	102	15
Dead ewes due to SBV (not culled and meat not sold)	251	73	228	66	42	12
Sum of costs	**2015**	**639**	**1782**	**560**	**3189**	**1119**
Expenditure saved						
Concentrate feed saved in finished lambs	137	49	89	31	26	10
Concentrate feed saved in store lambs	10	3	11	4	0	0
Concentrate saved on aborted ewes	40	20	30	15	88	40
Lamb vaccines saved	7	2	7	2	0	0
Ewes vaccines saved for clostridium and pasteurella	3	2	3	2	3	2
Deworming saved in culled ewes	2	1	2	1	2	1
Deworming saved in lambs not reared	2	1	2	1	1	0
Bedding saved in ewes culled	7	3	5	2	7	3
Costs saved in marketing, levy and transport on lambs not reared	15	6	15	6	15	6
Minerals and licks saved	4	2	2	2	6	2
Extra revenues						
Revenues from ewes culled due to SBV	295	112	224	85	215	85
Sum of benefits	**295**	**112**	**224**	**85**	**215**	**85**
Net total disease cost	1720	526	1559	475	2981	1034
Average flock size (heads)	100	100	100	100	100	100
Net total disease cost/ewe	17.20	5.26	15.67	4.75	29.81	10.34

HI, high impact; LI, low impact; SBV, Schmallenberg virus

replacement of ewes (22 per cent of the sum of costs) and revenues forgone from dead ewes due to SBV (12–13 per cent of the sum of costs). For dairy sheep, the main costs were related to the revenues forgone on milk by ewes culled or dead due to SBV (45 per cent of the sum of costs) and revenues forgone by not selling replacement lambs (38 per cent of the sum of costs).

The net SBV disease cost per ewe and year for an average sheep farm in the low impact scenario was estimated at £5.26 for GLCW farms, £4.75 for EL farms and £29.81 for dairy sheep farms (Table 5). In the meat sheep production type (GLCW and EL), the costs mainly accrued from young lambs not being sold (57–61 per cent of the sum of costs), replacement of ewes (22–23 per cent of the sum of costs) and revenues forgone from dead ewes due to SBV (12–13 per cent of the sum of costs). For dairy sheep, the main costs were related to the revenues forgone on milk by ewes culled or dead due to SBV (50 per cent of the sum of costs) and revenues forgone by not selling replacement lambs (37 per cent of the sum of costs).

Comparison of gross margins with and without SBV

The impact of SBV on the farm gross margins is shown in Fig 2. They illustrate the gross margin (expressed as £/ewe/year) for a farm not infected with SBV, a highly affected farm and a slightly affected farm. The reductions in gross margins for the UK for the high impact scenario are 43 per cent for LSL farms, 76 per cent for USL farms and 37 per cent for LEL farms. For the low impact scenario, the reductions are 14 per cent, 25 per cent and 12 per cent, respectively. The reductions in gross margins for France for the high impact scenario

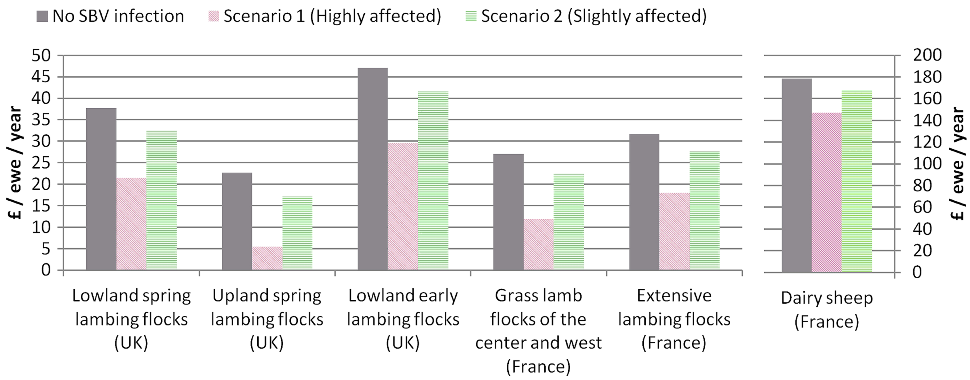

FIG 2: Gross margins for not Schmallenberg virus (SBV) affected, and highly and slightly SBV affected sheep farms in the UK and France

are 55 per cent for GLCW farms, 42 per cent for EL farms and 17 per cent for dairy sheep farms. For the low impact scenario, the reductions are 16 per cent, 13 per cent and 6 per cent, respectively.

Results from sensitivity analyses

Sensitivity analyses were performed for two of the most sensitive and uncertain disease parameters. The variation in the net SBV disease cost (£) per ewe per year are illustrated in Fig 3. The results show a linear increase in the costs of the disease. However, it can be observed that a substantial increase in the costs occurs when the proportion of ewes with malformations reaches 3 per cent. This is due to the assumption that at this level of abortion, the farmer will call in the veterinarian for investigation (Box 1).

The range from the best case (using the minimum values for all disease inputs from Table 3) to the worst case (using the maximum values for all disease inputs from Table 3) for the high impact scenario was £5.78–£31.64 per ewe and year for LSL farms, £5.79–£31.69 per ewe and year for USL farms and £5.93–£33.05 per ewe and year for LEL farms. For the low impact scenario, the ranges per ewe and year were estimated at £3.49–£9.32 for LSL farms, £3.50–£9.33 for USL farms and £3.61–£9.58 for LEL farms.

The net SBV disease cost ranges from the best case (using the minimum values for all disease inputs) to the worst case (using the maximum values for all disease inputs as defined in Table 3) for the high impact scenario (in £/ewe/year) were 4.8–27.1 for GLCW farms, 4.3–24.5 for EL farms and 8.8–45.1 for dairy sheep farms. For the low impact scenario, the ranges of net SBV disease cost (in £/ewe/year) were 2.8–7.6 for GLCW farms, 2.6–6.9 for EL farms and 6.0–14.7 for dairy sheep farms.

DISCUSSION

The present study aimed to estimate and compare the financial impact of SBV in different sheep production holdings in the UK and France using partial budget and gross margin analysis in combination with production models. The integration of production models with gross margin and partial budget analysis models can be a reliable method to assess disease impact. In the first instance, some disease parameters have a cascade effect on the economics of the farm. For example, an increase in abortions means that fewer lambs are born, which mean less revenues, but also more ewes dead or culled because of the abortion. This, if it is a closed farm, means that more lambs are kept for replacement and

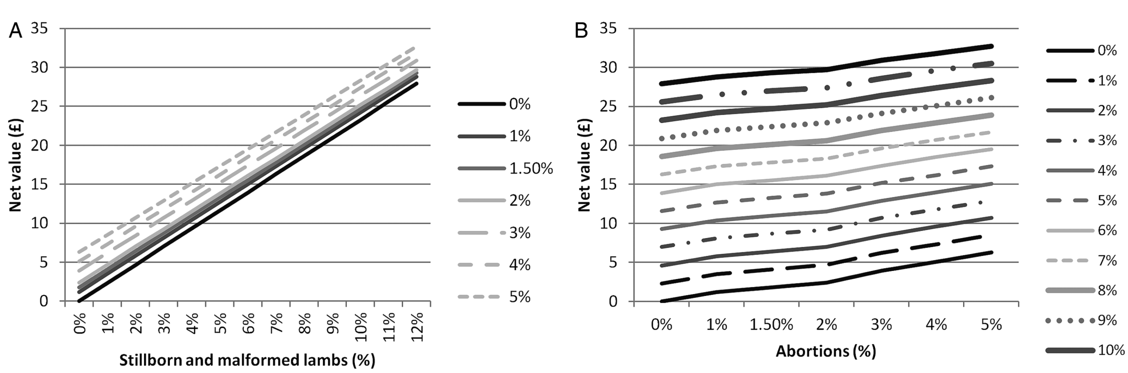

FIG 3: Variation of the net value (Schmallenberg virus disease impact) for (A) different values of percentages of stillborn and malformations (legend indicates different values of abortions) and (B) for different values of late abortions (legend indicates different values of proportion of stillborn and malformed lambs)

fewer lambs are finished, resulting in a loss in revenues. Production models can be used to calculate these effects in an easy and reliable way and allow capturing invisible direct costs related to changing population dynamics. They allow the assessment of how the population dynamics change due to disease. These changes can then be used to estimate the financial impact of a varying disease parameter. Although a straightforward partial budget analysis could have been done, some disease effects would have been difficult to estimate and the probability of model error would have been higher. Production models also help to estimate the gross margin of a farm, by understanding and quantifying the different inputs and outputs arising. This allows for comparison of outcome of the gross margin with the literature/benchmarking data. This comparison is important to validate the models (assess that the results are similar to the literature estimates) and to understand where the bias of the model lies. Furthermore, production models provide the basis to account for differences in production types. It is, however, important to note that the net value obtained in the partial budget analysis is equivalent to the difference in the gross margins with and without disease.

The UK and France sheep production types were chosen for this study for several reasons. These countries are among the most important sheep producers in the European Union (first and fourth largest producers) (Eurostat 2013). In terms of comparison of different sheep production types, important differences were expected between lowland and highland systems, due to the impact that the disease has on the reproduction of animals. The UK and France provide a good opportunity to investigate this, as they have both types of systems but in different settings (lowland/grassland v upland/EL). In addition, France has a large sheep dairy production which represents an important different farm type to investigate.

The results obtained indicate that the costs of SBV are similar for the different meat sheep production types of both countries. However, the impact on profitability was found to be most severe in the UK upland lambing flocks (with a 76 per cent reduction in gross profits) and in the French GLCW flocks (with a 55 per cent reduction in gross profits). The major costs of the disease were associated with the replacement of ewes culled or dead due to SBV and to the revenues foregone from finished lambs. For the UK, the losses due to the first parameter were higher in LSL flocks and in early lambing flocks, as these farms need to buy in replacement ewes. For France, the replacement costs of ewes culled or dead due to SBV were considerably higher in GLCW and EL compared with dairy sheep, for the same reason as in the UK. These results indicate that the common restocking procedures are a major disease costs element. The losses due to finished lambs not sold were found to be higher for early lambing flocks (£13/ewe) compared with lowland lambing flocks (£7.4/ewe if highly affected) and upland lambing flock (£8.2/ewe if highly affected). This is due to the higher value of the finished lambs in LEL flocks. However, it is important to note that the models do not account for farms selling breeding ewes. It is hypothesised that the costs of SBV for such farms will be considerably higher due to the loss generated by not being able to sell high value breeding ewes. For the French dairy sheep production type the net SBV disease cost was higher than for the other production types. In contrast, the disease impact on the gross margin was lower. This is mainly due to the fact that this farm type has much higher gross margin values due to revenues from milk production.

Importantly, the likelihood of being highly or slightly affected by the disease may differ substantially between the different production types due to management practices and related epidemiological factors. For instance, early lambing flocks may be more likely to be slightly affected by the disease due to the fact that their ewes are at risk of infection during the early gestation period, while lowland and upland flocks would most likely be infected during late gestation (Lievaart-Peterson and others 2012). Other factors that reduce the vector population (such as altitude, housing, etc) in the vicinity of the flock might contribute to this probability. Moreover, susceptibility of the animals (first infection or reinfection) may also influence the likelihood of being highly affected, although there is still much uncertainty about the duration and effectiveness of natural immunity. For France, no major differences in the contribution of the total costs of disease were seen between the GLCW and EL production types.

The SBV impact in milk sheep was almost twice that compared with meat sheep production. Yet the gross margin was approximately five times higher for dairy sheep, leading to a lower relative impact on profits for dairy compared with meat sheep. In dairy sheep farms, the highest losses accrued from the milk sales foregone followed by the revenues from replacement lambs not sold and to a much lesser extent from finished lambs not sold, veterinary expenditures and concentrate saved on aborted ewes. Assumptions made on sheep dairy production were principally derived from expert opinion on dairy cattle, and the results need to be interpreted with great care. However, the authors believe that the dairy cow data are a plausible approximation for dairy ewes in the absence of robust data.

In this study, the financial impact was presented for a low impact scenario and a high impact scenario without providing any information on the likelihood of a farm being in the high impact or low impact category. Although several extreme SBV clinical incidences have been reported by farmers, these were not considered in the analysis due to a lack of scientifically based evidence of a causal relationship between SBV and such cases. Furthermore, the impact of SBV on ewe fertility (i.e. empty ewes) was not considered in this study because there are currently no epidemiological data available to corroborate this hypothesis and there is a need for more in depth studies and data collection. As a consequence, an underestimation of disease impact may have occurred. Once scientific evidence becomes available, the models can be updated with the newly published data.

One of the main limitations of this study was the lack of data available in the literature on SBV disease effects, which may be partly due to a lack of reporting and absence of incentives for reporting. Most of the published scientific literature described the situation on Schmallenberg affected farms, but only in some exceptional cases compared them with non-affected farms or previous years before SBV emergence. As a consequence, attribution of disease estimates was not possible from these studies. Experimental studies or epidemiological studies comparing affected and non-affected farms are needed in order to obtain more accurate disease estimates. Expert opinion consultation was then needed to assess some of the parameters and assumptions. For instance, it was assumed that adult sheep do not show clinical signs apart from reproductive problems and milk loss. Also, although there is anecdotal evidence that SBV may cause infertility in ewes (empty ewes), this has not been corroborated by systematic scientific studies. The diversity of factors involved makes it very difficult for farmers and experts to establish a causal effect of SBV infection. In depth epidemiological and laboratory investigations would be needed to assess the reason for the infertility problem. Therefore, this clinical manifestation was not considered in this study. For dairy sheep it was assumed that adult sheep show clinical episodes with milk drop during the clinical episode, but milk production will return to normal when the ewe recovers (Doceul and others 2013). The disease estimates and assumptions used in this study were derived from scientific publications when possible and complemented by expert opinion consultation. Sensitivity analyses on disease estimates were used to account for this uncertainty and demonstrate the influence of the most uncertain input values used.

Importantly, only variable costs were included in this study. Labour costs were considered as fixed costs with the assumption that farmers would not pay extra time or increase staff numbers because of the disease. Furthermore, the models calculate the costs of disease without accounting for the costs of planned control and preventive measures, such as vaccination. While the costs of veterinary visits to treat affected animals are calculated, the costs of vaccination or preventive measures are not taken into account. These could be investigated in future studies aimed at assessing the efficiency of control measures.

In conclusion, although disease costs were found to be similar in all of the production types investigated, the UK USL flocks and the French GCLW flocks were shown to be most affected. The impact of SBV in high impact scenarios has been shown to be important for the farm in terms of costs (with up to £21 per ewe or 76 per cent reduction in profits). The models highlights that the main financial impact was due to 'finished lambs not being sold' and 'replacement of ewes culled or dead due to SBV'. This demonstrates that production systems can be affected very differently due to their different characteristics (prices, geography, management, etc) and highlights the validity of the approach chosen. Control measures aimed at reducing the impact of SBV in these sheep farm types should be considered. However, it is important to note that for farmers to make informed decisions on disease control, it is not sufficient to know the aggregate economic costs of the disease, but to understand what would be the avoidable disease costs (McInerney and others 1992). These avoidable costs will depend on the cost effectiveness of the different control measures available. Presently, the novelty of the disease and the lack of information on the effectiveness of control measures makes it difficult to incorporate this. However, the models presented here provide an important baseline that could be used as a basis to analyse the efficiency of possible SBV control strategies for different farm management systems by using, for example, cost–benefit analysis. Finally, this study shows the lack of data available in the literature regarding SBV disease parameters and indicates the necessity for further studies to accurately assess key disease parameters, such as the proportion of stillborn and malformed lambs and the proportion of ewes aborting due to SBV.

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Acknowledgements We thank the experts who made time to attend the expert workshop to discuss the models developed and the inputs used. We thank also the various colleagues in the UK and France for their willingness to provide information on the different production types, management and husbandry practices, and on potential disease impact.

Contributors All authors fulfil the authorship requirements, and any other contributions are listed in the acknowledgments.

Funding The project was funded by Merial France. BH acknowledges funding from the Leverhulme Centre for Integrative Research on Agriculture and Health.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement We are currently working on a web version of the models developed to make them accessible to the public. In the meantime, the Excel spreadsheets are available from the authors on request.

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