Risk Classification in Animal Disease Prevention: Who Benefits from Differentiated Policy?

Jarkko K. Niemi[1)], Tapani Lyytikäinen[2)], Leena Sahlström[2)], Terhi Virtanen[2)] and Heikki Lehtonen[1)]

1) MTT Agrifood Research Finland, Economic Research, Luutnantintie 13, FI-00410 Helsinki, Finland e-mail: firstname.lastname@mtt.fi

2) Finnish Food Safety Authority Evira, Risk Assessment Unit, Mustialankatu 3, FI-00790 Helsinki, Finland e-mail: firstname.lastname@evira.fi

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Risk classification of livestock farms can help stakeholders design and implement risk management measures according to the possessed risk. Our goal is to examine how differently pig farms may contribute to the societal costs of an animal disease outbreak, how valuable this information is to different stakeholders, and how it can be used to target risk management measures. We show that the costs of an outbreak starting from a certain farm can be quantified for the entire sector using bio-economic models. In further studies, this quantified risk can be differentiated so that farms and slaughterhouses internalise the full cost of risk in production decisions and inhibit animal densities, animal contact structures or other characteristics which pose a threat to the sector. Potential benefits due to risk classification could be received by society and producers, and in the long run also by consumers.

Key words: Risk classification, animal disease, simulation, partial-equilibrium, losses.

Introduction

Highly contagious animal diseases such as foot and mouth disease (FMD) have the potential to cause devastating damage. Besides costly eradication measures an outbreak can lead to problems in animal production: interruptions in production on uninfected farms and unexpected reductions of animal product exports for an unknown period followed by a drop in product prices in the short run (e.g. Paarlberg et al. 2008;

Schoenbaum and Disney 2003). As costs can be prohibitive, it is important that economic agents take sufficient preventive measures to reduce the potential magnitude of consequences.

Risk classification of livestock farms can help stakeholders to design and implement risk management measures according to the possessed risk. For instance, society can direct surveillance and early warning systems towards high-risk farms and promote measures which reduce the farm's risk to spread or receive a disease. Besides regulations, society can use economic incentives to urge high-risk producers to apply stringent biosecurity measures (c.f. Hennessy 2007a; Gramig, Horan, and Wolf 2009). Policies can be designed so that farms are liable for outbreak costs in proportion to the risk which they are predicted to pose to society. When doing so, policies can alter production decisions so that production would not be excessively concentrated in high-risk areas (cf. Jansson, Norell, and Rabinowicz 2005). This is due to the fact that producers can take true costs into account in production decisions and hence production is decreased if a farm is benefiting from a non-differentiated policy.

Regional herd density and animal transports are known to be critical determinants for outbreak size and disease spread. However, focusing only on infected premises can result in suboptimal policy, because consequential effects of disease can be decisive for the choice of an economic disease policy. This article contributes an extension to previously presented epidemiological risk classification (Lyytikäinen and Kallio 2008) by presenting an approach which can quantify economic effects of farm-related risk. We aim to quantify differences in risk to the extent that these differences are caused by variation between farms in their characteristics such as regional herd density and contact patterns affecting the magnitude of an outbreak. In developed approach, farms are divided into four epidemiological risk categories and direct and indirect economic effects of disease risk posed to public funds, producers and consumers, including the effects of trade distortions, are estimated for each farm and risk class. We show that the costs of an outbreak starting from a certain farm can be calculated for the entire sector by the joint use of epidemiological and economic models. In further studies, this quantified risk can be differentiated so that farms and slaughterhouses internalise the full cost of risk in production decisions and inhibit animal densities and animal contact structures which pose a threat to the sector. Finally, we contribute to the discussion about the role of economic incentives in animal disease risk management.

Our goal is to analyze how differently pig farms may contribute to societal costs of an animal disease outbreak, how valuable this information is to different stakeholders, and how it can be used to target risk management measures. For clarity, we focus on a single disease, FMD, but limit our analysis solely on the pig sector. The effects are simulated conditional on the first infected farm by using numerical dynamic epidemiological and economic models. This approach allows us to study how a certain farm contributes to disease losses, including consequential effects due to disease spread and export distortions, when it is the first farm which becomes infected in the country. Classification uses data linked to risk factors which are of primary concern for the government when it aims at mitigating disease. Finally, an analysis is made of the type of welfare effects which farms belonging to certain risk class can cause.

Model

The spread of FMD among pig farms in Finland was simulated using an epidemiological Monte Carlo simulation model which produced the number of infected farms at the end of each outbreak, the duration of the outbreak and the identity of infected farms. These data are further used in related economic models (figure 1). The analysis explored the influences within the pig sector whereas possible other routes and spreading by other production sectors were ignored. The model is described in more detail by Lyytikäinen and Kallio (2008). The developed model resembles simulation models which have been previously used to study the FMD control policies (e.g. Harvey et al. 2007; Mourits, Nielen, and Léon 2002; Sanson 1993; Velthuis and Mourits 2007). These models use the concept of transmission probabilities and contacts to estimate the number of infections.

Economic effects of an outbreak were estimated with a partial-equilibrium stochastic dynamic programming model which has been previously presented by Niemi and Lehtonen (2008). The model maximised the value of pig production to the society. It solved demand, supply and market clearing price for each month endogenously. Demand for pigmeat was stratified into domestic demand, two separate export markets and import demand. Besides impacts on animal stock, an outbreak was assumed to reduce export demand for pigmeat and meat intended for export markets to be consumed domestically. The analysis took into account that prices and production were adjusted when export distortions with unknown duration occurred. In each time period, the market was either in state 1) 'an outbreak with a full trade ban', or in state 2) 'no outbreak, no trade ban'.

Disease losses were calculated as the difference in the simulated value of the pig production sector between these two market states. When the time elapsed, the state of market was able to switch between these two alternatives and decisions could be updated according to the observed state of nature. Other variables characterising the state of market were the numbers of pigs in stock.

Epidemiological model

In the epidemiological model, disease transmission can occur when the susceptible farm receives at least one infective contact. Five different categories and probabilities of a contaminated contact to result in an infection were included in the model. These were 1) the receiving of live pigs (a high-risk contact), 2) a visit by a livestock transportation vehicle, 3) a person visiting animal holdings (a medium-risk contact), 4) a person visiting at the farm (a low-risk contact), and 5) having an infected farm within a 1.5 km or a 1.5 to 3.0 km radius of the farm. The last contact type is often referred to as the neighbourhood transmission, where the vector of spread is unknown and disease spread is associated to the herd density in the region.

In contrast with some previous models, the applied model employed event-based information as to the frequency of potential contacts and potential targets of contacts in time and space. The model used an actual animal registry database in order to characterise spatial and temporal patterns of animal transportation events including animal transports between farms and between farm and slaughterhouse. The registry provided data also for indentifying farms which were visited by certain animal transportation vehicle during the same day, but the order of the visits was unknown. Other personal contacts were constructed by two-mode networks connected by a separate factor, where the temporal component is described as Poisson process.

The epidemiological simulation started from a situation where one randomly selected farm had become infected with the disease but no other farm in the country was infected and ended when all infected farms were detected and disinfected. Each infected farm could induce further infections. Each farm’s infective period began 7 and ended 28 days after it became infected. Approximately 278 iterations per primary infected farm, 0.9 million iterations in total, were performed.

The first detection took place on the primary farm whereas other farms could be detected by producer, contact tracing or clinical and/or serological screening measures, which are taken in a 3 km protection zone and in a surveillance zone with a 3 to 10 km radius around each infected farm according to European Union (EU) legislation (European Council 2003). Once detected, pigs kept on an infected farm were culled and premises are cleaned and disinfected under the same Directive. The probability of disease spread decreased after detection because in the established restriction zones, the contacts were limited, the producers were obliged to inform the officials of any signs of disease, and farms located in the restriction zones were visited by a screening team. Contact farms outside the restriction zones could also face restriction measures.

Classification of farms

Farms were classified into four risk classes using an iterative K-means clustering method as applied by Lyytikäinen and Kallio (2008). The risk classification was based on the simulated results regarding 1) the probability of further spread from each primary farm, 2) the mean, and 3) the maximum number of subsequently infected farms during an epidemic, and 4) the duration of the epidemic. These variables were log-transformed and standardised with respect to their standard deviation before clustering.

Partial-equilibrium model

In this model, the social planner maximises the Bellman equation:

(1)
$$\begin{aligned} V_t\,(\mathbf{x_t}) = \max_{\{\mathbf{u_t}\}}\{ & \int_{\mathrm{q}}^{D_t^{\mathrm{dom}}} P_t^{\mathrm{dom}}(Q_t^{\mathrm{dom}}, \mathbf{x_t}, \mathbf{u_t})dQ_t^{\mathrm{dom}} + \int_{\mathrm{q}}^{D_t^{\mathrm{imp}}} P_t^{\mathrm{imp}}(Q_t^{\mathrm{imp}}, \mathbf{x_t}, \mathbf{u_t})dQ_t^{\mathrm{imp}} \\ & + P_t^{\mathrm{EU}}(Q_t^{\mathrm{EU}}, \mathbf{x_t}, \mathbf{u_t})Q_t^{\mathrm{EU}} + P_t^{\mathrm{row}}(Q_t^{\mathrm{row}}, \mathbf{x_t}, \mathbf{u_t})Q_t^{\mathrm{row}} \\ & - C_t\,(\mathbf{x_t}, \mathbf{u_t}) + \beta\, E(V_{t+1}(\mathbf{x_{t+1}}))\} \end{aligned},$$

where t=0,…,T, $\mathbf{x_t} = \{x_t^{\mathrm{sow}}, x_t^{\mathrm{pig}}, x_t^{\mathrm{trade\ ban}}\}$ and $\mathbf{u_t} = \{u_t^{\mathrm{serve}}, u_t^{\mathrm{weight}}\}$,

s.t. $x_{t+6}^{\mathrm{sow}} = x_t^{\mathrm{sow}}(1-r) + u_t^{\mathrm{serve}} - \delta(x_t^{\mathrm{sow}})$ (sow stock dynamics),

$x_{t+6}^{\mathrm{pig}} = x_t^{\mathrm{sow}}\, y^{\mathrm{pig}} - \delta(x_t^{\mathrm{pig}})$ (young animal stock),

$x_{t+1}^{\mathrm{trade\ ban}} = \Pr(x_t^{\mathrm{trade\ ban}})$ (trade ban imposed / not imposed),

x_t^{sow}, x_t^{pig}, x_t^{ban} and $V_T(\mathbf{x_T})$ are given, where $V_t(\mathbf{x_t})$ is the maximised net present value of domestic pigmeat market (i.e. consumer surplus plus producer profits); t is the time index measured in months; $\mathbf{x_t}$ is the vector of state variables; $\mathbf{u_t}$ is the decision rule; $P_t^{\text{dom}}(Q_t^{\text{dom}},\mathbf{x_t},\mathbf{u_t})$ is the inverse demand function for domestic demand which is used when integrating the area from q to market allocation D_t^{dom} below the demand curve; $P_t^{\text{imp}}(Q_t^{\text{imp}},\mathbf{x_t},\mathbf{u_t})$ is the inverse demand function for import demand which is used when integrating the area from q to market allocation D_t^{imp} below the demand curve minus purchase cost of imported meat; $P_t^{\text{EU}}(Q_t^{\text{EU}},\mathbf{x_t},\mathbf{u_t})$ is the export price at the EU market as a function of the state and control variables and quantity Q_t^{EU} exported to the EU market; $P_t^{\text{row}}(Q_t^{\text{row}},\mathbf{x_t},\mathbf{u_t})$ is the export price at the non-EU market as a function of the state and control variables and quantity Q_t^{row} exported to the market outside the EU; $C_t(\mathbf{x_t},\mathbf{u_t})$ characterises production costs incurred at period t; β is the discount factor; $E(\bullet)$ is the expectations operator; $V_{t+1}(\mathbf{x_{t+1}})$ is the value of sector in the next period; $x_t^{\text{trade ban}}$ is the state variable characterising whether export market are closed at period t; x_t^{sow} is the number of sows which farrowed at period t; x_t^{pig} is the number of pigs which are allocated to reproduction or slaughtered at period t and which depends on the past number of sows; the functions $\delta(x_t^{\text{pig}})$ and $\delta(x_t^{\text{sow}})$ indicate how the epidemic affects the number of pigs and sows on farms; u_t^{serve} is the control variable characterising the number of pigs currently allocated to reproduction; u_t^{weight} is the decision variable characterising slaughter weight per hog; r

is the share of sows removed from the stock each period; y^{pig} is the effective piglet yield per sow; $\Pr(x_t^{\text{trade ban}})$ characterises the probability of a trade ban occurring in the next period as a function of the current period trade ban status; and $V_T(\mathbf{x_T})$ is the value function at the terminal period *t=T.* The time horizon was set large enough so that the choice of *T* did not affect results.

The supply of pigmeat was determined by the decision vector and the disease:

$$(2)\ S_t(\mathbf{x_t},\mathbf{u_t}) = (x_t^{\text{pig}} - u_t^{\text{serve}} - \delta(x_t^{\text{pig}}))u_t^{\text{weight}} + x_t^{\text{sow}} r y^{\text{sow}} - r\delta(x_t^{\text{sow}}),$$

where $S_t(\mathbf{x_t},\mathbf{u_t})$ is the aggregate quantity of domestic pigmeat supplied to markets, y^{sow} is carcass weight of a sow and the other variables are as defined above. Production adjustments in the short run were limited, because it takes time to grow pigs and it is costly for a producer to remove animals prematurely.

The quantity of domestic pigmeat sold at different markets was set equal to the production of pigmeat in the same period whereas imported meat was considered an imperfect substitute for domestic meat. Hence, domestic meat prices adjusted and markets cleared each month and also in the event of a trade distortion. Inverse demand functions used to derive the market clearing price were based on four equations. These equations represented domestic demand D_t^{dom}, export demand to EU countries D_t^{EU} and non-EU countries D_t^{row}, and import demand D_t^{imp}:

(3) $D_t^{\mathrm{i}} = f^{\mathrm{i}}(p_t^{\mathrm{i}}, \mathbf{z}_t^{\mathrm{i}}),$ for i={dom, EU, row, imp},

where superscript i indicates respective market equation, p_t^{i} is the price of pigmeat demanded at market i, $\mathbf{z}_t^{\mathrm{i}}$ is a vector of predetermined variables such as substitute prices, pigmeat prices in major import sources and seasonal and event-specific demand shifters (dummy variables) which were held constant in the present analysis.

Due to biological constraints and marketing contracts between retailing and meat processing, supply, demand and prices are quite inelastic in the very short run. If meat deliveries to retail chains are agreed some months ahead of time, then large price changes in the short term are mitigated by contracts. This aspect was taken into account in the model as a factor limiting price changes in the very short run.

Although an outbreak was deemed quite short, trade distortions were able to last several months and their duration was unknown. The probability that the trade distortions are imposed in the period *t*+1 was modelled as a Poisson process which suits the logic of dynamic programming (cf. Dixit and Pindyck 1994, pp. 85-87):

$$(4)\ \Pr(x_t^{\text{trade ban}}) = \begin{cases} 1 - 1/(d-m) & \text{if trade ban is imposed and minimum duration exceeded} \\ 1 & \text{if trade ban is imposed and minimum duration not exceeded} \\ 1/\lambda & \text{if trade ban is not imposed,} \end{cases}$$

where *d* is the expected duration (months) of trade distortions, *m* is the minimum duration of the trade distortions and λ is the duration of period (months) that the country is expected to stay disease-free when there is neither disease nor a trade ban imposed at the moment. The minimum duration was associated to the hypothesis that trade restrictions can be lifted after the disease has been eradicated from the country. Based on the World Organisation for Animal Health recommendations (OIE 2007), it was assumed that they are lifted on average 3 months after the cleaning, disinfection and screening measures in the lastly detected farm have been completed. λ was zero in the present analysis.

Market parameter values

The model was parametrised and calibrated for the year 2006. Elasticity estimates were the key variables in the demand system, because prices and quantities in the demand equations were used in the logarithmic transformation. The following elasticity estimates with respect to Finnish pigmeat price (+processor's margin in export equations) were applied: -0.14 for domestic demand, 0.87 for import demand, and -0.51 for export demand to non-EU and -0.97 for export demand to EU destinations. Piglet production costs were obtained from ProAgria[1]. The costs of hog productions were simulated using the Finnish feeding recommendations and a growth model by Niemi (2006).

Direct costs of disease eradication

Official measures were implemented along the basic requirement defined by EU regulations (European Council 2003). The material resources for each task were estimated according to the terms of reference for veterinary officers with regard to a FMD outbreak in Finland. Labour requirements for which expenditures are paid out of public funds were estimated mainly by using data provided by Risk Solutions (2005) for the United Kingdom. Unit prices for each resource were collected from official statistics or requested from officials and firms capable of executing measures. The following costs were used to calculate direct costs: €286 586 per infected farm + €6 029 per uninfected farm in the protection zone + €467 per uninfected farm in the surveillance zone + €258 per culled hog + €827 per culled sow (including costs related to piglets). These figures excluded compensations paid to producers.

Results

The probability of an epidemic outbreak increased with the risk class. While in class 1 the disease spread from the primary farm only in 19% iterations, in class 4 it spread in 94% iterations. Moreover, the number of infected farms and the duration of an outbreak also increased with the risk class (table 1). The number of farms as well as the number of pigs located in infected farms, protection and surveillance zones were simulated to increase when the risk class was raised from class 1 to class 4.

Estimated losses and their variation according to risk measure of a farm

An outbreak was simulated to incur on average €21.1 (standard deviation €2.9 million) million per outbreak in incidental losses to society. Producers and public funds suffered losses whereas consumers were able to gain from an outbreak (table 2). However, estimates were not normally distributed (see figure 2). There was quite a little overlap between loss distributions simulated for risk classes 1 and 4, whereas distributions of intermediate classes overlapped with those of other classes.

Average total losses (including producers, consumers, public funds and other stakeholders) simulated for different risk classes were less than 10% of the market value of annual pigmeat production. The losses were mainly caused by simulated decrease in the pigmeat price which was due to export distortions. Trade losses were related to the duration and the size-measures of an outbreak. However, even a very small and short outbreak was able to incur more than €17 million in losses to society. Price reductions were not necessarily larger in outbreaks associated to risk class 4 farms than in outbreaks associated to risk class 1 farms, but export distortions were projected to last longer in class 4 than in class 1.

Economic welfare losses and gains increased when a severe outbreak was considered instead of an average outbreak. The severity of an outbreak was defined by using size measures in table 1. It was defined for each farm as an average-sized outbreak caused by that farm plus three times the standard deviation simulated for each item measured in table 1. In the event of a severe outbreak, consumers gained on average €2.5 million more per outbreak than in the average outcome, whereas producers lost 15.4, public funds €3.5 and society in total €16.4 million more per outbreak than in the average outcome.

There was a pattern in how the risk class affected stakeholders. In an average outbreak, farms belonging to risk classes 1 and 2 (3 and 4) caused less (more) incidental losses to producers, public funds and society in total than the average of all farms. On the contrary consumers gained less (more) due to incidental trade restrictions when an outbreak began from class 1 or 2 (3 or 4) farm than when the average of all farms was counted.

Class 1 farms (low-risk farms) and class 4 farms (very high-risk farms) represented the extreme results. Expected societal welfare losses simulated for farms belonging to risk class 4 were €8.0 million (45%) higher than those simulated for farms belonging to risk class 1. Risk class 4 farms incurred on average 22% higher incidental welfare losses to producers and 20% higher incidental gains to consumers than farms belonging to risk class 1. The largest, 18-fold, relative increase was simulated for public fund expenditures.

When epidemics became larger than the expected size of an outbreak, differences in euro per outbreak loss between risk classes increased. For instance, a severe outbreak beginning from a farm belonging to risk class 4 was able to incur 134% higher incidental losses to society than a severe outbreak beginning from a farm belonging to risk class 1.

Although losses per primary infected farm were larger in risk class 4 than in risk class 1 (table 2), societal losses per animal kept in the primary infected farm could be smaller when the farm belonged to risk class 4 than when it belonged to risk class 1. This result was observed in the event of both an average and a severe outbreak. However, expenditures of public funds per animal could be larger in risk class 4 than in risk class 1. These results were due to the fact that the primary infected farm in class 4 had on average 3.5 times more hogs and 8.0 times more sows than an average primary farm in class 1. As very high-risk farms (class 4) were on average larger than low-risk farms (class 1), they may have economies of scale in disease prevention.

An increase in the probability of a further spread of the disease or in the expected number of infected farms contributed to the farm's probability to belong to risk class 4. The probability of a further disease spread from the primary infected farm was associated to the number of contacts leaving the farm within a certain time period. Moreover, it was directly linked to farm density in the region. However, disease spread appeared to be an inadequate statistics when forecasting disease losses, because the number of further infected farms also affected losses (cf. figure 3). Although figure 3 suggests that the relationship between the probability of a further spread and welfare effects could be non-linear, a linear model with two mutually correlated variables, i.e. the probability of further spread and expected outbreak size, already explained welfare effects of an outbreak quite well (R^2>80%). The relationship between these variables and welfare effects to consumers and producers was nonlinear. The explanatory power of the model was significantly reduced when the expected size of an outbreak was eliminated from the model.

The effects of a liability cost imposed to the sector

Estimated economic losses can be allocated to the sector. Besides losses per outbreak, the cost that a sector can be liable is affected by the probability of an occurrence of disease.

Next we illustrate how an increase in the liability costs internalised by the sector was able to affect welfare in the long run, when the country is disease-free. As a partial result, we examined a flat-rate cost to entire production volume. Our model suggested that when the average cost of liability increased (*ceteris paribus*) by €10 per tonne of pigmeat produced, society lost on average €0.7 million per year and equilibrium production decreased by approximately 0.2%. The larger fee, the more production decreased and the larger were losses. The effects were nonlinear and the losses were suffered by consumers. The result was due to the fact that producers could ask a higher price for pigmeat when the cost of risk increased. Due to different time scope, this result did not conflict with the result that consumers were able to incidentally gain if an outbreak occurs.

Besides the effort put on preventive measures and funding outbreak losses, the model can examine discrete events such that liability is imposed only when an outbreak occurs.

Discussion and conclusions

Results suggest that outbreak costs depend heavily on market effects of the disease. Market effects further depend on export distortions and their duration, price elasticity of demand and volume of production affected by restrictive measures. The role of market effects is in line with previous studies on highly contagious animal diseases (e.g. Mangen and Burrell 2003; Paarlberg et al. 2008; Schoenbaum and Disney 2003). Another major factor affecting disease losses is the probability of disease introduction into the country. This factor was not examined in here.

The results highlight the value of being able to identify farms according to their risk in contrast to solely estimating average results. Variation in losses between farms is considerable. For instance, the most risky farm was expected to incur producer losses worth over half the annual operating margin of the sector whereas average losses in four risk classes were 35% to 43% of the annual operating margin. Moreover, classification criteria can be complex. Lyytikäinen and Kallio (2008) show that even if differences in the average farm size between risk classes may exists, farm size is not a particularly good indicator for the risk of spread of posed by a farm.

The quantification of differences in risk between farms requires that the risk is analysed explicitly in both epidemiological and economic models. Models applied here focused only on pig production. This may affect the consequences of a simulated outbreak. Because the present simulation of a spread of FMD exclude ruminants, the results presented here should be considered as an illustration of possible differences between farms (but not their absolute scale). If the spread within the pig production sector would be amplified by the other production sectors affected by the disease, the differences between the primary infected farms could be even larger than presented here. Nevertheless, the results show that there is a pattern between the probability of disease spread, outbreak magnitude and welfare effects in the sector, and that differences between farms in these items can be quantified.

Results suggest that it can be rational to consider the targeting of surveillance systems and other risk management measures according to the risk category. If risk management is stratified according to the risk posed by a farm, a high-risk farm could be required to ensure higher than average effort for disease costs, because society could benefit from the reduction of risk class. Farms which are able to spread disease rapidly can increase outbreak expenditures of public funds considerably. If an outbreak occurs, reduced trade distortions in the low-risk case would benefit also producers as a group, whereas consumers might not benefit as much from excess supply during an outbreak. Differences between risk classes even increase when the worst-case outcome for each farm is analysed, which highlights the targeting of preventive efforts into high-risk farms. Measures to reduce the risk level of high-risk farms could be related to issues such as the intensity of surveillance, adjustments in the frequency or the routing of animal transports from the farm or the introduction of more stringent bio-security practices.

Low-risk farms, consumers and society can be able to accrue further benefits over time when differentiated liability decreases outbreak costs and re-allocates production to farms with reduced costs (cf. Jansson, Norell, and Rabinowicz 2005). Information about the risk posed by a certain farm is particularly valuable to low-risk farms. They could use information about their low expected outbreak costs in order to reduce their production costs, such as to justify certain preventive measures or reduced insurance fees per farm.

Ultimately, consumers and society as a whole can benefit if differentiated measures are able to decrease the overall risk-rated unit production cost of pigmeat efficiently.

If the elevated liability cost would be imposed on high-risk farms, it could reduce their profits and production. However, farms do not belong to the most risky class only because of their own actions but also because of actions taken by other stakeholders, including their slaughterhouse, animal trading partners and other farms located in the vicinity. This highlights the production chain as an entity and suggests that increased costs could be shared between contributors of the risk.

The rationale behind differentiating liability is to motivate high-risk farms and other stakeholders which influence their risk to take measures which would reduce their risk exposure. However, differentiation can result in a moral hazard problem, an adverse selection problem, and discussion on moral or legal justification of the policy. Proper analysis on incentive mechanisms therefore requires a decentralised setting such as the one of Gramig, Horan and Wolf (2009) or Hennessy (2007b). The principal-agent approach where stakeholders can choose from risk level-related compensation options is useful as far as an agent can endogenously adjust the risk. On top of that, appropriately targeted (public) measures are valuable to producers who are unable to reduce their risk.

In conclusion, further research based on risk classification offers opportunities to design more cost-efficient preventive measures to combat contagious animal diseases. In particular, it can increase stakeholder engagement in disease prevention by providing more detailed economic criteria to stratify preventive efforts and economic bonuses or fees according to the risk exposure factors.

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[1] Production cost calculations for agricultural products obtained from ProAgria Association of Rural Advisory Centres are in Finnish and available at: http://www.agronet.fi/cgi-bin/mkl/julk/malli.cgi

Table 1. Epidemiological outcomes of simulated outbreaks on average in each four risk class and in all farms on average

Risk class	1	2	3	4	All
Probability of an epidemic	0.19	0.49	0.80	0.94	0.66
Expected number of infected farms[1)]	0.36	1.43	3.34	7.33	3.12
Number of farms in the risk class	340	1,093	1,196	598	3,227
Expected duration of an outbreak	32	35	40	45	38
Number of sows in the primary farm	15	29	59	119	55
Number of hogs in the primary farm	117	224	306	404	276
Total number of hogs in infected farms	29	100	241	554	229
Total number of sows in infected farms	221	756	1,684	3,773	1,602
Number of farms in protection zone	1	4	11	24	10
Number of sows in protection zone	47	237	629	1 418	581
Number of hogs in protection zone	264	1,422	3,835	9,026	3,602
Number of farms in surveillance zone	10	27	52	93	47
Number of sows in surveillance zone	520	1,571	3,237	5,926	2,884
Number of hogs in surveillance zone	2,892	8,618	17,730	31,617	15,649

1) In addition to primary infected farm

Table 2. Simulated welfare effects (€ million per average outbreak and € million per severe outbreak) caused by a disease outbreak to Finnish pig producers, consumers, public funds and society in total, and segregated according to the risk class of the primary infected farm and on average in all pig farms

a) Welfare effects associated to a specific farm in an average outbreak

Risk class	Consumers	Producers	Public funds	Society in total
1	5.6	-23.2	-0.2	-17.8
2	6.0	-24.4	-0.8	-19.2
3	6.4	-26.1	-1.9	-21.5
4	6.8	-28.4	-4.2	-25.8
No classification	6.3	-25.6	-1.8	-21.1

b) Welfare effects associated to a specific farm in a severe outbreak[1)]

Risk class	Consumers	Producers	Public funds	Society in total
1	7.5	-29.2	-1.5	-23.2
2	8.5	-35.9	-3.4	-30.8
3	9.1	-43.0	-5.6	-39.5
4	9.1	-53.2	-10.1	-54.2
No classification	8.7	-41.0	-5.3	-37.5

1) Severe outbreak is defined as an outbreak having magnitude mean outbreak + three standard deviations in terms of the number of infected farms, the number of uninfected farms and animals, and outbreak duration.

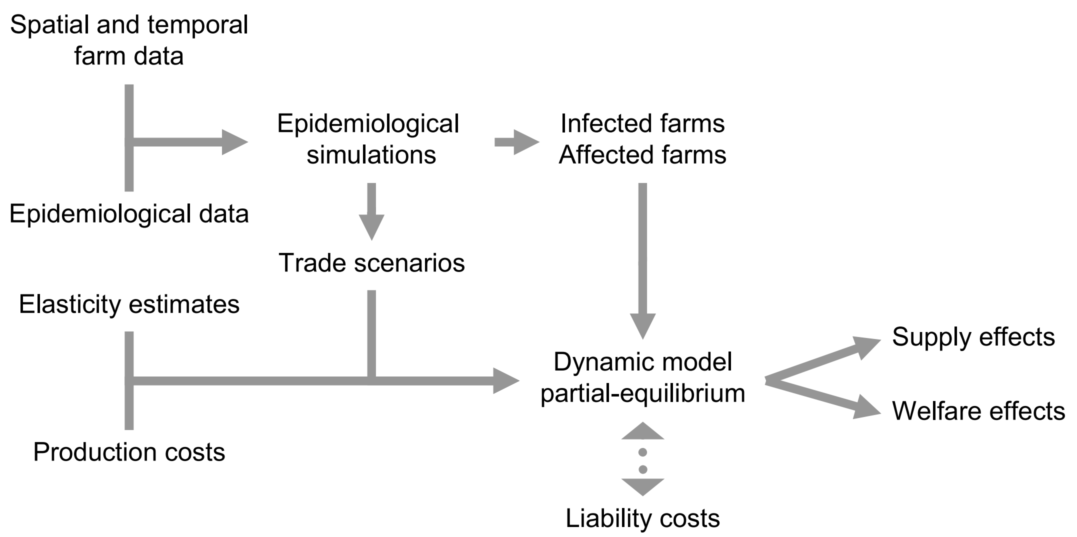

Figure 1. Links between main data sources, epidemiological and economic models applied in this study, liability costs and welfare and supply effects on an outbreak

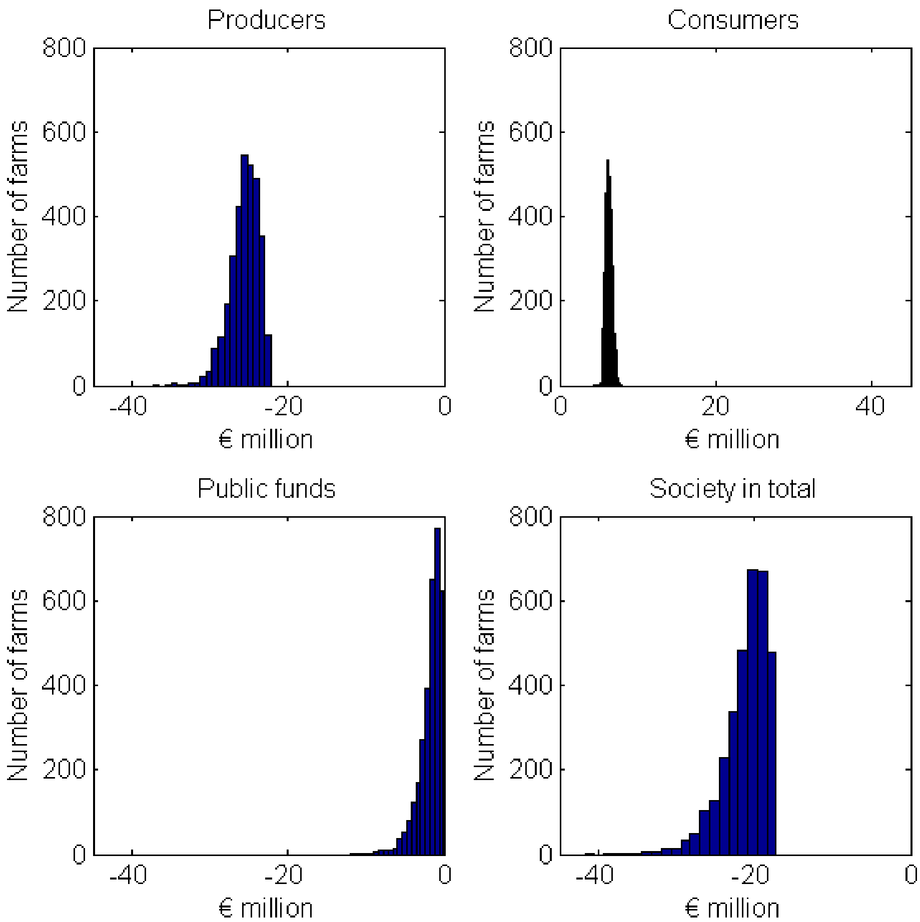

Figure 2. The distribution of simulated welfare effects which an average-sized outbreak initiating from a certain farm (an average-sized outbreak according to that farm) is expected to incur to producers, consumers, public funds and society in total: note the differences in the horizontal axis

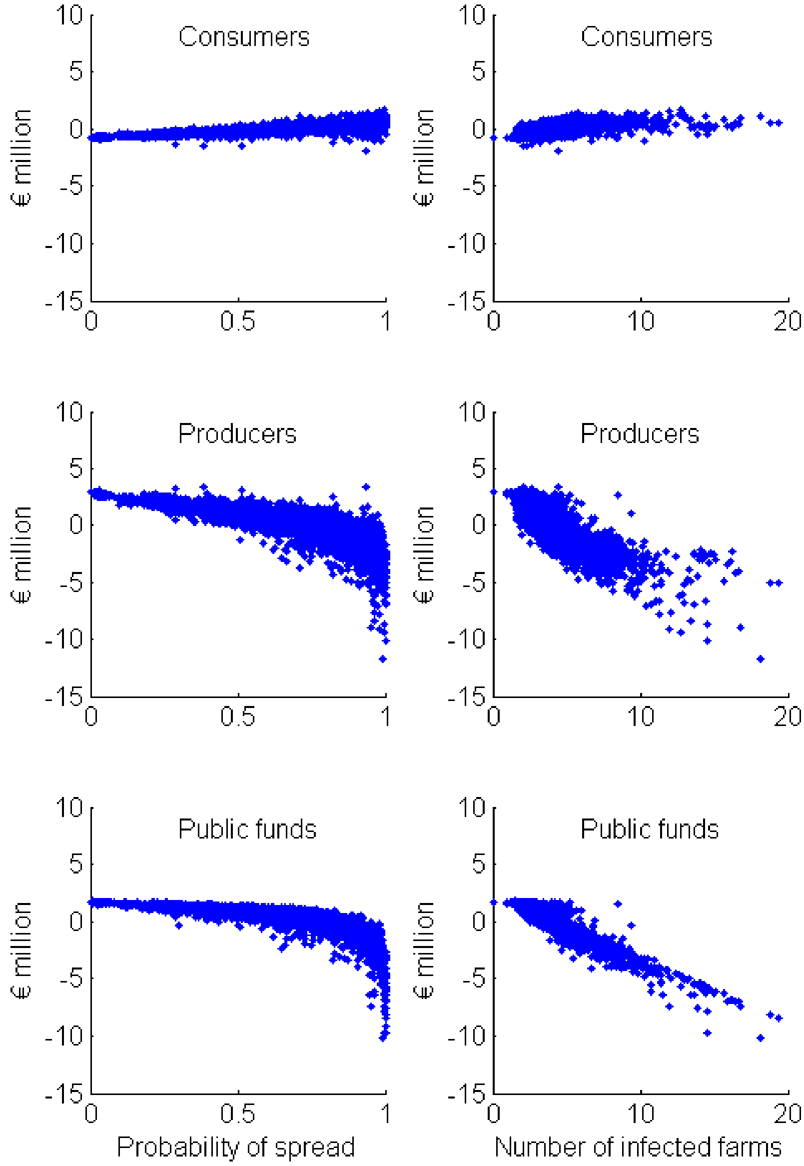

Figure 3. Differences 'expected welfare effects to consumers, producers and public funds (€ million per outbreak) simulated for an outbreak beginning from a certain primary infected farm (dot=one farm)' minus welfare effects simulated on average for all farms and presented in relation to the probability of further spread and the number of infected farms associated to the primary infected farm