Probability of introducing foot and mouth disease into the United States via live animal importation

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Summary
Foot and mouth disease (FMD) continues to be a disease of major concern for the United States Department of Agriculture (USDA) and livestock industries. Foot and mouth disease virus is a high-consequence pathogen for the United States (USA). Live animal trade is a major risk factor for introduction of FMD into a country. This research estimates the probability of FMD being introduced into the USA via the legal importation of livestock. This probability is calculated by considering the potential introduction of FMD from each country from which the USA imports live animals. The total probability of introduction into the USA of FMD from imported livestock is estimated to be 0.415% per year, which is equivalent to one introduction every 241 years. In addition, to provide a basis for evaluating the significance of risk management techniques and expenditures, the sensitivity of the above result to changes in various risk parameter assumptions is determined.

Keywords

Introduction
Foot and mouth disease (FMD) continues to be a disease of major concern for the United States Department of Agriculture (USDA) and livestock industries. The reasons for this concern are complex and interrelated.

First, FMD is a disease that occurs with regular frequency around the world. In the spring of 2011, there were 177 Member Countries of the World Organisation for Animal Health (OIE); 65 countries were ‘FMD free where vaccination is not practised’, one country was ‘FMD free where vaccination is not practised’, ten countries had zones that were ‘FMD free where vaccination is not practised’, and six countries had zones that were ‘FMD free where vaccination is practised’, with the remaining countries considered to be affected by FMD (28).

Second, although the USA has been free of FMD since 1929 the possibility of an outbreak is very real, and taken seriously by US officials. Planning and preparedness for the possible introduction of FMD is a continual and ongoing process. A recent evaluation of the preparedness of the USA for an FMD outbreak, carried out by veterinarians and officials who could act as ‘Incident Commanders’ in the event of such an outbreak, suggested that there is a need for improved response planning (20). The National Center for Animal Health Emergency Management (NCAHEM), which is part of the Veterinary Services at USDA, updated the response plans for FMD in 2010 and will receive public comment on the modified plans (26).

Third, FMD virus is a high-consequence pathogen for the USA, mainly because of the potential economic impacts that would be associated with outbreaks. These economic impacts are tied primarily to the trade implications for countries that have the disease and the methods used to control and eradicate the disease. Industries that are not directly connected to agriculture can also suffer substantial economic losses (21). The FMD outbreak in the United Kingdom in 2001 saw a large economic impact associated with tourism losses (1). Were an outbreak of FMD to take place in the USA, two actions could generally be expected to occur simultaneously. The FMD-free segment of the world would immediately restrict imports from the USA of any live
animals that could be affected by the disease, as well as imports of any product derived from these animals or any products that could potentially be a fomite or vehicle for transmission of FMD. Also, the Veterinary Authority of the USA would initially close exports. For countries, such as the USA, that export significant amounts of animal product, an outbreak of FMD is economically devastating because of such trade restrictions. Additionally, the methods a country chooses to eradicate FMD also contribute to the economic impacts in substantial ways. During an outbreak, stamping out all affected and at-risk animals is still the most widely used disease control measure. This response method has resulted in the destruction of millions of animals in affected countries and substantial economic loss, including loss of trade. The USA exports billions of dollars of animal products every year, so the exposure to economic loss is significant. As an example, pork exports for 2010 were the second-highest volume and value on record, totalling 1.94 billion kilograms (+28 billion pounds) valued at US$4.78 billion (2).

In order for high-level decisions to be made about allocation of resources to FMD exclusion strategies, it is important to assess the probability of importing a disease such as FMD into the USA. Resources cannot be optimally allocated at the national level without such information. The risk of disease introduction via live animal imports is part of the justification for the procedures and processes in place that control live animal importation into countries. However, assessments of the probability of introducing FMD into the USA via live animal imports have not been published in spite of the fact that a large number of live animals are traded between Canada, Mexico, and the USA. Indeed, the North American Free Trade Agreement (NAFTA) was put into place in part to encourage increased trade among these three countries.

The objective of this study was (i) to estimate the probability of an outbreak of FMD occurring in the USA as a result of the importation of livestock and (ii) to understand the sensitivity of the results to the various risk parameters used in estimating the probability. A better understanding and appreciation of these risk parameters can help to guide future resource allocations, identify improved methods for use at quarantine stations, and help make the USA better prepared for detecting and controlling an FMD incursion.

Methods

Quantitative model determining the probability of foot and mouth introduction into the United States

The basic approach used to develop this quantitative model for determining the probability of FMD introduction via live animal importation into the USA is that outlined originally by Miller et al. (12), and more explicitly developed by Martínez-López et al. (11) in their quantitative risk assessment of FMD introduction into Spain. Microsoft Excel 2007 is used as the software basis for the model. (The use of such standard and readily available software can help promote the accessibility of the model for use by other analysts. This in turn can promote active industry peer review and the testing of alternative assumptions.)

The probability of introducing FMD into the USA via the importation of live cattle, hogs, sheep, and goats is estimated. The study analyses the probability of introduction in one year. This probability is estimated as the sum of estimated probabilities that FMD would be introduced as a result of importing these live animal types from the eight countries which exported them to the USA from 2005 through 2010: Australia, Austria, Canada, Ireland, Mexico, New Zealand, Sweden, and the United Kingdom. The estimated probability reflects importation of an FMD-positive animal into any part of the USA. Thus, results from this study apply to considerations for the prevention of FMD introduction at the national level. In the case of the USA, prevention involves policy and regulations related to border crossings with Mexico and Canada, and importations at specified ports of entry of live animals from countries outside of North America. More broadly, the results may be valuable in considering differences in FMD introduction probabilities between countries where animal transport or movement across geographic regions or political boundaries is controlled and countries where animal transport or movement is not controlled.

The variable notations, variable descriptions, methods of calculations, and sources of data for the model are outlined in Table I. The period of time for the estimated probability of FMD introduction into the USA, \( \beta \), is assumed to be one year. The model is linked together by a series of simulated variables (and distributions) and their interconnections. Simulated values from stochastic variables were estimated using the Visual Basic Application within Excel; each simulation of import-related activity involved 10,000 iterations.

The probability of an undetected FMD case in country \( c \) when animals are shipped to the USA from country \( c \) during the time period of \( \beta \) is \( \alpha_c \). For most exporting countries, which have reported zero FMD epidemics for at least the last three decades, the following estimation approach is used. The probability, \( \alpha_c \), is estimated as the number of FMD epidemics reported from country \( c \) during the period of time \( t \) to the OIE (E<sub>c</sub>) divided by \( (t_c) \) the number of years for which information regarding the occurrence of FMD epidemics in country \( c \) was available on the OIE website (Table II). The country-specific probability of FMD infection P(A<sub>1</sub>) is a simulated
variable assumed to have a Gamma distribution \((\alpha_c, \beta)\) – i.e. a Gamma distribution with parameters \(\alpha_c\) and \(\beta\).

For the countries that have reported FMD within the last 16 years, namely Ireland (one outbreak) and the United Kingdom (two outbreaks), a slightly more sophisticated estimation method is used. For these two countries, the probability, \(\alpha_c\), is estimated via a maximum likelihood approach, based on the inter-arrival period (i.e. the number of years between reported FMD incidents), where inter-arrival periods are assumed to follow an exponential distribution. This approach recognises that the FMD-free period may extend into the future, beyond the data period being examined.
The probability that an animal survives an FMD infection, allowing potential transmission of FMD to another animal, \( P(A_2) \), is assumed to be Pert (min., mode, max.), i.e. a Pert distribution with parameters min., mode and max. (A Pert distribution, a form of the Beta distribution, is often used to reflect expert opinions; it is often employed as an alternative to the simpler Triangular distribution.) Morley (13) states a case fatality rate for FMD in cattle and swine of 2–20% with an assumed uniform distribution. Martínez-López et al. (11) allow a maximum probability of FMD survival of 1, which would occur with mild strains and no mortality. The Committee on Foreign and Emerging Diseases of Animals for the United States Animal Health Association (24) states that the mortality is 1–5% for adults and 20% and higher for young stock. Thus, considering that an overall animal population would consist of a wide range of ages, it is assumed that \( P(A_2) \) is Pert-distributed with min., mode, and max. values of 0.80, 0.97, and 0.99, respectively.

The probability of exporting an animal to the USA from one of the eight countries \( c \) is simulated as \( P(A_3) \). \( P(A_3) \) is assumed to have a Beta distribution, and uses the number of animals in country \( c \) expected to be infected prior to epidemic detection, the average herd size in country \( c \), the number of herds in country \( c \), the intra-herd prevalence of FMD, and the population of susceptible animals (assumed here to be only cattle, swine, sheep and goats) (Table I). The authors used data from the Food and Agriculture Organization of the United Nations (8) to ascertain the size of the susceptible population in each country from which the USA imported animals between 2004 and 2008 (inclusive). The average herd size was unknown and assumed to be 50. Intra-herd prevalence was assumed to be distributed as Pert with a minimum value of 0.05, a most likely value of 0.9, and a maximum value of 1.0 (as in Martínez-López et al. (11)).

The probability of surviving shipment to the USA is \( P(A_4) \). \( P(A_4) \) is \( 1 - P_s \) where \( P_s \) is the probability of mortality of species \( s \) during transportation to the USA. For hogs, \( P_s \) is assumed to be a lognormal distribution with \( \mu = -1.229 \) and \( \sigma = 0.599 \). The values of \( \mu \) and \( \sigma \) were determined using a method of moments technique (10) applied to a lognormal distribution with a mean of 0.35% and a standard deviation of 0.23%. The authors used data on the percentage of swine that died during shipment (22). These data showed that the overall mean shipment mortality across all seasons (with approximately the same number of trailer loads shipped each season) was 0.35%. It was assumed that the standard deviation within each season is equal, and a standard deviation of 0.23% will then provide a pooled standard error of the mean equal to that reported (0.09%) (22). For cattle, it was assumed \( P_s \) is distributed as Pert (0.13%, 0.24%, 0.52%) (17). Norris et al. found an overall death rate for cattle shipped of 0.24% among 4 million cattle exported, with a larger proportion of deaths on voyages to the Middle East (0.52%) than to South-East Asia (0.13%). For sheep and goats, it was assumed \( P_s \) was 0.75% (16).

The probability of establishing an effective contact (a contact capable of transmitting FMD should FMD exist) is \( P(A_5) \) and is 1 minus the probability of detecting FMD in US quarantine stations before livestock leave the quarantine station (\( P_d \), for all countries other than Mexico and Canada). \( P(A_5) \) was assumed to be an extremely low probability (personal communications with Drs Hernando Duque, Samia Metwally, and Ming Deng, Plum Island Animal Disease Center, 23 February, 2011). These individuals estimated that \( P(A_5) \) was essentially zero for all animals passing through quarantine stations in the USA. To allow for some probability that FMD would not be caught at a quarantine station (e.g. due to latent infection and inadequate testing to identify the disease), the probability of detection at a quarantine station in the USA was assumed to be 0.99. For Canada and Mexico, since these animals rarely pass through a quarantine station, \( P(A_5) \) was assumed to be 1.

The overall probability of an FMD outbreak occurring in the USA as a result of infected livestock importation is the sum of the country- and species-specific probabilities of FMD from importation. The probability of FMD infection due to livestock importation of species \( s \) from country \( c \) is \( 1-(1-P(A_1)\times\ldots\times P(A_3))P(A_4)P(A_5) \).

### Sensitivity analysis

Understanding the relative potential impact on loss probabilities of the underlying risk factors and parameters is the vital first step in the risk management process, and is necessary for evaluating alternative risk mitigation strategies. Some of the parameter values used in these analyses are assumed, since the actual values are uncertain,
either because of insufficient data availability, or because what data is available is extremely volatile. Thus, sensitivity analyses of parameters were conducted to assess the relative importance of the various parameters, as well as their potential impact on the overall risk probability for FMD introduction from livestock imports.

Sensitivity analysis of the probability $P(A_1)$ (i.e. the country-specific probability of having undiagnosed FMD herds) was conducted. For each additional year in which countries that are trading partners with the USA remain FMD free, $P(A_1)$ changes. Thus, the risk of FMD introduction into the USA is estimated for each additional year for the next ten years, and then in ten-yearly increments should these countries remain FMD free for the next 90 years.

In Morley (13), the suggested distribution for $P(A_2)$ (i.e. the probability of survival of an animal from FMD allowing potential transmission of FMD to another animal) is uniform, with an assumed maximum case fatality rate of 0.20 and an assumed minimum case fatality rate of 0.02. However, in Martínez-López et al. (11), it is suggested that the appropriate distribution for $P(A_2)$ is Pert (0.80, 0.98, 1.0), which corresponds to assuming a maximum survival probability of 1, a minimum survival probability of 0.80, and a most likely survival probability of 0.98. These values represent quite different assumptions about this one variable. Thus, the sensitivity analysis associated with $P(A_2)$ examines the impact of changing $P(A_2)$ from our starting point of a Pert (0.80, 0.97, 0.99) distribution to those of Martínez-López et al. (11), and to those of Morley (13).

$P(A_2)$ sensitivity is evaluated by allowing herd size to vary from 20 to 5,000. Increments on herd size were varied by increments of ten for low values, and by increments of 1,000 for values above 1,000.

$P(A_3)$ sensitivity is evaluated by allowing the probability of failure to identify infected animals in quarantine to vary from 0 to 1%, using increments of 0.1%. The three FMD experts consulted believed that the probability of failing to identify infected animals in quarantine was 0. However, the model assumes a probability of 1%, and hence the range used for the sensitivity analysis was from 0 to 1%.

### Results

The total probability of introducing FMD into the USA via imported livestock is estimated to be 0.415% per year, which is equivalent to one introduction every 241 years (Table III). Importation of hogs from Canada contributed the most (84%) to the total probability, with importation of cattle from Canada being the second-largest (12%) contributor to the overall probability, followed by imports of cattle from Mexico (4%). Other imports contributed either zero or almost zero to the overall probability of FMD introduction. The reason that Canada and Mexico are the most important contributors to the overall probability of

### Table III

<table>
<thead>
<tr>
<th>Species</th>
<th>Country</th>
<th>Mean no. of live animals imported per year</th>
<th>$P(A_1)$</th>
<th>$P(A_2)$</th>
<th>$P(A_3)$</th>
<th>$P(A_4)$</th>
<th>$P(A_5)$</th>
<th>$P(A_6)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>Canada</td>
<td>1,114,862</td>
<td>0.014</td>
<td>0.945</td>
<td>3.26E-08</td>
<td>0.997</td>
<td>1.000</td>
<td>0.048%</td>
</tr>
<tr>
<td>Cattle</td>
<td>Mexico</td>
<td>1,079,236</td>
<td>0.014</td>
<td>0.945</td>
<td>1.3E-08</td>
<td>0.997</td>
<td>1.000</td>
<td>0.018%</td>
</tr>
<tr>
<td>Cattle</td>
<td>Australia</td>
<td>4,831,576</td>
<td>0.006</td>
<td>0.946</td>
<td>7.91E-09</td>
<td>0.997</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
<tr>
<td>Hogs</td>
<td>Canada</td>
<td>8,063,642</td>
<td>0.014</td>
<td>0.945</td>
<td>3.26E-08</td>
<td>0.997</td>
<td>1.000</td>
<td>0.349%</td>
</tr>
<tr>
<td>Hogs</td>
<td>Austria</td>
<td>9,949,965</td>
<td>0.032</td>
<td>0.945</td>
<td>1.76E-07</td>
<td>0.997</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
<tr>
<td>Hogs</td>
<td>Ireland</td>
<td>238,343</td>
<td>0.014</td>
<td>0.946</td>
<td>6.91E-08</td>
<td>0.997</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
<tr>
<td>Hogs</td>
<td>Sweden</td>
<td>1,031,401</td>
<td>0.019</td>
<td>0.945</td>
<td>2.58E-07</td>
<td>0.997</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
<tr>
<td>Hogs</td>
<td>United Kingdom</td>
<td>27,236,969</td>
<td>0.061</td>
<td>0.945</td>
<td>1.96E-08</td>
<td>0.997</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
<tr>
<td>Sheep</td>
<td>Canada</td>
<td>801,6288</td>
<td>0.014</td>
<td>0.945</td>
<td>3.26E-08</td>
<td>0.993</td>
<td>1.000</td>
<td>0.000%</td>
</tr>
<tr>
<td>Sheep</td>
<td>Mexico</td>
<td>189,737</td>
<td>0.014</td>
<td>0.945</td>
<td>1.3E-08</td>
<td>0.993</td>
<td>1.000</td>
<td>0.000%</td>
</tr>
<tr>
<td>Goats</td>
<td>Australia</td>
<td>86,500,085</td>
<td>0.006</td>
<td>0.946</td>
<td>7.91E-09</td>
<td>0.993</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
<tr>
<td>Goats</td>
<td>New Zealand</td>
<td>108,2485</td>
<td>0</td>
<td>0.945</td>
<td>1.96E-08</td>
<td>0.993</td>
<td>0.010</td>
<td>0.000%</td>
</tr>
</tbody>
</table>

Total = 0.415%

*Rounded values are shown; values used in subsequent calculations employ more decimal places
FMD introduction is because of the amount of trade in animals that occurs in North America. Trade liberalisation that has occurred under NAFTA has increased live animal and product movements between these three countries (4). Live animals that are moved between these countries are not required to pass through quarantine stations. In many instances, animals are exported/imported specifically to go directly to slaughter. So, the probability that imports from these countries will introduce FMD into livestock populations in the USA may be overestimated. However, the number of animals imported from these two countries is large compared to imports from other countries. Thus, even if adjustments were made to the model to reflect an estimate of airborne transmission probability while animals were en route to slaughter plants (presumably a lower transmission risk probability than if such animals joined animal populations in the USA directly), it is likely that these two countries would remain the highest contributors to the overall risk of introducing the disease.

The probability \( P(A_1) \) (i.e. the country-specific probability of having undiagnosed FMD herds) was also an important influence on the overall probability of FMD introduction into the USA (Table III). As expected, the overall probability of FMD introduction generally declines as trading partner countries go for longer periods of time without FMD outbreaks (Fig. 1). It takes more than 70 years for the overall probability of introduction to fall by more than 50% if trading partner countries remain FMD free.

The probability of establishing an effective contact, \( P(A_5) \), was not as important as one might expect. The reason for this is that \( P(A_5) \) depends on whether or not the animals passed through a quarantine station. If animals did pass through a quarantine station, \( P(A_5) \) was small (0.01), but if animals did not pass through a quarantine station, \( P(A_5) \) was relatively large (25). \( P(A_5) \) was large for countries where import numbers were relatively high (Canada and Mexico), and small where import numbers were relatively low (all other import countries). Thus, making \( P(A_5) \) very large for all countries did not much change the overall probability, because of the relative dominance of imported numbers of animals.

The overall probability of FMD introduction changed only by 0.01% as herd size varied from 20 to 5,000. Sensitivity analysis showed total probability exposure changed minimally as herd size was varied (Fig. 2). The number of animals in country \( c \) expected to be infected before detection of an epidemic (\( N_{c} \)) is tiny compared to the population of susceptible animals in country \( c \) (\( N_{c} \)). Therefore, \( \alpha_1 \) is extremely small compared to \( \alpha_2 \), and has almost no impact on the mode of the distribution for \( P(A_3) \). Thus, it is felt that setting the average herd size at 50 was reasonable and had minimal impact on the overall results.

The probability of survival of an animal, thus allowing potential transmission of FMD to another animal, \( P(A_2) \), has some impact on the overall probability. If modelled as suggested by Martínez-López et al. (11), the total probability exposure is 0.419%, equivalent to expecting one FMD outbreak every 239 years. If modelled as suggested by Morley (13), the total probability exposure is 0.391%, or an expectation of one FMD outbreak every 256 years.

**Discussion**

The probability of FMD introduction via imports of livestock to the USA is low. It is hard for people to think about probabilities that have only a 25–30% likelihood of occurring in their lifetimes. It may also be hard for...
governments to justify spending to protect against such low probability events when there are catastrophes of substantial magnitude occurring regularly around the world. However, this is a common issue with respect to risk management efforts directed at low-frequency, high-severity events. (Note, for example, that these other actual catastrophic events, which all essentially compete for attention and for risk management resources with events such as FMD outbreaks, were probably considered highly unlikely a priori. For such risk exposures, mitigation efforts are enhanced, and made more efficient, by analysing the underlying risk factors and their relative importance in contributing to the potential event.)

One consideration for this type of modelling is whether the method of analysis sufficiently models reality to be of value. The most obvious consideration here is perhaps the recognition that time plays an important role in models. Movements of animals take time. Animals from other areas of the European Union (EU) moving into Spain were modelled by Martínez-López et al. (11). For the USA, more time may pass between the moment when an animal is designated to be shipped to the USA and the point at which it arrives, as compared to the time that an animal is designated to be shipped to Spain and the time it arrives. Trade/movement of animals in other areas of the world takes varying amounts of time. Given that this timing is essentially endogenous to the various parameters and assumptions, the model may overestimate the probability of FMD introduction from trade, particularly for countries other than Canada and Mexico. Indeed, if the estimates of P(A5) had been those suggested by the three experts consulted, there would be zero risk of importation of FMD for all animals that pass through quarantine station in the USA. This is, in part, because the time and testing required for animals to clear quarantine decreases the probability that an animal infected with FMD will be released from quarantine. Another issue connected to time is the ever-changing state of FMD around the world, and the changing risk associated with some areas (over time, risks may change in certain regions and countries, but they could remain stable in others). This consideration was beyond the scope of the analyses presented here.

It seems likely that the probabilities of FMD introduction into the USA associated with trade with Canada and Mexico are similar to those probabilities reflected in the EU trade. For example, most outbreaks in the Netherlands originate from countries neighbouring the Netherlands (9). These animal movements generally occur by truck, while imports from countries outside North America can occur by either aeroplane or boat (presumably requiring more time in transport). Still, it would be expected that, as time passes, animals that were incubating FMD and not showing signs of the disease at the time of shipment, would be more likely to show signs of disease, thus leading to an investigation and recognition that FMD is present. There has not been an introduction of FMD into a US quarantine station since the USA eradicated the disease (personal communication, Dr William White, Plum Island, 21 February 2011). If more time passes for shipments to the USA from Canada and Mexico, than typically occurs for animals transported to Spain, then we would expect that there would be an increased probability of recognition of a disease problem when they arrive in the USA. Hopefully, recognising a disease problem upon arrival would result in a response which at least makes immediate containment more likely. However, modelling of the style described here does not have an explicit way to handle this phenomenon.

The probability of an outbreak occurring following the importation of animals from Canada and Mexico may be overestimated. Some of the animals imported into the USA from these two countries originated from the USA, but this is not always the case. Indeed, as an example, Mexico exports 15% of its weaned cattle crop to the USA (15). Additionally, the USA cannot assume that animals spending a portion of their lives in Canada and Mexico and subsequently returned to the USA are without risk. Further refinement of the estimated probabilities which considers the trading partners of countries with which the USA trades is beyond the scope of these analyses.

P(A5) contains a mix of effects. If animals did not need to pass through quarantine stations, no matter the country of origin, it is very likely that import numbers from countries other than Mexico and Canada would increase. Additionally, other countries that are currently not exporting to the USA would likely want to export to the USA. So it is important to recognise that, even though the impact from P(A5) had somewhat of a mixed influence on total probability, it should not be interpreted to mean that quarantine stations and all that they represent, and the ways in which they protect animal populations, are not needed or important.

A number of assumptions are made in this model. Assumptions were similar to those previously outlined (11), with data reflective of importation of live animals into the USA. A model like the one developed and reported here cannot capture all of the complexities of FMD and FMD virus, but it can give a first order approximation of the probability of FMD introduction resulting from the importation of live animals into the USA. It also indicates the areas that are most significant to this probability; such indications are valuable for determining and prioritising future analyses and research.

The authors’ results predict a very low probability of FMD occurring in the USA as a result of live animal introduction. There are strict measures in place to safeguard the USA from such incursions. However, the consequences would be very severe should an outbreak
occur. These consequences are precisely the reasons why controls are in place and why FMD is so feared even though the probability of an event is very low. There is no trade without the risk of importing infectious diseases’ and recent experience shows that the paradigm “free of FMD without vaccination” is not synonymous with “risk-free” (23). The economic impacts of some strategies (vaccination and pre-emptive slaughter) for eradicating FMD in the USA have been estimated (3). A full risk assessment including such economic consequences would be valuable, but beyond the scope of the work reported here. These analyses could, for example, suggest the value of targeted surveillance of farms which regularly import animals from Mexico or Canada. They could also compare the marginal value from using this type of strategy to improvements at quarantine stations and the marginal value for altered exclusion strategies that occur in these locations.

Future research

To understand the overall risk impact of an FMD introduction it is important to consider the consequences of an outbreak. The overall risk impact can be thought of as the probability of the event times the consequences of the event. Considering the overall risk impact of FMD introduction by importation of livestock is valuable, but it requires several additional realistic estimates to be made. The first of these is an estimate of the economic consequences of an FMD outbreak. There are several models and papers that have made such estimates for the USA (6, 7, 18, 19). Second, the amount of money spent on handling the activities associated with importing livestock to the USA must be estimated. Additionally, the value from free trade, because of agreements such as NAFTA, must be estimated and considered. An overall economic risk estimate for FMD is of most value if there is a mechanism to ascertain that portion of foreign animal disease exclusion procedures attributable to FMD. The implications for trade of goods that are related to trade in live animals (e.g. animal feed) are also worthy of consideration but difficult to estimate. These estimates were considered outside the scope of the current analyses and were not attempted.

Conclusions

The probability of introduction of FMD from live animal importation is only 0.415% per year, which is equivalent to one introduction every 241 years. It may be difficult for governments to appropriately allocate funding for such low probability events. Nonetheless, the potential economic consequences of an FMD introduction are quite large. Thus, a full risk assessment which incorporates the economic considerations along with the probabilities associated in these analyses is warranted. This is beyond the scope of the work reported here.

It should be emphasised that parameter uncertainty is a significant issue in this type of analysis. For example, if the true or future values of our parameter $P(A_5)$ were double those documented in this report, the overall probability of FMD introduction would be approximately doubled. The fact that historical FMD frequencies are low is, of course, a good thing, but from a statistical and risk management standpoint, this makes estimating the values of future risk factors a challenge, especially in a world that is becoming ever more complex and interconnected.

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Probabilité d’introduction de la fièvre aphteuse aux États-Unis suite à l’importation d’animaux vivants

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Résumé
La fièvre aphteuse est une maladie grave qui préoccupe aussi bien le Département d’agriculture des États-Unis d’Amérique (USDA) que la filière de l’élevage de ce pays. Aux États-Unis, le virus de la fièvre aphteuse est classé parmi les agents pathogènes ayant de fortes répercussions. Les échanges d’animaux vivants constituent un facteur de risque important d’introduction du virus. L’étude présentée par les auteurs avait pour objet d’évaluer la probabilité d’introduction de la fièvre aphteuse dans le pays associée aux importations légales de bétail. Cette probabilité a été estimée à environ 0,415 % par an, ce qui équivaut à une introduction tous les 241 ans. En outre, l’incidence escomptée d’un certain nombre de paramètres de risque sur le résultat exprimé ci-dessus a été prise en compte, afin d’étayer l’estimation de la portée des techniques de gestion du risque et des dépenses qui y sont consacrées.

Mots-clés

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Probabilidad de introducción de la fiebre aftosa en los Estados Unidos por la importación de animales vivos

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Resumen
La fiebre aftosa sigue siendo motivo de gran preocupación para el Departamento de Agricultura de los Estados Unidos (USDA) y el sector ganadero. El virus causante de la enfermedad es un patógeno considerado “de graves consecuencias” en los Estados Unidos (EE.UU.). El comercio de animales vivos es un importante factor de riesgo de penetración de la fiebre aftosa en un país. Los autores describen una investigación encaminada a estimar la probabilidad de introducción de la fiebre aftosa en los EE.UU. a resultas de la importación legal de ganado bovino. Para ello cifran la probabilidad de introducción desde cada uno de los países que exportan animales vivos a los EE.UU. Calculan así que la probabilidad total de introducción de fiebre aftosa en los EE.UU. a través de ganado importado es de un 0,415% al año, lo que equivale a un caso cada 241 años. Además, a fin de poder evaluar con fundamento la pertinencia de las técnicas y gastos de gestión del riesgo, determinan el grado de sensibilidad de ese resultado a eventuales cambios en las premisas en que se basa la estimación de diversos parámetros relativos al riesgo.

Palabras clave
References


