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Implementation and validation of an economic module in the Be-FAST model to predict costs generated by livestock disease epidemics: Application to classical swine fever epidemics in Spain

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ABSTRACT

Be-FAST is a computer program based on a time-spatial stochastic spread mathematical model for studying the transmission of infectious livestock diseases within and between farms. The present work describes a new module integrated into Be-FAST to model the economic consequences of the spreading of classical swine fever (CSF) and other infectious livestock diseases within and between farms. CSF is financially one of the most damaging diseases in the swine industry worldwide. Specifically in Spain, the economic costs in the two last CSF epidemics (1997 and 2001) reached jointly more than 108 million euros. The present analysis suggests that severe CSF epidemics are associated with significant economic costs, approximately 80% of which are related to animal culling. Direct costs associated with control measures are strongly associated with the number of infected farms, while indirect costs are more strongly associated with epidemic duration. The economic model has been validated with economic information around the last outbreaks in Spain. These results suggest that our economic module may be useful for analysing and predicting economic consequences of livestock disease epidemics.

1. Introduction

Classical swine fever (CSF) is a highly contagious viral disease that affects wild and domestic swine, and it is considered one of the most economically damaging diseases in the swine industry worldwide (Boklund et al., 2009; Horst et al., 1999). Spain is the second largest producer of swine in the European Union (Eurostat, 2014). It was declared CSF-free in 1988, but two CSFV incursions have occurred since then: one in 1997–98 that affected the provinces of Lleida, Seville, Segovia and Saragossa; and another in 2001–02 that affected the provinces of Lleida, Castellón, Valencia, Cuenca and Barcelona. Both epidemics caused significant estimated economic costs (Table 1).

Although the characteristics and economic consequences of each CSF epidemic depend on the location, time period and type of holdings infected, strict control measures are always required in order to stop the spread of disease and eradicate it. Detection of a CSF epidemic in Europe triggers the following control measures, as mandated by Spanish and European Union regulations (MAGRAMA, 2011): (1) immediate culling of all swine on the infected farms and destruction of the carcasses; (2) restriction of movements related to the swine industry within CSF outbreak areas, including movements of animals, vehicles and people; (3) strict biosecurity measures, including disinfection of holdings, transport vehicles and other material at risk of contamination; (4) close monitoring and tracing to determine the infection source, with an emphasis on veterinary staff visits and movements of vehicles transporting animals and products; (5) zoning around infected holdings to accelerate the detection of infected farms in the vicinity and better control movements of vehicles that may spread disease.

All these control measures generate economic costs that are supported by government authorities and the swine industry. The

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Table 1
Summary data of CSF epidemics in Spain since 1988 (Del Pozo Vegas, 2006). Number of depopulated farms, duration of the epidemic in months, number of culled animals and estimated costs to compensate farmers by culled animals, shown in millions of euros (M€).

Epidemic costs in Spain				
Year	Depopulated farms	Months	Culled animals	M€
1997	99	16	609,147	60
2001	48	11	378,407	48

study of the potential spread patterns of CSF into an area may help to identify risk zones to improve the prevention and management of future outbreaks. In the present work, we consider the time-spatial stochastic epidemiological model, called Be-FAST: *Between-Farm-Animal Spatial Transmission* (Ivorra et al., 2012). This model has been developed at Complutense University of Madrid by the MOMAT (www.mat.ucm.es/momat) and VISAVET (www.sanidadanimal.info) research groups. The main objectives of Be-FAST focus on the next four points considered for a particular livestock disease (e.g., CSF, African Swine Fever or Foot and Mouth Disease) and area (e.g., region, province, country), as previous in works (Martínez-López et al., 2013, 2014): (1) to evaluate the spatial risk of disease spread between farms in a particular area, (2) to identify the disease diffusion pattern, (3) to predict the amplitude and duration of particular outbreaks, and (4) to evaluate the efficiency of applied control measures.

Be-FAST is based on a Monte-Carlo algorithm that generates M scenarios of possible epidemic evolutions; the algorithm has been described in detail elsewhere (Martínez-López et al., 2011, 2012) and is summarised in Fig. 1. Starting from a user-specified database of information about farms and their commercial network, the algorithm assumes that at time $t = 0$, every farm is free of disease and therefore in a susceptible state except for a predefined number of randomly selected farms that are assumed to contain a given number of infected animals. During a period of time $[0, T]$, with T being the maximum number of days in the simulation, the disease spreads *within-farm* through a Susceptible-Infected model, and *between-farm* through an Individual-Based model with farms playing the role of individuals. Every day of the simulation, the authorities may detect contaminated farms, in which case the six control measures described above are activated in order to stop the spread. If the epidemic has resolved by the end of the day (defined as no infections in the study area), the simulation concludes and the next one begins until the last scenario M.

The objectives of the present work were to develop an economic model to evaluate various economic costs of simulated livestock disease outbreaks, to include this model as a module in Be-FAST and to validate it using historical data on the two most recent CSF incursions in Spain. Our approach follows the recommendations of Saatkamp et al. (2000) by assigning costs to four categories (explained in Section 2.1): (1) payable costs, (2) transferred costs, (3) calculated costs and (4) indirect costs. At the end of a Be-FAST simulation, various statistical economic indicators are computed such as maximum and mean epidemic losses or the proportions of total costs falling into different cost categories. The main goal was to provide a useful tool for authorities and insurance companies to estimate an initial budget needed to fight against a particular disease in a specific area, as well as predict how costs will evolve during an epidemic. We used our model to analyse relationships among model behaviour and public health and economic impact. We simulated different scenarios in order to analyse how each type of cost evolved over the course of the epidemic. We compared our model output with real historical economic data for CSF epidemics in Spain (Martínez-Lopez, 2009; Del Pozo Vegas, 2006).

2. Material and methods

2.1. Economic module

The economic module operates at the end of each simulation day, Fig. 1, in order to evaluate the daily costs of the given livestock disease epidemic in the specific area until eradication. Costs were classified according to the proposal by Saatkamp et al. (2000): (1) payable costs (C_p), which are the costs paid directly by government authorities to control and eradicate the epidemic; (2) transferred costs (C_t), which are the costs paid by the authorities to compensate other entities, such as farmers; (3) calculated costs (C_c), which are losses generated in the livestock industry (e.g., transportation companies) that may occur between epidemic onset and eradication and that are not compensated by authorities; and (4) indirect costs (C_i) suffered by the livestock industry as a result of the devaluation of meat.

2.1.1. Payable costs

Human and material resources needed to apply the disease control measures, presented previously in Section 1, were considered payable costs since these resources should be paid directly by the authorities. This category included the following costs (details for each cost can be seen in Appendix):

- $C_{p,zn}(i, t)$, which denotes the daily costs related to zoning around a detected farm i on day t. Establishing protection areas where restricted activities are controlled requires administrative and security resources In order to compute these costs, the algorithm assumes an estimated daily mean cost associated to the control of one farm, denoted by $MC_{p,zn}$.
- $C_{p,cul}(i, t)$ denotes the cost of culling and disinfecting an infected farm i on day t. It includes human and material resources as well as cleaning products needed during this process. Here, to estimate $C_{p,cul}$, the algorithm considers $MC_{p,cul}$, the estimated mean cost per animal of culling and disinfecting a farm.
- $C_{p,sm}(i, t)$ denotes the cost of detecting possible infection on any farm i on day t. This cost involves sampling, laboratory analysis and employee salaries. We denote by $MC_{p,sm}$ the mean cost of testing one sample.

Taking into account previous costs, the total payable cost is given by the sum of $C_{p,zn}$, $C_{p,cul}$ and $C_{p,sm}$.

2.1.2. Transferred costs

After culling animals, authorities usually compensate the affected livestock producers. These costs, so-called transferred costs, are denoted as C_t, and they are strictly controlled by the authorities through a census of culled animals per outbreak. These costs are thought to cause significant economic impact (Saatkamp et al., 2000). The algorithm assumes a mean compensation per animal depending on whether a farm i is of the type fattening, farrowing or farrow-to-finish, denoted by $MC_{t,cul}(i)$ (details can be seen in Appendix).

2.1.3. Calculated costs

Losses borne by livestock companies during an epidemic are the most difficult to estimate (Saatkamp et al., 2000). In the present study, we considered the following costs (details can be seen in Appendix):

- $C_{c,ds}(i, t)$ denotes the daily cost of removing or destroying feed and material on day t on a farm i under quarantine. We assume that this cost is proportional to the number of animals per farm and we consider $MC_{c,ds}(i)$ the daily mean of material disposal per animal