The value of market uncertainty in a livestock epidemic

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Abstract

Introduction of foot and mouth disease (FMD) into country typically initiates eradication procedures removing animals from the market, and halts the export of livestock products from the infected country. The magnitude of these effects can be highly uncertain. This paper presents a stochastic dynamic programming model which simulates possible market implications of alternative FMD and export scenarios in the Finnish pig sector. It takes into account dynamics and adjustment of the animal stock, price movements and uncertainty related to the duration of the trade ban. Results suggest that losses to pig producers can increase considerably when the risk of prolonged export ban increases. Production adjustments also strengthen. Consumers can gain from a trade ban, because options to adjust supply in the short run are limited.

Key words: Livestock epidemics, dynamic programming, demand, supply, export

Introduction

It is one of the vital tasks of society to secure food supply. This requires that risk and economic losses caused by different types of hazards are under control. Studies show that events related to animal diseases can cause heavy losses to individual producers and society (e.g. Franks et al. 2001; Thompson et al. 2002; Mangen and Burrell 2003; Schoenbaum and Disney 2003; Bennett and Ijpelaar 2005; Neumann et al. 2005). Highly contagious animal diseases such as avian influenza, foot and mouth disease or classical swine fever can have particularly devastating economic impact on food production in the affected country. Due to their threat to animals, human health and/or livestock production, World Organization for Animal Health (OIE) puts special emphasis on preventing these diseases from spreading, and governments often control combating highly contagious animal diseases. Policy in the European Union (EU) includes measures such as the culling of all susceptible livestock at infected premises, disinfection measures, restrictions on animal movements, possibly the culling of uninfected herds at infection risk, and compensations paid for agricultural producers due to their losses (e.g. European Commission 2001, European Commission 2003).

An outbreak of a highly contagious animal disease typically affects livestock market by removing animals from the market and reducing export demand for animal products unexpectedly. The trade effect is due to the fact that importing countries can prohibit imports of livestock and livestock products from the infected country or region. Foreign trade thus becomes one-sided: infected region can import livestock products but not export them (hereafter called as the trade ban). Producers in export-oriented countries can be hit particularly badly, if they face excess supply and suffer from plummeting producer prices. Ekboir et al. (2002) also point out that if exports are allowed, disease status of an exporting country affects export prices of pig meat because markets are segmented according to country's disease status.

When planning disease policy, it is important to take into account that economic agents can minimise losses due to an epidemic by adjusting production and consumption decisions. Adjustments can sometimes, however, result in undesirable behaviour which flaws disease policy. Stakeholders therefore need information on how an epidemic affects market, food supply and demand.

This paper examines the adjustment of pig production to an animal disease epidemic. We raise two major aspects regarding the adjustment. Firstly, even if the characteristics of an epidemic depend on the structure of farming, agricultural producers face a great uncertainty about the number of animals removed from market and the duration of export distortions. It is important to take this uncertainty into account in the adjustment process. Previous studies modelling the pig sector (e.g. Mangen and Burrell 2003; Niemi et al. 2008) have paid attention to the fact that epidemic duration is stochastic. According to our knowledge, less attention is paid to how uncertainty affects market when it is explicitly taken into account in production decisions. Mahul and Gohin (1999) have illustrated that uncertainty related to disease spread affects the choice of disease control policy. We provide an example on modelling market dynamics when trade ban duration is stochastic. It illustrates how the pattern of production adjustment depends on the expected duration of epidemic. In particular, it matters whether disease shock extends to two or more production cycles. This may have significant impact on production in an export-oriented country.

Secondly, livestock production is inelastic in the short run. When an outbreak occurs, producers are unable to quickly increase aggregate production because it takes time to produce reproduction animals or to raise fattening animals. Even if producers are able to decrease production in the short run e.g. by culling animals prematurely, it may be costly for an individual producer to reduce yield levels or the number of animals in stock unless policy or market explicitly provide incentives for such behaviour. This is an important issue from the modelling point of view, because models of agricultural economics typically operate at annual level where production is fully adjusted according to the market, whereas production dynamics imply that producers have limited options to adjust production in the very short run.

This paper contributes to the discussion about the role of economic incentives in animal disease risk management. It also contributes by illustrating modelling and policy issues which are ignored in animal disease analysis, but which are important for estimating and mitigating losses caused by animal disease epidemics. Our goal is to simulate market losses caused by a FMD outbreak to pig production sector and consumers in Finland. The production volume of modelled sector is around 210 million kg pig meat per year, of which about 20% is exported. Beef and milk are excluded from the analysis for simplicity. The decline of beef prices and subsequent impact on pig meat prices due to FMD is assumed to be modest in Finland since beef exports are few compared to imports. The analysis is carried out with a recursive dynamic programming (Bellman 1957) model. It optimises the supply of pigs by taking into account the best interest of producers and consumers in Finland, and price movements induced by the epidemic and the trade ban. Epidemiological scenarios are based on a separate epidemiological study (Lyytikäinen and Kallio 2008).

Model

Dynamics of disease and market

The dynamic programming model maximises the value of Finnish pig market and simulates market implications of an epidemic. It takes into account both uncertainty related to the future of the epidemic (figure 1) and biological dynamics of pig production (figure 2). At each time period the state of market is characterized with one of two alternatives: {trade ban, no trade ban}. Epidemic in this paper refers to the hypothetical scenario that FMD would have been observed[1] in Finland and the trade ban is assumed as a direct consequence of it. The trade ban is imposed by importing countries and it can last longer than the epidemic. OIE (2007) recommendations already suggest the trade ban to be removed 3 months after the disease has been eradicated from a country free from FMD without vaccination.

Losses due to disease epidemic are obtained as difference in the value of pig production sector when market are at the state "trade ban" rather than being at the state "no trade ban". As figure 1 illustrates, when starting from a given state of nature at period t, the subsequent period $t+1$ market can enter either of two alternatives with probability associated to the current epidemiological state. Thus, decisions made at market can be updated according to the state observed when time passes from period t to period $t+1$. Since sow farrows approximately every sixth month, decisions made currently are linked to time period which is six months from now and decisions or states between these periods are assumed to separate.

The model simulates demand, supply and market clearing price at pig meat market using monthly steps and thus taking into account biological constraints (figure 2). Representative agent's objective is to maximise the market value of pig production minus production costs plus consumer surplus. "Consumer" here includes meat processing, retail and final consumers. The model is solved numerically and it produces socially optimal production pattern by allocating piglets to reproduction or

[1] Finland is free from FMD. The disease was last observed in Finland in 1959.

fattening and by adjusting slaughter weights. It also takes into account the number of sows, weaners and hogs currently kept in Finland, biological dynamics of production process, and the impact of export distortions. Due to biological constraints and long-term marketing contracts between retailing and meat processing, supply, demand and prices are in fact quite inelastic in the very short run.

Demand for pig meat is stratified into four market and equations which are estimated from Finnish meat market data. These equations represent domestic demand (D_t^{dom}), export demand to EU (D_t^{EU}) and non-EU (D_t^{row}) countries separately, and import demand (D_t^{imp}). Imports and Finnish meat are considered as an imperfect substitutes. In demand equations, meat prices in Finland, import and export prices and a set of seasonal dummy variables explain the amount of meat demanded.

Even if the trade ban interrupts export of pig meat from Finland for an exogenously given time, all meat does not physically enter domestic market because of meat storing. Storing capacity is, however, quite limited. Based on our data, approximately 33% of exports to non-EU countries and 9.5% of exports to EU-countries are due to changes in meat storing. Thus, we assume that once a trade ban occurs, the amount of excess meat entering domestic market is 67% of exports to non-EU countries and 90.5% of exports to EU countries. In addition, marketing contracts between meat industry and retailing affect market prices. The terms of meat deliveries in Finland are generally agreed some four months ahead in time. Thus, meat demand and meat prices in the domestic market are partly fixed and large changes in pig meat prices are ruled out in the short run by contracts. This limitation is relaxed over time.

The Bellman equation

Optimizing agent maximises consumer surplus from consuming Finnish and imported meat and producer profits. The Bellman equation is of the form:

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

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

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

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

$x_{t+1}^{\text{ban}} = \Pr(x_t^{\text{ban}})$ (trade ban dynamics),

$$
\begin{aligned}
S_t\ (\mathbf{x_t}, \mathbf{u_t}) = & (x_t^{\text{pig}} - u_t^{\text{serve}} - \delta(x_t^{\text{pig}}) u_t^{\text{weight}} + x_t^{\text{sow}} r y_t^{sow} \\
& - r\delta(x_t^{\text{sow}}) \equiv D_t^{\text{dom}} + D_t^{\text{EU}} + D_t^{\text{row}}
\end{aligned}
\quad \text{(market clearing)}
$$

x_t^{sow}, x_t^{pig}, x_t^{ban} and $V_T\ (\mathbf{x_T})$ are given,

$V_t\ (\mathbf{x_t})$ is the maximised net present value of Finnish pig meat market (i.e. "consumer" surplus plus producer profits); t is 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 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 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; $P_t^{\text{EU}}(Q_t^{\text{EU}}, \mathbf{x_t}, \mathbf{u_t})$ is 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; and $P_t^{\text{row}}(Q_t^{\text{row}}, \mathbf{x_t}, \mathbf{u_t})$ is 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; $C_t(\mathbf{x_t}, \mathbf{u_t})$ characterizes production costs incurred at period *t*; β is discount factor; $E(\bullet)$ is expectations operator; $V_{t+1}(\mathbf{x_{t+1}})$ is the value of sector in the subsequent period; $S_t(\mathbf{x_t}, \mathbf{u_t})$ is the aggregate quantity of Finnish pig meat supplied to market; x_t^{sow} is the number of sows in Finland which were inseminated at period *t*-4 and farrow at period *t*; x_t^{pig} is the number of pigs which were born at period *t*-9 and are allocated to reproduction or slaughtered at period *t*, and which by definition is a function of the number of sows; $\delta(x_t^{\text{pig}})$ and $\delta(x_t^{\text{sow}})$ indicate how the epidemic affects the number of pigs and sows on farms; x_t^{ban} is state variable characterizing which share of export market are closed at period *t*; u_t^{serve} is control variable characterizing the number of pigs currently allocated to reproduction; u_t^{weight} is decision variable characterizing slaughter weight per hog; r is the share of sows removed from the stock each period; y_t^{pig} is effective piglet yield per sow; $\Pr(x_t^{\text{ban}})$ characterizes the probability of trade ban in the subsequent period, given current period trade ban status ; and $V_T(\mathbf{x_T})$ is the value function for the terminal period *t=T*.

Equation 1 considers welfare changes in Finland only. Effects to consumers in other countries or effects to other sectors are excluded from the analysis.

Transition equations imply that an insemination today shows up as hogs sold to slaughter almost one year from now. The supply of pig meat depends on the share of pigs at slaughter age, slaughter weight and the low-valued meat obtained from removed sows. The aggregate quantity of Finnish pig meat sold at different market is set equal the aggregate production of pig meat in the same period.

Probability parameters

Probability parameters included in the model utilize Poisson process, which suits well into the logic of dynamic programming (cf. Dixit and Pindyck 1994, p. 85-87). This property is due to the fact that Poisson process has "no memory". This paper assumes that the trade ban can have a minimum duration (*m*), which implies that the probability parameter is set λ_t^{b}=0 in the beginning of an epidemic. In general, the probability of the trade ban being lifted before the subsequent period *t*+1 (cf. "mean arrival rate") is:

(2) $$\lambda_t^{\mathrm{b}} = \begin{cases} 1/(d-m) \text{ if minimum duration is exceeded and} \\ 0 \text{ otherwise} \end{cases},$$

where *d* is expected duration (*d*) of the trade ban and *m* is the minimum duration.
If the trade ban is imposed for the first time at period t', we can compute prior probability for the event that the trade ban is still imposed at period *t*. Equations 3a and 3b illustrate how this can be done for the median epidemic scenario and for the large epidemic scenario when λ_t^{a} is zero:

(3a) $$\Pr(x_t^{\text{ban}} \mid \text{trade ban}) = \begin{cases} 1-(1-1/(d \quad -1))^{(t-t'-1)} & \text{if } t > t'+1 \\ 1 & \text{otherwise} \end{cases}$$ for the median epidemic,

(3b) $$\Pr(x_t^{\text{ban}} \mid \text{trade ban}) = \begin{cases} 1-(1-1/(d \quad -2))^{(t-t'-2)} & \text{if } t > t'+2 \\ 1 & \text{otherwise} \end{cases}$$ for the large epidemic,

where t is the time period under examination ($t > t'$), and t' is time period when the trade ban was imposed for the first time. The difference $t-t'$ indicates the number of time periods passed after trade ban was imposed. For instance, when the trade ban's expected duration is 4 months, the probability that the trade ban is still imposed 9 months later in the median epidemic scenario is 4 %.

The existence of a marketing contract between meat industry and retailing is modelled with expected probabilities which utilise Poisson process and pay an income transfer between producers and consumers according to a probability parameter. It is used to ration cuts in producer prices and thus income losses in the beginning of an epidemic so that the model would fit better in the current structure of Finnish meat market. Probability of a marketing contract is formed as a joint distribution by using the fact that slaughterhouses and retailing sector in Finland generally agree meat deliveries four months ahead and assuming that in the short run (<10 months) stakeholders take into account expected export market situation, which in turn is affected by expected probability that export demand recovers when entering period n. This implies that if quantity supplied would be fixed, producer losses and price reductions would increase over the first few months after imposing the trade ban, but be expected to recover when time passes.

Data and parameter values

Data for demand function estimation were obtained from statistics and they consisted of monthly observation for January 1997-November 2006. Quantities and values of exports and imports were retrieved from the Eurostat website (Eurostat 2007). These data were used to calculate representative import and export prices. Data on prices and meat production in Finland were obtained from the information Centre of Ministry of Agriculture and Forestry in Finland. All prices used in the estimation were deflated with consumer price index (Statistics Finland 2007) and logarithmic transformation[2] was applied on other estimation variables than dummy variables.

Demand functions were estimated with three-stage least squares procedure provided by Le Sage (2004). Elasticity estimates of demand for pig meat with respect Finnish pig meat price were (t-statistics in parenthesis) -0.97 (-3.0) for export demand to EU countries, -0.51 (-3.4) for export demand to non-EU countries, 0.87 (1.1) for import demand, and -0.14 (-2.2) for domestic demand. Export demand equations were estimated using export prices and domestic and import demand equations using producer prices as explanatory variables. In the course of optimisation, export prices for Finnish pig meat were set to equal domestic producer price plus fixed margin, which was estimated from the data.

Piglet production costs were obtained from the website of ProAgria Association of Rural Advisory Centres (ProAgria 2007). Variable production cost ($C_t^{\text{weaner}}(\mathbf{x_t}, \mathbf{u_t})$), excluding the cost due to replacement gilts (€350 per purchased gilt), was generally €55.84 per weaner. This figure and piglet yield were adjusted according

[2] ln(Demand)=ln(Explanatory variables)

to the share of gilts in the sow stock. Variable production costs (€/slaughtered hog) including feed, weaner, labour and miscellaneous cost, minus subsidy payments were:

$$
\text{(4)} \quad \begin{aligned} C_t^{\text{meat}}(\mathbf{x_t},\mathbf{u_t}) = {} & 1216.24 - 0064.64u_t^{\text{weight}} + 119.88(u_t^{\text{weight}})^2 10^2 - 9.46(u_t^{\text{weight}})^3 10^3 \\ & + 0.26(u_t^{\text{weight}})^4 10^4 - C_t^{\text{weaner}}(\mathbf{x_t},\mathbf{u_t}) \end{aligned},
$$

which excludes fixed production costs (C_t^{fixed}) of about €5.4 million per month and replacement costs. The cost function was based on Finnish Feeding recommendations and growth models provided by Niemi (2006).

Capacity costs were used to calibrate the model. Capacity costs to take into account that it is costly for an individual producer to keep capacity units idle if market prices cover variable costs. If prices are favourable, efficient producers can have incentives to enter the market or to expand production. The cost of capacity was structured as a function of producer price at disease-free time and meat supply:

$$
\text{(5)} \quad C_t^{\text{capacity}} = ((C_t(\mathbf{x_t},\mathbf{u_t}) + C_t^{\text{fixed}}) / S_t(\mathbf{x_t},\mathbf{u_t}) - P_t^{\text{producer}}(\mathbf{x_t},\mathbf{u_t}) - \alpha) S_t(\mathbf{x_t},\mathbf{u_t}),
$$

where $P_t^{\text{producer}}(\mathbf{x_t},\mathbf{u_t})$ is the price producer is expected to receive during the disease-free time and α=0.5 is a calibration parameter, which refers to the cost of capital.

When solving slaughter weight, it is taken into account that in the short-run production costs are mostly sunk costs. Furthermore, reducing meat yield per weaner incurs additional costs as production capacity is used less efficiently:

$$
\text{(6)} \quad \begin{aligned} C_t^{\text{weight}}(\mathbf{x_t},\mathbf{u_t}) = {} & 0.0679 S_t(\mathbf{x_t},\mathbf{u_t})(-71.4989 - 0.114u_t^{\text{weight}} \\ & + 0.011(u_t^{\text{weight}})^2)(u_t^{\text{weight}} - 84.5) \qquad \text{for all } u_t^{\text{weight}} < 84.5\text{ kg.} \end{aligned}
$$

Expenditures paid by public funds are approximated based on information available on epidemics and official measures related to epidemics.

Scenarios

Several scenarios with respect to epidemic were formed. Each epidemic scenario was a combination of three different characteristics. Firstly, epidemic size, which affected the number of pigs animals ($\delta(x_t^{\mathrm{pig}})$ and $\delta(x_t^{\mathrm{sow}})$) kept at infected farms and thus removed from the stock, was either <0.2% of pig population (hereafter median epidemic) or about 2% of pig population (hereafter large epidemic). Epidemic size was based on separate epidemiological simulations performed by the Finnish Food Safety Authority (Lyytikäinen and Kallio 2008). Secondly, the trade ban's expected duration was set 0, 4, 6 or 8 months for a median epidemic and 0, 5, 7 or 9 months for a large epidemic. Of these periods, the first month was unavoidable during a median epidemic and first two months during a large epidemic. Zero duration refers to the case where trade ban would not take place. Expected duration of trade ban affects probability λ_t^{b} in figure 1. Thirdly, the probability that a trade ban would occur when entering subsequent production cycle (λ_t^{a} in figure 1) was assigned values 0 %, 5 % or 10%. This probability refers only to cases were there is no trade ban imposed at period *t*. As a combination of these, 12 scenarios are examined (Table 1). It is emphasized that these scenarios consider mainly the cases where exports are fully halted.

Regarding the baseline scenario, which refers to simulating market when there is no FMD involved, the model was calibrated so that at the equilibrium it produced average monthly prices and demand quantities for the year 2006. Constant terms in each demand equation was adjusted so that the data met average monthly prices and demand quantities in 2006, and then adjusting the cost of capital so that meat supply correspond 2006 figures. The model was solved numerically for the period T=60 and by discretizing state and control spaces. Results should be interpreted with caution because parameter estimates and calibration values are point estimates.

Results

Production and price adjustments

Results suggest that producers are able to adjust supply in the short run through hog slaughter weights and by storing meat for later export market procurement. While storing activities are implicitly included in demand functions, insemination decisions and slaughter weights are solved explicitly. Despite the fact that production decisions can be adjusted, producer prices of pig meat fall when trade ban is imposed. If market become fully closed, price reductions in scenario typically range from €0.27 per kg to €0.42 per kg or more, which correspond 21% and 33% decrease in producer prices, respectively. Prices decrease more when trade ban's expected duration increases, as well as when time passed after imposing the trade ban increases, i.e. first month of the trade ban implies smaller price reduction than second, third, etc. month. In contrast to this, after lifting the trade ban prices typically rise above those in the absence of an epidemic. Prices soar especially if epidemic is expected beforehand to be large and trade ban be long-lasting, but it becomes only large epidemic. Then, both epidemic and production adjustments decrease meat supply after the epidemic.

Producers generally have little incentives to adjust slaughter weights. In contrast to this, the number of sows responds to increased risk of prolonged trade ban. In scenarios which assume trade ban to last for 4-5 months, the risk of long-lasting trade ban decreases meat supply in the subsequent production cycle by about 0.5%. If expected duration increases by further 2 months, total decrease in production is close to 2% (depending on scenario). If the trade ban is expected to last 8 months, meat supply in the subsequent parity could decrease by 3-4% and producer prices after the trade ban increase by €0.19-€0.29 per kg.

The importance of the number of inseminated sows increases, when the expected duration of export distortions increases to cover over two or more parities. When the trade ban's expected duration increases, price reductions become larger and production quantities decrease, but in a nonlinear manner. When export distortions are expected to last for several months, animal stock adjustment option is valuable enough to be used, and producers benefit from the opportunity to reduce excess meat supply.

In the very short run (<4 months), producers may bear quite large reductions in pig meat price, because about half of production costs of pig meat are sunk cost, and marginal cost for fattening pigs is just around €0.6 per kg and day. For an individual producer and society it seems beneficial to fatten pigs currently in the stock until regular slaughter weight, and only thereafter have a break in production. Even if producers had market power to recover prices back to disease-free time prices, it would require 10-15% reduction in the production volume.

On the other hand, if the epidemic would remove very large number of pigs from the market and thus result in temporary undersupply and high prices, producers would have incentives to benefit from favourable prices by increasing slaughter weights and increasing imports. In contrast to this, in the medium-long run (>6 months) most scenarios assume that market situation improves. Incentives to reduce supply therefore decrease and adjustments remain still small as long as variable costs exceed meat price. Producers nevertheless take into account that the trade ban may extend to two or more parities when they choose to inseminate less gilts.

Impact of epidemic size and duration on simulated disease losses

Simulated welfare losses to consumers, producers and public funds due to a trade ban and epidemic range from zero to €0.41 per kg pig meat produced per month. When examined separately, producers loose and consumers gain from an outbreak combined with a trade ban. Net loss increases when market distortions expand over several months, or over two or more production cycles. When normalised according to the trade ban's expected duration, epidemic and trade ban jointly result €3-7 million in losses per month. A large epidemic generally result about €1 million in higher expected losses per month than a median epidemic. In most scenarios, consumers gain between €1-2 million per month from a trade ban whereas producers generally loose €4-8 million per month. Consumers benefit more from a median epidemic than from a large epidemic when benefits are measured both in absolute losses per epidemic and losses per month under the trade ban. A large epidemic incurs about €5 million more in direct costs paid by public funds than a median epidemic (table 2).

When a trade ban is imposed on Finnish pig meat exports, the median epidemic can incur more than €27 million in economic losses to society in six months. Producers can loose more if the epidemic is large than if it is median. This result in table 2 is due to the fact that scenarios assume the large epidemic to last longer than the median epidemic. It can be shown that producers can be better off in a large epidemic, which removes a lot of animals from the market, than in a median epidemic. Thus it is a matter of the trade-off between epidemic size and the trade ban duration. Compensations paid to producers and elasticity of demand also affects the result. Even the large epidemic is nevertheless quite small in terms of the number of affected pigs.

An increase in the expected duration of export ban affects losses in a nonlinear manner (table 2). Increasing the expected duration from 4 to 6 months in a median epidemic (ceteris paribus), for instance, increases the total loss by €10.8 million. Two months more in the trade ban's expected duration increases total loss by further €13 million. Corresponding figure for consumers' welfare gain are €4.4 and €7.3 million, respectively, and for producer income loss €15.1 and €20.3 million. Marginal effects are higher for a large epidemic than for a median epidemic.

Impact of probability of disease introduction on simulated disease losses

When the probability of market distortions suddenly increases, the value of pig sector decreases. Most scenarios assume that the probability of having a trade ban and FMD is negligible. Aggregate welfare over the 30-years-period decreases by €12.6-39.2 million when probability of experiencing a new trade ban in six months increases from zero to 5 % or 10%. The loss depends on the size of an epidemic and the probability of disease introduction (λ_t^a) (table 3). When probability λ_t^a increases from 0 to 5%, quantities traded in the market slightly (<1%) decrease and consumer welfare therefore decreases. Producers also suffer from increased cost of disease risk. The figures are well below €0.01 per kg pig meat produced over 30 years. We emphasize that 5% and 10 % scenarios represent quite high probabilities when compared to the fact that FMD has not been observed in Finland since 1959.

Losses due to a trade ban and FMD epidemic may also increase, but not those of producers. In fact, since the risk of trade ban decreases the value of disease-free pig sector and since producers are compensated for lost animals, producer losses due to individual epidemic can decrease when λ_t^a increases. Increase in total loss per epidemic in that case is mainly due to increased direct costs, which in our simulations are exogenously given. It is a consequence of introducing the cost of trade ban risk into the model that both value functions shift.

Discussion and conclusions

This paper has provided one example on how to simulate market implications of possible FMD epidemics when trade ban duration is unknown. Results suggest that trade ban duration can have large impact on losses. When the expected duration of the trade ban increases, losses increase at an increasing rate for durations which we simulated. Results also suggest that if export market become completely closed and remain closed for sufficiently long time, meat market can in practice collapse. That is, if there is a large excess supply after current marketing contracts terminate, meat buyers can use their market position and temporarily push down prices.

Given quite small direct impact of FMD on the animal stock, it is not surprising that the trade ban is the main reason for disease losses once it is imposed. Previous studies have already shown that consequences of a disease listed by the OIE can result in losses to producers (e.g. Thompson et al. 2002; Mangen and Burrell 2003; Schoenbaum and Disney 2003; Rich and Winter-Nelson 2007), and that consumers can even gain from a trade ban (e.g. Mangen and Burrell 2003).

Trade ban duration is an important issue, because the durations of epidemics can vary quite a lot (e.g. Kobayashi et al. 2007, Velthuis and Mourits 2007, Lyytikäinen and Kallio 2008). Results from earlier studies also suggest that a large FMD or CSF epidemic tends to have longer duration than a small epidemic (e.g. Mangen, Nielen and Burrell 2002; Velthuis and Mourits 2007; Raulo and Lyytikäinen 2005; Lyytikäinen and Kallio 2008). Taking into account OIE recommendations it seems reasonable to assume that if trade bans are imposed, large epidemics on average result in longer trade bans than small epidemics. If these correlations are strong enough, the risk of trade ban motivates producers as a group to put effort on disease prevention, but this may not hold for individual producers who take prices as given. Based on our results, reducing epidemic duration is likely to reduce market losses.

Governments can do market interventions during an epidemic. One intervention is that animals on infected farms are culled and their value is compensated for producers, for instance, by using prices observed before the epidemic. If animals are compensated generously and producer prices fall, some individual producers may be tempted to reduce losses by ignoring good hygienic practices. This may be a problem despite the fact that infected premises must be kept idle for a specified time. Solving this problem demands stakeholders to provide such producers a way out. It could, for instance, justify buying-out schemes and storage aids paid to industry during an epidemic. Thus, it is argued that market interventions during an epidemic are justified from the incentives point of view in the sense that they can enhance producer motivation to maintain proper biosecurity when market situation is poor. Market interventions can also help to secure food supply during crisis e.g. when it would be profitable to reduce yield levels and thus destroy production and welfare. One downside of market interventions is that in disease-free time they can result in producers to under-price the cost of disease risk. Thus, price insurance should be conditional on good biosecurity practices. Our results combined with low probability of disease introduction in many industrialized countries suggest that levy per unit of output to finance market losses of highly contagious animal diseases shouldn't bee too large.

Losses are partly associated to the fact that meat storing capacity is insufficient to handle large amounts of excess meat. Thus there is only a small buffer to stabilize meat market. If the risk of prolonged trade ban increases, meat supply could reduce over time as forecast profitability of pig production weakens and thus provides producers with incentives to cut production. If government wishes to reduce possible market adjustment due to the risk of the trade ban, it is essential that the disease is eradicated rapidly, which reduces the risk of long-lasting trade bans.

According to our results producers are reluctant in adjusting production when they face plummeting prices. There can be several plausible reasons for this. One major reason is the fact that production costs are mostly sunk cost in the short run and the cost of feeding few more days is probably less than the price of additional kilogram of pig meat. Reduced slaughter weight would also increase production costs per kilogram of meat. Sunk costs imply that it is hardly ever profitable to reduce slaughter weights. Producers nevertheless take into account that the trade ban may extend to two or more parities when they choose not to inseminate all sows. E.g. low productivity animals may be removed from the stock. Transaction costs may also increase due to premature culling of animals. Another reason driving the relatively sluggish production adjustment in our results could be functional forms[3] used in the demand equations and very inelastic domestic demand, according to our estimation results. Hence any improvement in product prices would require a significant, and thus costly, decrease in production when there is severe oversupply.

It is difficult to compare specific market implications to those obtained in other studies, because they depend on issues such as the structure of livestock production, disease, export orientation and elasticity estimates. We estimated own-price elasticity of domestic demand at -0.14. When compared to some other studies, this suggests that our losses per kilogram of pig meat produced can be quite high for a long trade ban. It also implies that if epidemic would be exceptionally large, producers in disease-free areas could benefit from the epidemic considerably.

Modelling approach proposed in this paper has the potential to examine how rationally behaving producers could adjust production after observing epidemics and export shocks of different magnitudes. Models such as this are best suited for comparing differences in results between scenarios. In contrast to this, the results of an

[3] Logarithmic demand equations make price adjustments proportional to meat quantity. When meat supply changes but export status is constant, price movements in absolute terms are larger when there is oversupply than when there is undersupply.

individual scenario should be interpreted with caution, as they are affected by parameter values, such as elasticity estimates, calibration values and production costs, which are to some extend normative. Our approach could be complemented by more thorough analysis of behaviour of consumers, producers and adjustment options. As the duration of market shock seems to be important, an interesting application is to combine epidemiological and economic models in order to study disease policy issues such as emergency vaccination, where uncertainty and time play an important role.

References

European Commission. 2001. "Council Directive 2001/89/EC of 23 October 2001 on Community Measures for the Control of Classical Swine Fever." *Official Journal of the European Community* L316: 5–35.

European Commission. 2003. "Council Directive 2003/85/EC of 29 September 2003 on Community Measures for the Control of Foot-and-mouth Disease Repealing Directive 85/511/EEC and Decisions 89/531/EEC and 91/665/EEC and Amending Directive 92/46/EEC." *Official Journal of the European Union* L306: 1-87.

Eurostat 2007. *Eurostat Data*. available on-line at: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_30298591&_dad=portal&_schema=PORTAL.

Bellmann, R. 1957. *Dynamic Programming*. New Jersey: Princeton University Press.

Bennett, R. and J. Ijpelaar. 2005. "Updated Estimates of the Costs Associated with Thirty Four Endemic Livestock Diseases in Great Britain: A Note." *Journal of Dairy Research* 66: 455-459.

Dixit, A.K., and R.S. Pindyck. 1994. *Investment Under Uncertainty.* New Jersey: Princeton University Press.

Ekboir, J., L.S. Jarvis, D.A. Sumner, J.E. Bervejillo, W.R. Sutton,. 2002. "Changes in Foot and Mouth Disease status and Evolving World Beef Markets." *Agribusiness* 18: 213 – 229.

Franks, J., P. Lowe, J. Phillipson, and C. Scott. 2001. "The Impact of Foot and Mouth Disease on Farm Businesses in Cumbria." *Land Use Policy* 20: 159–168.

Kobayashi, M., T.E., Carpenter, B.F. Dickey, and R.E. Howitt. 2007. "A dynamic, Optimal Disease Control Model for Foot-and-mouth disease: I. Model Description." *Preventive Veterinary Medicine* 79: 257-273.

LeSage, J.P. 2004. *Econometrics toolbox for Matlab*. http://www.spatial-econometrics.com/. Last accessed 14 May 2004.

Lyytikäinen, T., and E.R. Kallio. 2008. "Risk-Classification of Finnish Pig Farms by Simulated FMD Spread." In Peeler, E.J., L. Alban, A. Russell and the SVEPM Executive Committee, eds. *Proceedings of a Meeting Held at Liverpool, UK on the 26th-28th March 2008*. Society for Veterinary Epidemiology and Preventive Medicine, pp. 285-313.

Mahul, O., and A. Gohin. 1999. "Irreversible Decision Making in Contagious Animal Disease Control Under Uncertainty: An Illustration Using FMD in Brittany." *European Journal of Agricultural Economics* 26: 39-58.

Mangen, M.-J.J., M. Nielen, and A.M. Burrell. 2002. "Simulated Effect of Pig-population Density on Epidemic Size and Choice of Control Strategy for Classical Swine Fever Epidemics in The Netherlands." *Preventive Veterinary Medicine* 56: 141-163.

Mangen, M.-J.J., and A.M. Burrell. 2003. "Who Gains, Who Loses? Welfare Effects of Classical Swine Fever Epidemics in the Netherlands." *European Review of Agricultural Economics* 30: 125-154.

Neumann, E.J., J.B. Kliebenstein, C.D. Johnson, J.W. Mabry, E.J. Bush, A.H. Seitzinger, A.L. Green, and J.J Zimmerman. 2005. "Assessment of the Economic Impact of Porcine Reproductive and Respiratory Syndrome on Swine Production in the United States." *Journal of the American Veterinary Medical Association* 227: 385-392.

Niemi, J.K. 2006. "Dynamic Programming Model for Optimising Feeding and Slaughter Decisions Regarding Fattening Pigs." *Agricultural and Food Science* 15 (Supplement 1): 1-121. Dissertation. Available on-line at: http://urn.fi/URN:ISBN:951-729-997-4

Niemi, J.K., H. Lehtonen, K. Pietola, T. Lyytikäinen, T. and S. Raulo. 2008. "Economic Implications of Potential Classical Swine Fever Outbreaks for Finnish Pig Production Sector." *Preventive Veterinary Medicine* 84: 194-212.

OIE 2007. *Terrestrial Animal Health Code*. Paris. Available on-line at: http://www.oie.int/eng/normes/mcode/en_sommaire.htm

ProAgria 2007. *Tuottopehtoori*. Available on-line at (user code required): http://www.agronet.fi/cgi-bin/mkl/julk/malli.cgi?sivu=hakemisto2006.

Raulo, S. and T. Lyytikäinen. 2005. *Quantitative risk assessment – epidemic outbreak of classical swine fever in Finland.* In Finnish with an English abstract. EELAn Julkaisuja 06/2005. Helsinki: National Veterinary and Food Research Institute.

Rich, K.M., and A. Winter-Nelson. 2007. "An Integrated Epidemiological-economic Analysis of Foot and Mouth Disease: Applications to the Southern Cone of South America." *American Journal of Agricultural Economics* 89: 682–697.

Schoenbaum, M.A. and W.T. Disney. 2003. "Modeling Alternative Mitigation Strategies for a Hypothetical Outbreak of Foot-and-mouth Disease in the United States." *Preventive Veterinary Medicine* 58, 25-52.

Statistics Finland. 2007. *Statistics Finland's PX-Web databases*. Available on-line at: http://pxweb2.stat.fi/database/StatFin/databasetree_en.asp.

Thompson, D., P. Muriel, D. Russell, P. Osborne, A. Bromley, M. Rowland, S. Creigh-Tyte, and C. Brown. 2002. "Economic Costs of the Foot and Mouth Disease Outbreak in the United Kingdom in 2001." *Revue Scientifique et Technique Office International des Epizooties* 21: 675-687.

Velthuis, A.G.J. and M.C.M. Mourits. 2007. "Effectiveness of Movement-prevention Regulations to Reduce the spread of Foot-and-mouth Disease in The Netherlands." *Preventive Veterinary Medicine* 82: 262-281.

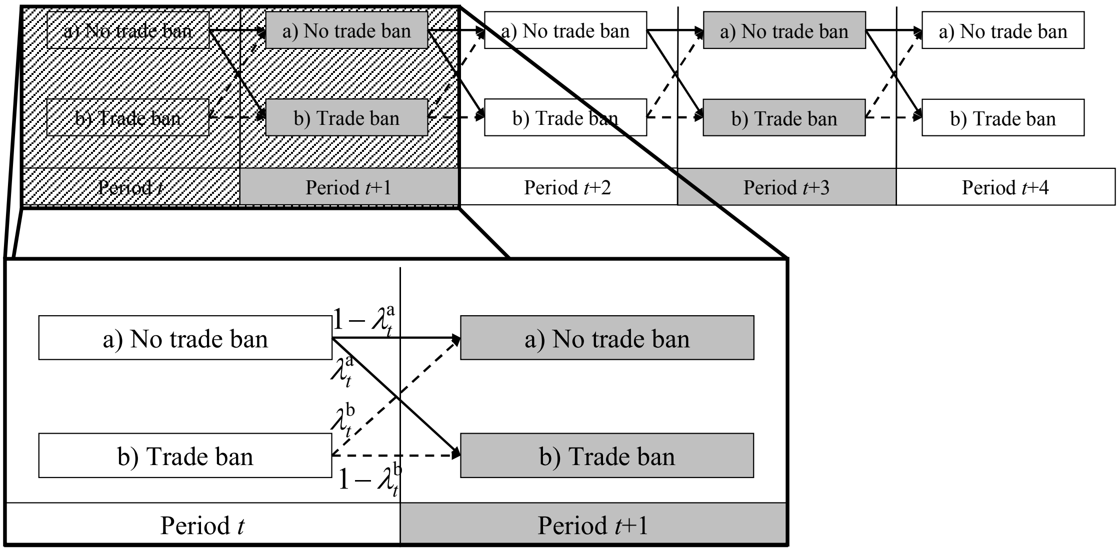

Figure 1. Possible transitions from each market state (denoted with superscripts a and b) between successive time periods t, t+1,…,T, and corresponding transition probabilities λ_t^a and λ_t^b.

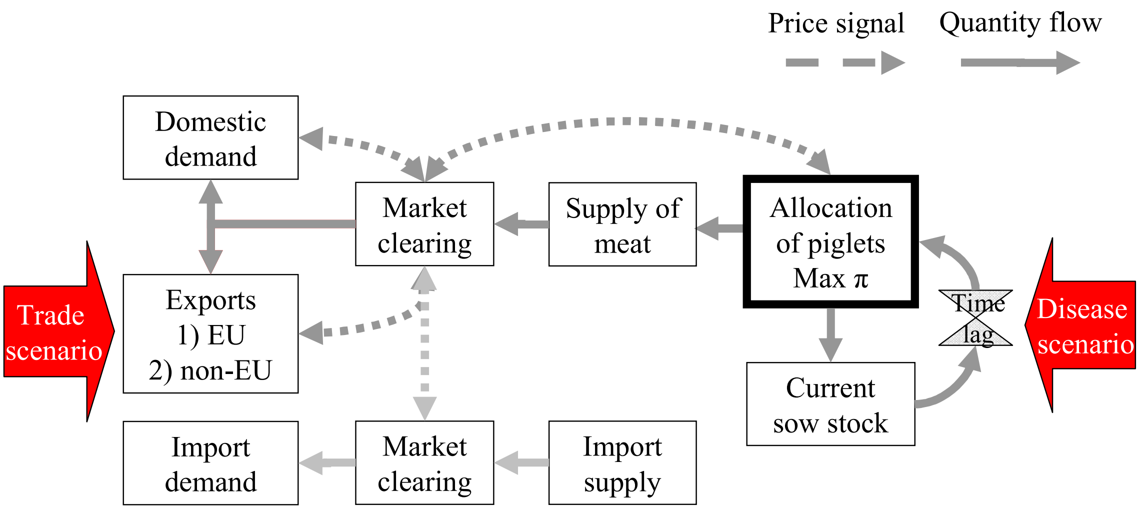

Figure 2. Illustration of information and good flows and time lags in the model.

Table 1. Characterization of scenarios examined.

	Epidemic size, % of pig population culled	Trade ban's expected duration, months (associated to λ_t^b)	Probability of a new trade ban at subsequent production cycle (λ_t^a)
Scenario 1	Median, <0.2 %	0	0%
Scenario 2	Median, <0.2 %	4	0%
Scenario 3	Median, <0.2 %	6	0%
Scenario 4	Median, <0.2 %	8	0%
Scenario 5	Median, <0.2 %	4	5%
Scenario 6	Median, <0.2 %	4	10%
Scenario 7	Large, 2.0%	0	0%
Scenario 8	Large, 2.0%	5	0%
Scenario 9	Large, 2.0%	7	0%
Scenario 10	Large, 2.0%	9	0%
Scenario 11	Large, 2.0%	5	5%
Scenario 12	Large, 2.0%	5	10%

Table 2. Simulated changes in the welfare of producers, consumers, public funds, and the total loss due to epidemics which are of different size, where the expected duration of the trade ban varies from 0 to 9 months and the probability of a new trade ban taking place in the subsequent production cycle varies from 0 to 10%.

Event type			Welfare effects (€ million)			
Epidemic	Duration	Introduction	Consumers	Producers	Public funds[1)]	Total loss
Median	0	0 %	-0.4	1.0	-0.6	0.1
Median	4	0 %	5.5	-21.7	-0.6	-16.7
Median	6	0 %	9.8	-36.8	-0.6	-27.5
Median	8	0 %	17.1	-57.1	-0.6	-40.6
Median	4	5 %	5.0	-18.9	-1.3	-15.2
Median	4	10 %	6.8	-16.1	-1.9	-11.2
Large	0	0 %	-7.8	10.7	-5.7	-2.8
Large	5	0 %	3.6	-24.4	-5.7	-26.6
Large	7	0 %	7.2	-41.6	-5.7	-40.1
Large	9	0 %	18.4	-69.3	-5.7	-56.7
Large	5	5 %	3.0	-21.2	-12.9	-31.1
Large	5	10 %	4.8	-18.1	-19.3	-32.6

1) Exogenously given. Direct costs added on top of the total loss.

Table 3. Changes in the welfare of stakeholder groups under the median and the large epidemic scenarios when the probability (introduction, %) of facing 4 or 5 months trade ban and disease losses in the subsequent production cycle increases from zero to 5 % or 10%.

Event type			Welfare effects (€ million)			
Epidemic	Duration	Introduction	Consumers	Producers	Public funds[1)]	Total loss
Median	4	5 %	-3.7	-8.1	-0.7	-12.4
Median	4	10 %	-8.0	-16.8	-1.3	-26.1
Large	5	5 %	-3.6	-8.6	-6.8	-19.0
Large	5	10 %	-7.9	-17.8	-13.5	-39.2

1) Exogenously given. Direct costs added on top of the total loss.