Evira Research Reports 1/2011

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A quantitative risk assessment

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Description

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Authors	Tapani Lyytikäinen, Jarkko Niemi, Leena Sahlström, Terhi Virtanen, Heikki Lehtonen
Abstract	Foot-and-mouth disease (FMD) is a highly contagious viral epizootic disease of cloven-footed animals, which is controlled both by domestic and EU legislation. FMD has not been found in Finland since 1959. The aim of this risk assessment was, by using Monte Carlo simulations, to assess how FMD would spread, the economic consequences of an outbreak and the feasibility of emergency vaccination in case of an outbreak in Finland. The study was based on data from the Finnish cattle and swine production sectors from 2006. If FMD was introduced to a Finnish pig or cattle farm, it would in most cases spread to four other farms and the disease would be brought under control after 5 weeks. In one-third of the cases, the disease would remain a sporadic case and would not spread at all from the first infected farm. Even a larger outbreak would remain relatively small and short. In the worst case scenario, FMD virus would spread to 29 farms before the disease was eradicated. The mean economic consequences of a sporadic outbreak would be €23 million. In the worst case scenario, the economic losses would be more than €38 million. Emergency vaccination is not a feasible option according to this study, because the current EU measures are able to stop the spread of disease and because vaccination can incur considerable extra costs due to prolonged export distortions.
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Kuvailulehti

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Tekijät	Tapani Lyytikäinen, Jarkko Niemi, Leena Sahlström, Terhi Virtanen, Heikki Lehtonen
Tiivistelmä	Suu- ja sorkkatauti on sorkkaeläinten virustauti, joka kuuluu EU-lainsäädännössä vastustettaviin eläintauteihin. Tautia ei ole esiintynyt Suomessa vuoden 1959 jälkeen. Tässä riskinarvioinnissa tutkittiin Monte Carlo -simulaatioiden avulla, miten suu- ja sorkkatauti leviäisi Suomessa, mahdollisen taudinpurkauksen taloudellisia seurauksia, sekä hätärokotusten hyödyllisyyttä taudinpurkauksessa. Tutkimus perustuu vuoden 2006 tietoihin Suomen sika- ja nautatuotannosta. Jos suu- ja sorkkatauti päätyisi suomalaiselle sika- tai nautatilalle se tavallisimmin leviäisi neljälle tilalle ja leviäminen olisi päättynyt viisi viikkoa ensimmäisen tartunnan jälkeen. Kolmasosassa simulaatioista tauti ei leviäisi eteenpäin ensimmäiseltä tilalta. Mahdollinen laajempikin epidemia jäisi suhteellisen pieneksi ja lyhytkestoiseksi. Pahimmassa tapauksessa suu- ja sorkkatautivirus leviäisi 29 tilalle ennen kuin tauti olisi hävitetty. Yhteen tilaan rajoittuvasta taudinpurkauksesta kansantaloudelle aiheutuisi taloudellisia menetyksiä keskimäärin vajaat 23 miljoonaa euroa. Pahimmassa tapauksessa epidemian aiheuttamat menetykset nousisivat keskimäärin yli 38 miljoonaan euroon. Hätärokotuksilla ei juuri saavuteta hyötyä, koska EU-lainsäädännön mukaiset vastustustoimet riittävät pysäyttämään taudin leviämisen ja lisäksi rokotusten talousvaikutukset ovat suuret viennin pitkäkestoisemman estymisen vuoksi.
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Beskrivning

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Resumé	Mul- och klövsjuka är en virussjukdom som smittar klövdjur, och klassas som en smittsam djursjukdom som skall bekämpas genom myndighetsåtgärder. Sjukdomen har inte påträffats i Finland sedan 1959. I denna riskvärdering har vi med hjälp av Monte Carlo- simulering studerat hur mul- och klövsjuka skulle spridas i Finland, dess ekonomiska följder, och nyttan av nödvaccinering i fall av ett utbrott. Studien baseras på uppgifter från Finlands nöt- och svinproduktion från år 2006. Om mul- och klövsjuka skulle drabba en nöt eller svingård skulle den mest sannolikt spridas till ytterligare fyra gårdar och epidemin skulle vara under kontroll efter fem veckor från det första fallet räknat. I en tredjedel av fallen skulle smittan inte alls spridas vidare. Även ett eventuellt större utbrott skulle förbli relativt litet och kortvarigt. I värsta fall skulle viruset spridas till 29 gårdar innan man får sjukdomen under kontroll. Den ekonomiska förlusten av ett utbrott som begränsas till endast en gård skulle uppnå i medeltal 23 miljoner Euro. I värsta fall skulle de ekonomiska förlusterna av ett utbrott kunna stiga till mer än 38 miljoner Euro. Enligt studien, skulle man inte få någon nytta av nödvaccineringar, eftersom de av EU reglerade bekämpningsåtgärderna skulle vara tillräckliga för att stoppa sjukdomens spridning. Dessutom skulle vaccineringen medföra stora ekonomiska följder på grund av exportbegränsningar.
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Contents

1 Abbreviations and definitions

Abbreviations:

ETT	Finnish Association for Animal Disease Prevention
EU	European Union
Evira	Finnish Food Safety Authority
FABA	The Finnish Animal Breeding Association
MAF	Ministry of Agriculture and Forestry
Mela	The Farmers' Social Insurance Institution
MTT	Agrifood Research Finland
MVO	Municipal Veterinary Officer
OIE	World Organisation for Animal Health
PVO	Provincial Veterinary Officer
FGFRI	The Finnish Game and Fisheries Research Institute (RKTL)
TIKE	Information centre of the Ministry of Agriculture and Forestry

Definitions:

AI
Artificial insemination, a technique of placing semen from the male in the reproductive tract of the female by means other than natural service.

Bayesian information criterion (BIC)
A criterion used to choose between competing statistical models that takes in account the likelihood-ratio statistic, degrees of freedom and the sample size.

Case of FMD
An individual animal infected by foot-and-mouth disease virus.

Coefficient of variation
The standard deviation divided by the mean; can be given as a percentage, which then indicates the proportion of the standard deviation from the mean.

Competent authorities
The authority of a member state competent to carry out veterinary checks.

Confidence interval for the mean
An estimate of the range of the mean with a given certainty.

Consumer's surplus
The excess of the benefit a consumer gains from purchases of goods over the amount paid for them. Typically obtained by integrating the area below the inverse demand curve minus the market value of goods purchased at the market price.

Demand curve
A graph relating the demand for a good or service to its price. Its reverse is the inverse demand curve, which represents the price as a function of the quantity of a good.

Detection time
The time between the introduction of FMD virus and the positive diagnosis of FMD on a farm.

Direct costs
Costs of implementation of disease eradication and preventive measures after an infection has been observed at the farm. In this study, direct costs mainly refer to expenditures that are paid by tax payers.

(Economic) welfare effects
Net change in the benefit to society due to a change in the economy. In this study, measured as the aggregate change in consumer's surplus, producer's surplus and public expenditures due to an FMD outbreak.

Elite breeding farm
Farms producing breeding animals for the domestic market as well as for export. The farms participate actively in the national pig breeding program by sending animals to the performance test stations and producing AI boars. An elite breeding farm must comply with the requirements of the National Health Scheme for domestic swine breeding farms.

Endemic disease
The constant presence of disease within a given population or a geographical area.

Epidemic
Introduction of a highly contagious pathogen into a susceptible population followed by the spread of the pathogen within the susceptible population.

Export shock
A situation where importing countries prohibit the importation of cloven-hoofed animals and products originating from such animals from a country where FMD has been observed. Consequences of the shock are referred to as trade distortions.

Exposure assessment
Describing the biological pathway necessary for exposure of the population at risk to FMD, released from a given risk source, and qualitatively or quantitatively estimating the probability and magnitude of the exposure.

Farrowing farm
Farms mainly producing piglets to be sold to finishing farms.

Farrowing-to-finishing farm
Farm producing piglets and raising all or part of the piglets until slaughter.

Finishing farm
Farm purchasing piglets from farrowing farms and rearing them until slaughter

Heifer
A female of the cattle species less than three years of age that has not borne a calf.

High risk period
The time period between the release of FMD virus into the susceptible population and the execution of the first restrictive measures due to a suspicion of disease. The high risk period includes the incubation period.

Incubation period
The time period between the introduction of the pathogen into the animal and the occurrence of the first clinical signs of the disease.

Indicator
A variable that has a value of 1 when the argument is true and otherwise it has a value of 0.

Indirect costs
Indirect costs – or consequential costs – include all other economic effects of an FMD outbreak except direct costs. Trade losses, business interruption losses on farms located in restriction and surveillance zones, and the costs of breeding a new animal stock after the outbreak are examples of indirect costs.

Intra-community trade
Trade within and between the countries of the European Union.

Iteration
One simulated outcome starting from a case of FMD infection on one farm to the end of an outbreak. In this report, an iteration is a Monte Carlo simulated outbreak.

Monitoring
On-going programmes to detect changes in the prevalence of disease in a given population.

Multiplying farm
Farms producing young crossbred or purebred breeding gilts for distribution to farrowing or farrowing-to-finishing farms.

Neighborhood spread
Transmission of FMD between herds in close proximity, where no other means of transmission of the disease can be identified.

Outbreak of FMD
FMD virus has been introduced into a farm and caused more than one case of FMD after introduction.

Partial-equilibrium
A situation where the demand and supply in a certain sector are equal, and the buyers and sellers are in agreement over the prices required for the transaction. In the equilibrium, changes in this particular sector would not increase the net benefit to consumers and producers. However, changes in other sectors could contribute to the net benefit.

Percentile
An approximate value of cumulative distribution located on a given percentage of the distribution, whereby the same percentage of the population is either smaller than or equal to the given value.

Producer's surplus
The excess of total sales revenue going to producers over the area under the supply curve for a good. The revenue obtained to cover fixed production costs.

Protective vaccination
Emergency vaccination is carried out on holdings in a designated area in order to protect animals of susceptible species within this area against foot-and-mouth disease virus. The animals are intended to be kept alive following vaccination (2003/85/EY) ("vaccination to live").

Protection zone
An area with a minimum of a 3 km radius around the infected herd.

Risk
The likelihood of the occurrence and the likely magnitude of the consequences of an adverse event on animal health in a specified area during a specified time period.

Risk assessment
In this report, risk assessment includes the evaluation of the biological and economic consequences of the entry of a pathogenic agent within the cattle and pig population in Finland.

Simulation
A set of iterations that have been carried out with a certain set of parameters, in order to estimate the mean and variance of outcomes of iterations. Simulation typically includes several thousands of iterations.

Stamping-out
Killing of FMD-infected herds and/or other herds that have been exposed to infection by direct animal-to-animal contact, or by indirect contact likely to cause the transmission of FMD. All carcasses of killed animals are destroyed by burning or burial, or by any other method that will eliminate the spread of infection through the carcasses or products of the animals killed.

Suckler farm
A farm with a herd of cattle composed of dams and their young calves up to the point of weaning.

Supply curve
A curve showing the amount that firms in an industry are willing to supply at each possible price.

Suppressive vaccination
Emergency vaccination that is carried out exclusively in conjunction with a stamping-out policy in a holding or area where there is an urgent need to reduce the amount of foot-and-mouth disease virus circulating and to reduce the risk of it spreading beyond the perimeters of the holding or the area, and where the animals are intended to be destroyed following vaccination (2003/85/EY) ("vaccination to cull").

Surveillance zone
The surveillance zone includes an area of a minimum radius of 10 km around the infected herd, excluding the protection zone.

Third country
Countries that are not members of the EU.

Trade ban
A trade ban in this study refers to the situation where other countries prohibit the importation of animals and animal products from Finland to their country because of an animal disease outbreak being observed in Finland.

Weaner farm
A farm where 1- to 2-week-old calves are moved and raised until they are 5–6 months old.

Worst-case scenario
A scenario that can occur with low probability and in which the consequences are most severe.

2 Yhteenveto

Suu- ja sorkkatauti on sorkkaeläinten virustauti, joka kuuluu Suomen lainsäädännössä vastustettavien, helposti leviävien tautien ryhmään. Suu- ja sorkkatautia ei ole esiintynyt Suomessa sitten vuoden 1959.

Taudille tyypilliset oireet naudalla ovat rakkulat suun limakalvoilla, kielessä, huulissa, sorkkaväleissä ja utareissa. Muita oireita akuutissa vaiheessa ovat kuume, maidontuotannon lasku, syömättömyys ja runsas syljentuotanto. Sioilla näkyvin oire on ontuminen, joka johtuu sorkkien väliin kehittyvistä rakkuloista. Suu- ja sorkkatauti on taloudellisesti merkittävää vahinkoa aiheuttava tauti. Tauti ei aiheuta ihmisille oireita tai sairautta. Tartunta leviää nopeasti samassa tilassa pidettäviin sorkkaeläimiin sairastuneiden eläinten eritteiden sekä hengitysilman kautta. Virusta erittyy jo muutamaa päivää ennen oireiden alkamista. Tartunta voi levitä tilalle joko ostettujen, tautia kantavien eläinten, kuljetusautojen, elintarvikkeiden, rehujen, ihmisten, villieläinten tai jopa tuulen mukana.

Riskinarvioinnin tavoitteena oli tutkia simulaatiomallin avulla 1) miten suu- ja sorkkatauti leviäisi Suomessa, kun se olisi jo levinnyt yhdelle suomalaiselle tilalle, 2) mitkä olisivat taudinpurkauksen taloudelliset seuraukset sekä 3) hätärokotuksen merkitystä taudinhallintakeinona. Tämä riskinarviointi perustuu vuoden 2006 tietoihin Suomen sika- ja nautatuotannosta.

Tulokset

Riskinarvioinnin tulosten mukaan jopa kolmasosa Suomen epidemioista olisi sporadisia, eli vain yksi tila saisi tartunnan ennen kuin tauti saataisiin hävitettyä maasta. Mahdollinen epidemia jäisi suhteellisen pieneksi ja lyhytkestoiseksi. Tavallisimmin epideemisenä ilmenevä tauti leviäisi viidelle tilalle ja leviäminen saataisiin pysäytettyä viiden viikon kuluessa ensimmäisen tilan tartunnasta. Pahimmassa skenaariossa suu- ja sorkkatautivirus leviäisi 29 tilalle ennen kuin tauti olisi hävitetty ja taudin leviäminen kestäisi korkeintaan 10 viikkoa. Suomessa epidemia olisi siis pahimmillaankin huomattavasti pienempi kuin esimerkiksi Iso-Britannian vuoden 2001 suu- ja sorkkatautiepidemia. Pääasiassa tulos johtuu Suomen Iso-Britanniaa harvemmasta tilatiheydestä ja vähäisemmistä kontakteista tilojen välillä.

Simuloidut epidemiat olivat samankokoisia Suomen eri osissa. Välilliset seuraukset olisivat kuitenkin suurimpia tilatiheillä alueilla, suurempien suoja- ja valvontavyöhykkeillä olevien tartuntaa saamattomien tilojen lukumäärän vuoksi. Lisäksi näillä alueilla vaikutusten laajuuden vaihteluväli oli hieman muita alueita suurempi.

Yhteen tilaan rajoittuvan taudinpurkauksen kansantaloudelle aiheuttamiksi taloudellisiksi menetyksiksi arvioitiin keskimäärin vajaat 23 miljoonaa euroa. Yli 18 tartuntatilan epidemioiden aiheuttamat menetykset nousivat keskimäärin yli 38 miljoonaan euroon.

Taloudellisia menetyksiä kertyi elintarvikeviennin häiriintymisestä, tartuntatilojen puhdistuksesta, viranomaistoimenpiteistä uusien tartuntojen estämiseksi ja jäljittämiseksi, sekä näiden tiloille ja elintarviketeollisuudelle aiheuttamista häiriöistä. Tuottajien menetykset olivat suuremmat kuin koko yhteiskunnan menetykset, sillä kuluttajat hyötyisivät hieman tukkoisen markkinatilanteen vuoksi laskevista hinnoista. Suu- ja sorkkataudin leviäminen Suomeen saattaakin aiheuttaa merkittäviä tappioita alkutuotannolle.

Kansainvälisen eläintautijärjestön ohjeiden mukaan toimittaessa vienti voi häiriintyä kuukausien ajaksi, vaikka maassa olisi havaittu vain yksi tartunta. Pitkittyessään vientihäiriöt ovat merkittäviä, sillä yli 20 % Suomessa viime vuosina tuotetusta sianlihasta, yli 2/3 voista ja lähes puolet juustoista on viety ulkomaille. Suurissa epidemioissa myös tartuntatilojen määrä vaikutti tuloksiin, suuri tartuntatilojen määrä kasvatti suoria kustannuksia.

Epidemian koon luotettava ennustaminen on tärkeää rokotuspäätöksen tekemisen kannalta. Ensimmäisen tautitapauksen ja tartunnan saaneen tilan ominaisuuksien perusteella ei epidemian kokoa voida ennustaa luotettavasti. Tartuntatilalla tehdyn epidemiologisen selvityksen jälkeen ennustetta voidaan tarkentaa. Paras ennuste saadaan kuitenkin vasta kun tiedetään tartuntatilojen havaitsemisvauhti. Luotettavan tiedon saaminen viivästyttää päätöksentekoa epidemiatilanteessa vähintään viikolla.

Epidemian pienen koon ja sen lyhyen keston vuoksi hätärokotus ei ole epidemiologisesti perusteltu taudinhallintakeino Suomessa. Pahimmissa tautitilanteissa rokotus voisi vähentää tartunnan saaneiden tilojen määrää vähäisesti, jos rokotukset kyettäisiin aloittamaan välittömästi ensihavainnon jälkeen. Tämä ei kuitenkaan näytä mahdolliselta rokotuspäätökseen, rokotteiden saatavuuteen ja rokotusten käynnistämiseen liittyvien viiveiden vuoksi. Estorokotusta käytettäessä lopetettavia eläimiä olisi moninkertaisesti rokottamattomuus-politiikkaan verrattuna.

Hätärokotus suu- ja sorkkatautia vastaan ei ole myöskään taloudellisesti mielekäs taudinhallintakeino, sillä ilman rokotustakin taudinpurkaukset jäisivät melko pieniksi ja lyhytkestoisiksi. Lisäksi olisi vaikea tunnistaa tilanteet, joissa hätärokotus saattaisi olla taloudellisesti mielekäs ja aloittaa rokotukset riittävän ajoissa menetyksiä vähentävän rokotesuojan saamiseksi. Suojarokotuksessa kannattavuutta heikensi se, että maan tautivapauden saaminen takaisin – ja siten vientihäiriöiden kesto – on lähtökohtaisesti kolme kuukautta pidempi kuin ilman suojarokotusta. Markkinaongelmien mahdollisuus aiheuttaisi merkittäviä lisäkustannuksia suojarokotusta käytettäessä. Estorokotuksen kannattamattomuus puolestaan johtui pienehkön epidemiakoon lisäksi siitä, että lopetettavia eläimiä olisi selvästi enemmän kuin ilman hätärokotusta.

Loppupäätelmä

Riskinarvioinnin mukaan suu- ja sorkkataudin purkaus jäisi Suomessa verrattain pieneksi ja se saataisiin pysäytettyä käyttämällä EU:ssa säädettyjä vähimmäisvastustuskeinoja. Hätärokotukseen ei yleisesti ottaen kannattaisi Suomessa ryhtyä, vaan tärkeämpää olisi varmistaa tehokkaat vastustustoimet, jotka takaavat taudin nopean hävittämisen maasta ja joita tarvittaessa täydennetään vaikutuksiltaan hätärokotusta edullisemmilla toimenpiteillä. Muut taudinvastustustoimet saattavatkin olla hätärokotusta kustannustehokkaampia.

3 Introduction

Foot-and-mouth disease (FMD) is a highly contagious epizootic disease of cloven footed animals such as pigs and ruminants. The mortality rate in FMD is low, but morbidity is very high and convalescence is extended, which makes this disease especially important in countries previously free from the disease. International agreements and restrictions regarding the trade of cloven-hoofed animals and products originating from these animals emphasize the economic significance of the disease, as the introduction of the disease can impact on the exportation of animal products. FMD may have a significant economic impact on food production in the case of an outbreak. This is due to the suppression of domestic meat production caused by eradication measures, such as the culling of large numbers of production animals and the loss of export markets and revenues.

Finland has been free from the disease since 1959. The largest epidemic in previously free European countries has been in the UK 2001, followed by outbreaks in neighbouring countries such as France and the Netherlands. Another outbreak in the UK occurred as recently as in 2007.

The disease is controlled both by European directive (2003/85/EC) and domestic legislation. The primary control policy is eradication through stamping out, which means that all animals of the susceptible species on infected farms are killed and destroyed. Emergency vaccination is a possible control measure, but vaccination impacts on the trade of animals and animal products, so the economic and epidemiological gain must be accounted for. Vaccination has not been used in Finland as a preventive measure against FMD for 50 years.

The aim of this project was to assess the size, speed and duration of a possible spread of FMD (PanAsia serotype O), as well as the feasibility of emergency vaccination in the case of an outbreak in Finland.

This project was an assignment of the Finnish Ministry of Agriculture and Forestry and was financed by MAKERA, Evira, MTT Agrifood Research Finland and the National Emergency Supply Agency.

4 Objectives

The spread of foot-and-mouth disease into and within Finland and the role of emergency vaccination in disease control in the case of an epidemic.

There were four main objectives, which were to determine:

1. How many farms would typically and at most become infected if either a pig or a cattle farm in Finland were to become infected by FMD (PanAsia serotype O) virus, and how long the outbreak would last;
2. How the minimum eradication measures laid down by EU legislation would affect the size and duration of an outbreak, and whether there would be spatial variation in the efficacy of eradication measures;
3. What could be the economic impact of an outbreak on the Finnish livestock sector, taxpayers and consumers; and
4. Whether there would be epidemiological or economic justification to suppress the spread of FMD by emergency vaccinations in Finland, and how a vaccination programme should be performed so that it would prevent the further spread of the disease and benefits would result from the vaccination.

5 Hazard identification and characterization

FMD Virus

Foot-and-mouth disease (FMD) is an extremely contagious epizootic disease caused by a small (23 nanometres) icosahedral, single-stranded RNA virus (genus *Apthovirus*), which belongs to the family of *Picorna viridae*. Seven different serotypes are identified serologically (A, O, C, Asia 1, and South African Territories (SAT) 1, 2 and 3), and each serotype includes multiple subtypes totalling more than 60 subtypes (Grubman & Baxt 2004). Evolution of the virus is continuous and new types of virus have emerged during recent years, for instance in the Middle East (Knowles et al. 2010).

The FMD virus is stable between pH 6–9 (optimum pH 7.4–7.6), but is rapidly destroyed at a pH less than 4 and higher than 11. Inactivation in the environment is mainly due to a combination of high temperature, solar radiation and low humidity. The virus is stable at temperatures of up to 56 °C and can survive for one year at 4 °C. In freezing temperatures, it is stable and survives for a very long time.

The virus serotype in the UK outbreaks of 2001 has been identified as a serotype O PanAsia lineage virus (Knowles et al. 2001), and this is the serotype of primary interest in this risk assessment report. This particular serotype was selected because it is the one that has recently caused widespread epidemics in Europe, and sufficient literature was available to parameterize the model for this strain.

Host species

The host species for FMD virus are all cloven-hoofed animals. Those of greatest significance are found among domestic species: cattle, pigs, sheep and goats. Besides cloven-hoofed domestic animals, wild ruminants, wild boar (*Sus scrofa*), African buffalo (*Syncerus caffer*), llamas and camels are also susceptible to FMD, but the risk of spread of the infection by wildlife is not well known. African buffalo (*Syncerus caffer*) are, however, known to play an important role in FMD epidemiology in Africa, where FMD is endemic and the buffalo can be a long-term carrier of the virus. In other countries, wildlife is not regarded to play an important role in the transmission of FMD, and as long as the infection is eradicated from the country the wildlife is not regarded to be able to spread the virus back to domestic animals (Anderson 2003). For instance, after a serosurveillance with negative results performed after the Dutch FMD outbreak in 2001, Elbers et al. (2003) concluded that wild boar and roe deer

(*Capreolus capreolus*) would be very unlikely to transmit FMD to cattle. Additionally, camelids (llama, alpaca and dromedary and Batrician camel) are found not to be as susceptible and not as efficient transmitters of FMD as cattle, sheep, goats and pigs (Wernery & Kaaden 2004; Alexandersen et al. 2008). On the other hand, Highfield et al. (2008), consider white-tailed deer (*Odocoileus virgianus*) to be a potential host species of FMD. There is a lack of information on Finnish moose (*Alces alces*) and reindeer (*Genus Rangifer*) and their susceptibility to FMD. It seems that elk (*Cervus elaphus nelsoni*) in North America are fairly insensitive to FMD and develop only mild clinical disease, and are also rather unable to transmit the virus (Rhyan et al. 2008).

FMDV may also occur in non-cloven-hoofed wild animals, such as rodents, hedgehogs, elephants and grizzly bears (Meyer & Knudsen 2001). Horses and other hoofed animals are considered resistant to FMD.

FMD is not considered zoonotic. Humans are very rarely infected by FMD, but in those unusual cases, influenza-like symptoms or vesicular lesions can be seen. In humans, the disease is usually mild and self-limiting (CFSPH 2007).

Pathogenesis

The virus most commonly enters through the naso-pharyngeal area or the lungs, but infection may also occur through a skin injury (Kitching 2002). The virus starts to replicate in the upper respiratory tract (pharynx), mucosa or skin. Thereafter, the FMD virus enters the bloodstream, muscles, lymph glands, bone marrow and organs (Alexandersen et al. 2001). The virus is excreted during viraemia (Davies 2002), and the viraemic stage is considered the period when the animal has the highest and most widespread virus titres in its tissues (Ryan et al 2008). There is, however, a considerable difference between animal species in the amount of virus excreted (see below “disease transmission). Antibodies appear three to five days and the early antibodies (IgM and IgA) peak 10–14 days post-infection (Salt 1997; De Clercq 2003). Animals stop being infectious when the lesions heal (Davies 2002). After this there is a lower probability of virus in the carcass and organs (Sutmoller 2001).

Incubation time

The incubation time is dependent on the dose, virus strain, route of transmission and susceptibility of the individual host (Kitching 2002; Quan et al. 2009). A smaller infectious dose requires a longer time to develop into clinical disease (Alexandersen et al. 2001). In general, the incubation time for cattle and pigs is approximately between 2–7 days (Sutmoller et al. 2001; Gibbens et al. 2001; Alexandersen & Mowat 2005; Ryan et al. 2008). It might last for up to two weeks (Kitching & Hughes 2002; Grubman & Baxt 2004; Ryan et al. 2008), or be as short as 1 day (Meyer & Knudsen 2001; Alexandersen et al. 2003b; Quan et al. 2009). The incubation time in sheep is reported to usually be 3–8 days (Kitching & Hughes 2002; Quan et al. 2009).

Clinical signs

The clinical signs appear with different intensity depending on the virus strain, infectious dose, species and the individual susceptibility of the host (Kitching 2002; Quan et al. 2009). Cattle are the most sensitive to FMD, but swine and sheep are also severely affected. The signs are apparent for 7–10 days (Alexandersen et al. 2001), but in sheep vesicles may be visible for less than three days (Kitching & Hughes 2002). However, virus excretion usually starts 1–5 days before vesicles are apparent.

The first signs in cattle are usually fever (around 40 °C) (Kitching 2002), depression, decreased milk production and a reluctance to eat. Vesicular lesions on the tongue, nose, feet and teats, lameness and drooling develop within 12–24 hours from the first signs (Sutmoller 2001; Kitching 2002). Lameness and drooling are due to vesicular lesions and erosions on the feet and mouth, respectively. The mortality rate is low, except in young animals, but the morbidity rate is very high. According to Orsel et al. (2006), calves show milder clinical signs than cows; however, young calves may die due to virus invading and destroying developing heart muscle (myocarditis) (Kitching 2002).

The clinical disease in pigs is dominated by lameness and a reluctance to stand due to painful foot lesions. Vesicular lesions in the mouth are less prominent than in cattle, but large vesicles that quickly rupture are common on the snout.

FMD in sheep is difficult to detect due to mild clinical signs (Barnett & Cox 1999). The duration of viraemia in sheep is 1–5 days. The first clinical signs that appear about three days after the onset of viraemia in sheep, goats and wild ruminants are foot lesions accompanied by lameness. Sheep and goats also develop fever, are reluctant to walk and may separate themselves from the rest of the flock. Vesicles are not as common and more difficult to observe in sheep and goats. Deaths occur (up to 90% of an affected flock) among young lambs and kids due to heart failure and without the appearance of vesicles (Kitching & Hughes 2002).

Detection of FMD

The period between the first infection and first detection of disease is called the high risk period (HRP) and is considered crucial for the range of disease transmission. During the last epidemics, the HRPs are estimated to have been around 12–21 days in the UK in 2001 (Gibbens et al. 2001; Scudamore & Harris 2002; Tomassen et al. 2002; McLaws & Ribble 2007) and 24 days in the Netherlands in 2001 (Tomassen et al. 2002). In recent epidemics in Europe (McLaws & Ribble 2007), HRPs have typically lasted 2–3 weeks.

The first suspicion of the 2001 FMD outbreak in the UK was raised at an abattoir in the ante-mortem inspection of pigs. The clinical signs observed in 27 animals were lameness and vesicular lesions in their interdigital clefts and around the coronary bands, but no vesicles were visible on their snout or in their mouths and they did not have any fever (Gibbens et al. 2001; Alexandersen et al. 2003a).

The clinical signs of FMD are most obvious in high yielding dairy cattle and in intensively reared pigs. In adult sheep and goats, FMD is usually only a mild disease and the clinical signs in these animals can easily be missed by the farmer or veterinarian (Kitching et al. 2005). However, as stated by Sutmoller (2001): "If none of the cattle in the herd have developed macroscopic lesions, the herd is likely to pass all farm and slaughterhouse inspections." A rule of thumb is that if vesicles or vesicular lesions are observed in the mouth region or feet of cattle, pigs, sheep or goats, it is to be suspected as an FMD infection until the suspicion is out ruled. According to Gibbens et al. (2001), FMD has been detected earlier in cattle than in sheep, probably due to the degree of morbidity or more intense management of cattle compared to sheep.

FMD has most often been detected through a farmer alerting a veterinarian, through routine surveillance activities, ante mortem inspection at slaughterhouses, or more seldom by someone else (McLaws & Ribble 2007).

After the identification of the first case in an epidemic, determination of the FMD status can be fairly accurately based on clinical signs only (McLaws & Ribble 2007). A clinical diagnosis is easier to make for pigs and cattle than for sheep (McLaws et al. 2006).

Disease transmission

The virus is excreted in aerosols and in all secretions including urine, faeces, saliva, milk and semen. Transmission between infected and susceptible animals mainly occurs through the respiratory route by virus aerosols.

Cattle are the most sensitive animals to FMDV aerosols. They are mainly infected via the respiratory route and considered as an "indicator host" for the disease. Pigs are relatively resistant to airborne FMDV infection compared to cattle and sheep (Alexandersen & Donaldson 2002; Donaldson & Alexandersen 2002). According to Sørensen et al. (2000), pigs require a 128 times higher dose of virus than cattle to become infected by the airborne route. Pigs are mainly infected by direct contact with infected animals or ingestion of contaminated food or other materials.

Virus excretion already begins during the incubation period, and airborne excretion mainly occurs during a 4- to 5-day period in the infected animal (Sellers & Parker 1969; Donaldson et al. 2001). The maximal excretion occurs during the early acute phase of the disease, i.e. the peak is when the vesicles appear (Alexandersen et al. 2003b). The expression of clinical signs correlates positively with the ability to transmit infection (Quan et al. 2009). Virus can be excreted in the milk before clinical symptoms occur (Reid et al. 2006). Sheep differ from other species with their maximum viral emission 1–2 days before the onset of clinical disease (Donaldson & Alexandersen 2002).

Pigs are considered an "amplifying host" because they act as effective disease transmitters, exhaling more infective virus particles than cattle and sheep (Donaldson & Alexandersen 2002). As the number of animals is usually 10–50 times larger in a pig farm than in a cattle farm, pig farms are more potent emitters than cattle farms. Different coefficients indicating the relative efficiencies of pig and cattle farms in emitting FMDV have been used in earlier simulation studies. Yoon et al. (2006) considered pig farms as 5 times more infective than cattle farms. Ward et al. (2009) considered only pig farms and large feedlot farms with over 50 000 cattle as possible sources of windborne spread. Because feedlots were 20 times larger than pig farms in the study of Ward et al. (2009), it was assumed that a cattle specimen is therefore at least 20 times less efficient as an emitter than a pig. Larger differences between species have also been applied, for instance by Rubel et al. (2004), who assumed in their worst-case scenario that pigs are over 1000 times more efficient emitters than cattle.

Due to their smaller lung volume, sheep excrete fewer viruses than cattle and pigs. In contrast to pigs and cattle, FMD can spread in a sheep herd without visible clinical symptoms.

Carriers

Animals that have recovered from the disease may remain as infective carriers for a variable period of time. A carrier is defined as an animal from which the virus can be recovered 28 days post-infection (Davies 2002). Under experimental conditions, up to 50% of cattle can remain infective for weeks, months, or in extreme cases for several years. Sheep and goats less frequently remain as carriers than cattle (Sutmoller et al. 2003), and for a shorter period of time of up to 6–9 months (Doel 2003; Wernery & Kaaden 2004). Pigs do not remain persistently infected (Fenner et al. 1987; Davies 2002). Among wildlife, the African buffalo (*Syncerus caffer*) is considered to act as an important carrier of FMD in Africa (Anderson 2003).

Vaccination does not stop the virus from entering the body. In other words, vaccinated individuals can also be carriers of the virus that they are vaccinated against. Vaccinated animals may intermittently emit virus, but significantly less than unvaccinated infected animals.

Transmission routes

Previously developed models offer an insight into how separate epidemiological experiments and field observations have been summarized into a set of contact routes that are believed to be able to spread FMDV. Morris et al. (2001) and Stevenson (2003) applied a version of an InterSpread model in the prediction of FMD spread. The model contained several contact routes to spread the disease. These included direct animal contact, animal transportation vehicles and dairy tankers, persons visiting the farm, neighbourhood and airborne spread. According to Morris et al. (2001), the model operated reasonably well in the prediction of the final epidemic, as confidence interval was around the observed final size. A similar analysis in Cumbria later on led Stevenson (2003) to the same conclusion.

Airborne transmission

Aerosols containing FMDV may transmit the virus through the air. Aerosols have travelled very long distances, in exceptional cases up to 250 km (Donaldson et al. 1982; Donaldson & Alexandersen 2002). The airborne spread of virus is dependent on the wind direction and speed and favoured by high humidity, low temperature, and overcast skies (Donaldson, 1972). The virus is highly dependent on the relative humidity for survival. Humidity below 60% will rapidly destroy the airborne virus (Gloster et al. 2005). Airborne spread has in several models been applied as species-specific. Rubel et al. (2004) simulated the spread of virus from swine and concluded that in a worst-case scenario, 10 infected pigs were able to infect cattle 5 km, sheep up to

0.7 km and swine up to 0.2 km downwind in moderate wind conditions. Velthuis & Mourits (2007), Stevenson (2003) and Morris et al. (2001) all have applied species-specific correction factors that in practice mean that airborne spread is possible from pigs to cattle and sheep, but the relevance of cattle and sheep as a source of airborne spread is less important. In a recent Dutch study examining between-pen transmission of FMD – when only airborne transmission was possible – the ability of pigs to spread the disease, even within the same unit, appeared to be 10–20 times lower than within the pen (van Roermund et al. 2010). The results indicated that airborne spread between pig farms is probably not relevant.

In several InterSpread-based FMD simulations, airborne spread has been assumed to be relevant in a kernel of 3 km around the infected farm (for instance Sanson et al. 2006). Similar results have previously been observed by Taylor et al. (2004) in northern Cumbria, where most of the spread was observed to occur within 3 km from the farm. Larger kernels have also been applied, for instance a kernel with a tail of up to 5 km in the Netherlands (Boender et al. 2010). Such a kernel was also applied in some models developed for the UK outbreak (Ferguson et al. 2001; Keeling et al. 2001; Yoon et al. 2006). Both airborne spread kernel and probabilities have been subject to species-specific estimates and variability in recent modelling literature on FMD.

Transmission by contact

The movement of infected live animals is one of the most important routes of infection. Infected animal products, fomites and indirect contact may also transmit FMD virus (Valarcher et al. 2008).

Transportation vehicles have been assumed to be an important transmission route in several FMD outbreaks and simulation models. If vehicles are considered as medium risk contacts, then the usual infectivity of vehicle contact would be 1/3 to 1/5 of the infectivity of direct animal contact (Stevenson 2003; Velthuis & Mourits 2007; Ward et al. 2009).

Milk tankers were involved in the 1967/68 FMD epidemic in UK by spreading FMDV-infected milk aerosols and as a source in the spread in the UK epidemic in 2001 (Gibbens et al. 2001). Milk tankers were also included as a component of spread models applied in the UK in 2001 (Stevenson 2003). In simulation models, milk tankers are considered to posses a very low risk, as one contact can have less than 1.5% of the infectivity of one direct animal contact (Stevenson 2003).

Clinical examinations of animals in the incubation phase pose a high risk of transmission of the disease via the contamination of persons (veterinarians) who are unaware of the risk of spreading the disease. Humans are able to carry the virus in the respiratory system or in the lung residual air (Jones 2007). Humans who might have been exposed to infected animals should avoid direct contact with ruminants for 3–5 days (Sutmoller et al. 2003). Humans in close contact with infected animals can carry and transfer FMDV on their skin, hair, clothes and in their nasopharyngeal area (Sutmoller et al. 2003; Jones 2007), and transmission occurs via direct contact to susceptible individuals. People can carry the virus in their nasopharynx for more than 24 (to 48) hours, which has been considered a risk for transmission of the disease. Veterinary surgical instruments and insemination equipment have transmitted the infection in

Denmark (1982) and in Italy (1993). FMDV can also be spread through vehicles and ova. In simulation models, human contacts are considered as a low risk, having 1/20 to 1/40 of the infectivity of direct animal contact (Stevenson 2003; Velthuis & Mourits 2007).

Neighbourhood transmission

Neighbourhood spread includes indirect spread by rodents, birds, dogs, cats and other contacts that show spatial tendencies, or where the contact route remains unidentified. Neighbourhood transmission can be modelled, for instance, as a fixed transmission probability within a given distance from an infected farm (Taylor et al. 2004; Velthuis & Mourits 2007) or as a declining function with increasing distance (Stevenson 2003). Species-specific corrections are not usually applied in neighbourhood transmission.

5.1 Livestock production in Finland

Finnish farms

The agricultural sector in Finland has experienced a major structural change in the last few decades. The number of pig and cattle producers has decreased during recent years, whereas the herd size has increased, and the number of pigs and cattle has thus remained quite stable. Finnish pig and cattle farms are typically family owned and their average size is still quite small from a European perspective (Table 1). The Finnish cattle population is 1/10, the pig population 1/3 and the sheep population 1/300 of the population in the UK.

Table 1. Number of live animals and holdings in some European countries: a comparison from 2007 (EFSA 2009; NVI 2007).

Country	Cattle	Cattle holdings	Pigs	Pig holdings	Sheep	Sheep holdings
Finland	926 694	18 624	1 448 041	2 744	119 252	1 885
Sweden*	1 590 409	25 054	1 680 535	2 414	505 466	9 152
Norway*	918 200	20 500	813 800	3 000	2 334 200	16 000
Denmark	1 545 000	24 883	13 900 000	12 342	180 641	na.
Netherlands	3 762 784	48 256	11 662 654	11 234	1 369 343	29 505
United Kingdom	8 998 377	79 760	4 834 000	na.	33 946 000	na.

*2006; na. = not available

Pig production

Number of farms and animals

There were 3225 pig producers and about 1.44 million pigs in Finland on 1 May 2006. Of the Finnish farms, 228 (1% of all pig and cattle farms) had both pigs and cattle (Table 2).

The pig farms were classified into three groups based on their type of production:

1. farrowing farms,
2. farrowing-to-finishing farms,
3. finishing farms.

These production types were equally represented in Finland (Table 2). The production type classification is our own and is based on the number of sows and the ratio of finishing pigs to sows on the farm. If there were <2 finishing pigs per one sow, the farm type was classified as a farrowing farm, and if there were >2 finishing pigs per one sow, the farm type was classified as a farrowing-to-finishing farm. A finishing farm is a farm without any sows. Farrowing herds are linked by animal transportation with finisher herds, as they deliver piglets, while farrowing-to-finisher herds are self-sufficient in piglets and hence are less connected with other pig farms.

Table 2. Pig farm types in Finland (Finnish Farm Registry 2006).

Farm type	Number of farms
Farrowing farm	1 090
Farrowing-to-finishing farm	1 046
Finishing farm	1 089

The number of pigs on the farms varies. Statistics for the number of pigs are based on mandatory monthly notifications by farmers and on subsidy notifications, which are given on 1 May every year. For example, while the mean number of sows in a farrowing herd was 96, the maximum number was 1900 sows (Table 3). The mean number of piglets per sow on a farm was 5.7 (Finnish pig registry 2006) and was not included in Table 3.

Twenty-nine percent (29%) of the farms that had fattening pigs were managed by the all-in-all-out principle, 48% had a continuous flow system and 23% were compartmental all-in-all-out systems. Ca. 65% of farms had only one building for pigs and 23% had two buildings, although maximum number of buildings was six. Typically, farms had only one holding in the farm registry (82%), so buildings are often within a 2 km range and are regarded as one holding. Six percent (6%) of the farms offered pigs an opportunity to go outside for at least part of the year (see the questionnaire to pig farmers in 2007 in the data sources section).

Table 3. Number of pigs on different farm types (Finnish Farm Registry 2006).

Farm type	Number of sows			Number of finishers		
	maximum	mean	median	maximum	mean	median
Farrowing farm	1 900	96	51	2 306	69	28
Farrowing-to-finishing farm	1 210	69	46	4 183	318	209
Finishing farm	19	0	0	3 668	446	299

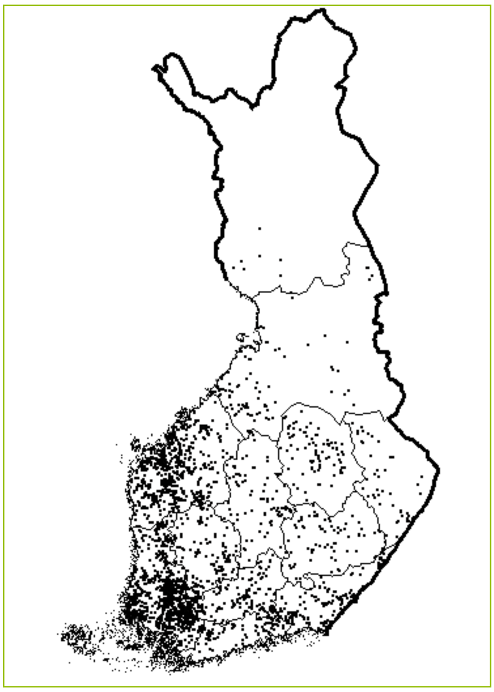

Figure 1. *Location of pig farms (n = 3225) in Finland in 2006. Each dot represents one farm. Finnish pig farms are concentrated in western and south-western Finland.*

The location of pig herds in Finland is presented in Figure 1. Pig production in Finland is largely concentrated in south-western and western Finland (PVO districts Vaasa and Turku) (Table 4), which together hold for two-thirds of the Finnish pig farm population.

Table 4. Number of pig farms in different PVO districts in 2006.

PVO district	Number of farms	Percent	Number of holdings	Percent of holdings
Helsinki	105	3.3	125	3.3
Vaasa	974	30.2	1 183	30.6
Oulu	108	3.3	120	3.1
Lappi	10	0.3	12	0.3
Turku	1 151	35.7	1 370	35.5
Hämeenlinna	238	7.4	291	7.5
Tampere	153	4.7	178	4.6
Kouvola	172	5.3	205	5.3
Mikkeli	73	2.3	86	2.2
Joensuu	50	1.6	59	1.5
Kuopio	95	2.9	115	3
Jyväskylä	96	3	118	3.1
Total	**3 225**	**100**	**3 862**	**100**

There is no concentration of pig production types in certain areas. The largest farrowing herds are located in Lappi and Oulu PVO districts, but the number of farms in these districts is low. Large finishing herds are more evenly distributed, but the smallest ones are in Joensuu and Jyväskylä (Table 5).

Table 5. Number of pigs (mean) on different farm types in Finland in 2006.

PVO district	Farrowing farm		Farrowing-to-finishing farm		Finishing farm	
	sows	finishers	sows	finishers	sows	finishers
Helsinki	96	79	59	261	0	489
Vaasa	97	59	62	337	0	497
Oulu	126	89	71	297	0	423
Lappi	181	19	25	134	0	411
Turku	102	78	82	355	0	476
Hämeenlinna	97	82	63	307	0	442
Tampere	91	89	63	240	0	314
Kouvola	76	53	58	232	0	313
Mikkeli	85	38	27	123	0	386
Joensuu	45	12	56	281	0	245
Kuopio	107	120	60	207	0	398
Jyväskylä	57	48	52	198	0	239
Total	**96**	**69**	**69**	**318**	**0**	**446**

Special production structures

Special production structures form a relatively small part of Finnish pig production, but their practices may differ from conventional production.

Sow pools

There were 22 sow pools in Finland in 2006 (ETU register 2006), and altogether 90 satellite units. Four percent (4%) of the Finnish pig farms belong to these pools. Five percent (5%) of 571 respondents of the farm questionnaire were members of a sow pool and 2% had a central unit of the pool (questionnaire to pig farmers 2007).

In sow pool systems, all dry sows are kept at a central unit and before farrowing they are leased by piglet producing units (satellites). Following weaning, the sows are returned to the central unit for mating or insemination. The system is operated in cycles of 16 weeks at the satellites, starting with the arrival of pregnant sows three weeks prior to farrowing, followed by weaning in this unit at 5 weeks of age and the return of sows to the central unit before the arrival of a subsequent group of sows eight weeks later.

Artificial insemination (AI) farms

FABA Sika Oy produces and delivers semen. Their boar stations were situated in Ilmajoki and Kaarina (Kaarina station was closed down in 2009). The leading slaughterhouse companies purchasing pigs in Finland (LSO Oy and A-tuottajat) had their own semen production (Finnpig Oy) for their own farmers.

AI centres received boars from performance test stations and elite breeding farms. AI centre boars were only distributed to slaughterhouses.

Performance testing stations

Performance tested pigs were brought to the testing stations from elite breeding herds at approximately 25 kg (10–12 weeks) and were distributed to slaughterhouses or to AI centres. Suomen Sianjalostus Oy, a subsidiary of FABA, had 4 performance test stations. Finnpig Oy (owned by LSO Oy and A-tuottajat) also had its own performance test station for boars.

Elite breeding farms

Breeding animals were moved from the elite breeding farms to some of the following: another elite breeding farm, AI centres, a performance test station, a multiplying farm, farrowing farms, farrowing-to-finishing farms, finishing farms or directly to the slaughterhouse. Breeding pigs were raised on 93 farms and cross-breeding pigs on 63 farms. These were partly the same farms.

Multisite systems and other networks

Four percent (4%) of the farms were members of a multi-site system and 10% were part of some other sort of joint production (questionnaire to pig farmers 2007). A multisite system consists of a number of herds that form a chain, through which all animals pass from birth until slaughter. Each herd in this chain is specialised in only one production stage. A multisite system consists of one or several farrowing herds where the insemination of sows and the weaning of piglets take place simultaneously. The piglets from one or several farrowing herds are reared at a separate rearing facility from where the young finishing pigs are distributed to several finishing herds. On the contrary, it is also possible that several small farrowing herds have joined and deliver piglets together to one or more large finisher unit/s without an intermediate phase.

Cattle production

Number of farms and animals

On 1 May 2006 there were 20 211 farms with cattle and about 950 000 bovines in Finland. As for pigs, the number of cattle is based on farmers' subsidy notifications, which are given on 1 May.

Cattle farms were classified into seven types based on different factors. These factors were:

1. the main line of production (dairy or beef),
2. regular visits of a milk transport lorry to the farm,
3. participation in the national milk surveillance, indicating regular inspector visits, and
4. whether the farm had received or delivered cattle to other farms (Table 6).

Table 6. Cattle farm types in Finland (Finnish Farm Registry 2006).

Farm type	Milk collection	Animals to other farms	Animals from other farms	Dairy cows	Suckler cows	Number of farms
Closed dairy farm, "self-sufficient"	yes	no	yes/no	yes	yes/no	2 717
Dairy farm	yes	yes	yes/no	yes	yes/no	12 188
Finishing beef cattle farm	no	no	yes/no	no	no	2 197
Weaner farm*	no	yes	yes/no	≤ 3	no	288
Closed suckler herd farm, "self-sufficient"	no	no	yes/no	yes	yes	971
Suckler herd farm	no	yes	yes/no	yes	yes	946
Other cattle farm**	no	no	yes/no	yes	no	904

*identification from registers is problematic, true number is ca. 50 farms (in 2009)

**no dairy collection, no animal transportations, typically the number of animals is small

About 78% of the herds were dairy cattle, and hence formed the most common cattle farm type in Finland (Table 6). Altogether, 76% of questionnaire respondents had a cow house, 13% had a farm cow shed and 15% a cold cow shed. Some 3% of respondents produced organic milk or meat. Farms usually started the grazing season in May or June and finished it in September or October, so that it typically lasted 4 to 6 months (questionnaire to cattle farmers 2007). The number of dairy cows and other cattle varies on different farm types (Table 7).

Table 7. Number of cattle on different farm types in Finland (Finnish Farm Registry 2006).

Farm type	Number of dairy cows			Number of other cattle		
	maximum	mean	median	maximum	mean	median
Dairy farm	209	23	20	304	9	4
Beef cattle farm*	3	0	0	1 913	65	39
Suckler farm	96	2	0	594	50	33
Other	71	5	4	436	9	3

*beef cattle farm includes finishing and weaner farms

Cattle production is concentrated in the PVO districts of Vaasa, Oulu and Kuopio (Table 8, Figure 2). There is no clear difference in the number of dairy cattle between PVO districts. However, beef cattle herds are clearly larger in Vaasa and Kuopio than in the rest of the country, and big suckler farms are mainly represented in Oulu (Table 9).

Table 8. Number of cattle farms in Finland in 2006.

PVO district	Number of farms	Percent of farms	Number of holdings	Percent of holdings
Helsinki	557	2.8	575	2.8
Vaasa	3 988	19.7	4 065	19.7
Oulu	3 177	15.7	3 230	15.6
Lappi	864	4.3	875	4.2
Turku	1 578	7.8	1 632	7.9
Hämeenlinna	1 134	5.6	1 167	5.7
Tampere	1 102	5.5	1 127	5.4
Kouvola	1 191	5.9	1 220	5.9
Mikkeli	1 379	6.8	1 413	6.8
Joensuu	1 427	7.1	1 460	7.1
Kuopio	2 446	12.1	2 525	12.2
Jyväskylä	1 368	6.8	1 396	6.7
Total	**20 211**	**100.0**	**20 685**	**100.0**

Table 9. Mean number of cattle on different farm types in Finland in 2006.

PVO district	Dairy farm[a]		Beef cattle farm[b]		Suckler farm[c]		Other cattle farm[d]	
	dairy cows	other cattle	dairy cows	other cattle	dairy cows	other cattle	dairy cows	other cattle
Helsinki	28	7	0	58	1	30	5	7
Vaasa	26	13	0	80	2	49	7	13
Oulu	23	10	0	76	3	72	6	11
Lappi	21	7	0	76	2	54	5	16
Turku	22	8	0	57	2	55	4	8
Hämeenlinna	24	7	0	55	2	46	5	6
Tampere	24	7	0	42	1	39	4	5
Kouvola	23	6	0	50	1	45	6	3
Mikkeli	20	7	0	52	2	38	5	6
Joensuu	21	8	0	59	1	55	5	10
Kuopio	23	8	0	82	2	51	7	16
Jyväskylä	21	7	0	59	1	47	6	5
Total	**23**	**9**	**0**	**65**	**2**	**50**	**5**	**9**

[a] both types of dairy farms,

[b] weaner and finisher farms,

[c] both types of suckler farms,

[d] other cattle farms

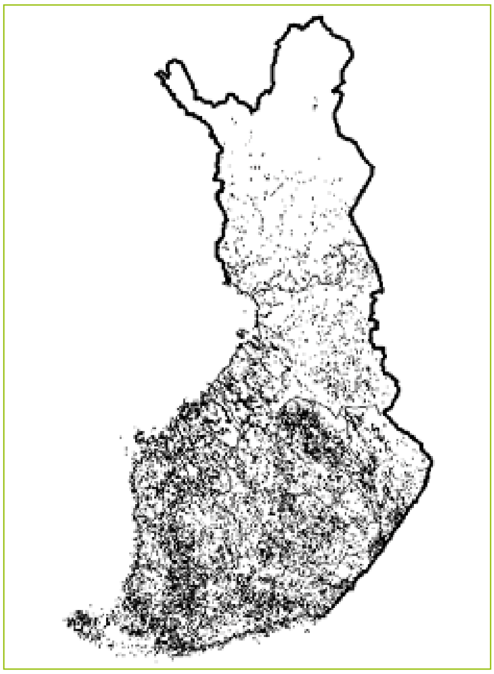

Figure 2. *Location of cattle farms (n = 20 211) in Finland in 2006. Each dot represents one farm.*

Special production structures

Organic farming

The number of organic animal farms in Finland is low in both pig and cattle production. Organic production is much more common in the cattle sector (Table 10).

Table 10. Number of organic animal farms and the number of animals at the farms during 2007 in Finland (TIKE 2008) and their proportion (%) of all farms.

Species	Number of animals on organic animal farms	Percent out of total number of animals (%)	Number of organic animal farms	Percent out of all farms (%)
Cattle	18 261	1.9	368	1.9
Pig	2 050	0.1	15	0.5

Bull stations

FABA Palvelu is responsible for semen production in Finland. The bull breeding station is located in Muhos and the semen production is in Pieksämäki. Approximately 40 young bulls are in production at the same time.

Weaners

Calves aged 1–2 weeks are moved to a special rearing farm (weaner farm), where they are raised until they are 5–6 months old and then moved to a final rearing farm until they are 15–18 months old. The number of weaner herds is difficult to determine from registry data, as other farms may resemble the weaner farm definition (Table 6). According to meat companies, there were approximately 50 weaner farms in 2009.

Co-production of pigs and cattle

Altogether, 228 farms (1% of all pig and cattle farms) had a combination of cattle and pigs in 2006. Every PVO district had at least one farm that produced both animals, although most of these farms were located in the Vaasa and Turku PVO districts (Table 11).

Table 11. Number of farms that have both cattle and pigs in Finland in 2006.

PVO district	Number of farms	Percent out of mixed farms
Helsinki	13	5.7
Vaasa	68	29.8
Oulu	7	3.1
Lappi	1	0.4
Turku	57	25
Hämeenlinna	18	7.9
Tampere	17	7.5
Kouvola	13	5.7
Mikkeli	11	4.8
Joensuu	5	2.2
Kuopio	8	3.5
Jyväskylä	10	4.4
Total	**228**	**100**

The number of pigs and cattle on the farms correlated significantly (Pearson $r = 0.485$, $p = 0.01$) (Table 12): if a farm produced a relatively large number of pigs, it also had a high probability of having a relatively larger number of cattle than if it only had a small number of pigs. In comparison with a typical farm that produces only either cattle or pigs, the farms with mixed production were usually smaller (Tables 3, 7, 12).

Table 12. Mean, median and maximum number of different animal groups on farms that have both pigs and cattle, in 2006.

Animal	Number of animals		
	maximum	mean	median
Sows	708	23	1
Finishers	1 764	151	31
Dairy cattle	263	13	2
Other cattle	529	33	9

Farm density in Finland

The farm density in Finland is low (Table 13, Figure 3). The farms are also clustered in a relatively small area. In larger areas the average density drops and is only a fraction (1/2 to 1/7) of the estimate that is based on a 3 km radius around a farm. Similarly, relative variation within the country also decreases with increasing radius. Within a 3 km radius the coefficient of variation of farm density is 76%, but within a 20 km radius the figure is only 60%. The maximum density in an area within a 10 km radius around a farm is only one-third of the maximum density within a 3 km radius around a farm.

Table 13. Average and 95th percentile of the number of farms around a farm in a given PVO district in 2006.

PVO district	Number of farms			Farm density/squared km	
	3 km	3-10 km	10-20km	mean	<97,5%
Helsinki	4.8 (11)	28.7 (53)	87.9 (178)	0.17	0.39
Vaasa	12.1 (29)	62.9 (119)	178.7 (279)	0.43	1.03
Oulu	8.7 (30)	36.8 (122)	101.2 (247)	0.31	1.06
Rovaniemi	3.7 (10)	8.9 (28)	22.7 (71)	0.13	0.35
Turku	7.7 (18)	49.7 (100)	143.2 (253)	0.27	0.64
Hämeenlinna	6.6 (14)	42.2 (80)	122.3 (217)	0.23	0.50
Tampere	5.6 (12)	35.3 (69)	111.2 (189)	0.20	0.42
Kouvola	6.5 (16)	41.0 (81)	96.5 (169)	0.23	0.57
Mikkeli	4.7 (11)	29.0 (56)	86.9 (139)	0.17	0.39
Joensuu	6.8 (17)	36.8 (76)	86.7 (152)	0.24	0.60
Kuopio	7.9 (19)	52.3 (107)	147.9 (276)	0.28	0.67
Jyväskylä	5.4 (18)	25.8 (51)	74.3 (124)	0.19	0.64

*densities are estimated within a 3 km radius around a farm

Farm density varies between PVO districts and according to the radius applied in analysis. In a single protection zone there would be 8 farms and one infected farm. In a single surveillance zone there would on average be 43 additional farms. In a 10 km wide area surrounding a surveillance zone there would on average be 122 farms. In the district of Vaasa there would be over three times more farms in a single protection zone than in Rovaniemi PVO district. Relative differences are even greater when surveillance zones are compared, as the difference between Vaasa and Rovaniemi PVO districts is seven-fold. (Table 13).

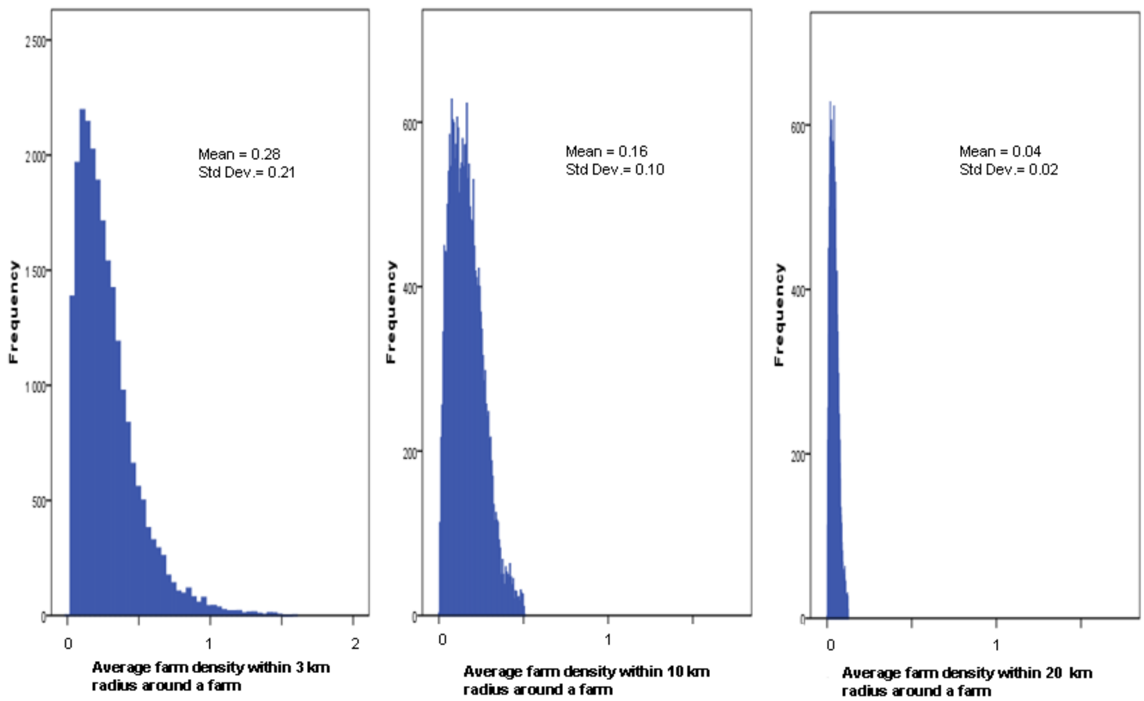

Figure 3. *Farm density (farms per km²) around a farm in Finland estimated by three different radiuses (3, 10 and 20 km) in 2006.*

Co-operation between farms

When pig farmers were asked about co-operation between farms, 21% reported that they used the same equipment for manure transport (questionnaire to pig farmers 2007). However, almost 60% of respondents stated that they had no co-operation with other farms. Buying and selling of services was also quite rare, as only 8% had sold manure spreading services and 11% threshing services. Altogether, 70% of farms had not sold any services. The most common services that farmers bought were manure spreading (16%) and maintenance services (7%); 65% of farms had not bought any services.

When cattle farms were asked about co-operation between farms, 34% told that they used shared forage harvesting equipment and 24% shared equipment for manure transport. Almost 40% of respondents reported that they had no co-operation with other farms. The most common services that cattle farmers bought were forage harvest (28%), threshing (27%), maintenance service of machines (25%) and manure spreading (15%). About one-fourth of the farmers stated that they did not buy any services. Six percent (6%) of cattle farms had hired workers.

Manure

Altogether, 92% of pig farmers and cattle farmers spread manure on their own fields. In addition, 39% of pig farmers and 14% of cattle farmers sold or gave manure to other farms. Pig manure was typically spread on the fields twice a year and cattle manure once or twice a year (questionnaires to pig and cattle farmers 2007).

Biosecurity on cattle and pig farms in Finland

The Finnish Association for Animal Disease Prevention (ETT) is an organisation that promotes animal health and welfare in the Finnish livestock sector. ETT prepares explicit instructions for the import of animals, semen and embryos and supervises every case. It contributes to instructions for farms for the management of disease risks and preventive measures. ETT also draws up rules for the management of animal feed imports and salmonella risks. Additionally, Sikava and Naseva are voluntary health databases for pig and cattle farmers, respectively, maintained by ETT.

There are several ways to enhance biosecurity and decrease the risk of disease transmission between farms. Control measures applied to the trade and movement of animals, including quarantine, vaccination, veterinary inspection and documentation, as well as logistical planning of transport routes, are important ways of avoiding the spread of disease.

The transportation logistics are organised such in a way that contacts between farms are minimized. If there is a known transmissible disease at a farm, it is visited last or separately to avoid contact with other farms. Transport vehicles are cleaned every day and the driver avoids entering the animal buildings. All visitors should also be advised to follow strict hygienic routines when visiting a farm.

Biosecurity measures performed by the producer that may reduce the risk of receiving infection in the herds are several, for instance the use of protective clothing and boots, hand washing, a disinfection foot bath, a separate loading area for animals at the farm and a physical barrier (e.g. a bench) that separates the "clean" area from the "dirty" one.

Biosecurity data, especially the above mentioned, were collected from Finnish pig and cattle farmers through questionnaires (2007) and compared to similar data collected from veterinarians practitioners in Finland (2007) (see data collection in the section on risk assessment).

In general, pig herds have better biosecurity than cattle herds in Finland (Figure 4). The most common measures applied seem to be protective boots and hand washing facilities. On the contrary, barriers and disinfectant footbaths were used less frequently in both the pig and cattle production sectors (Figure 4).

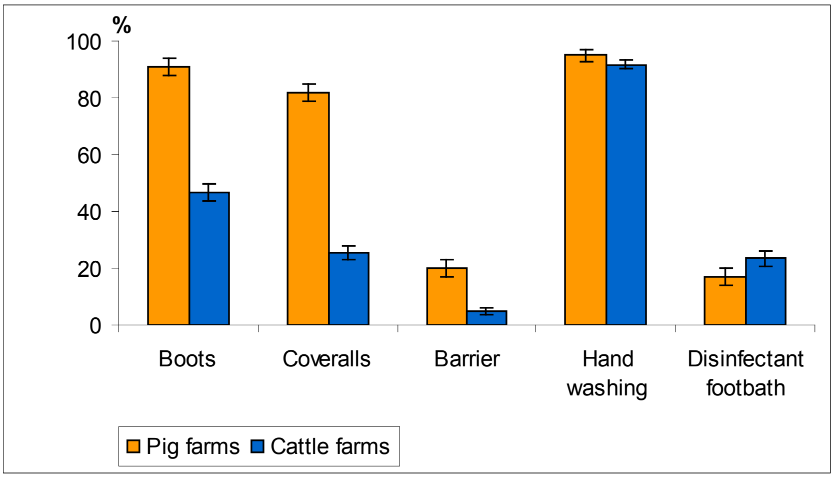

Figure 4. *Biosecurity at cattle and pig farms in Finland. Error bars indicate 95% confidence interval for the mean.*

The analysis of the survey of farmers revealed that biosecurity actions were more frequently used on larger than smaller pig farms (Figure 5).

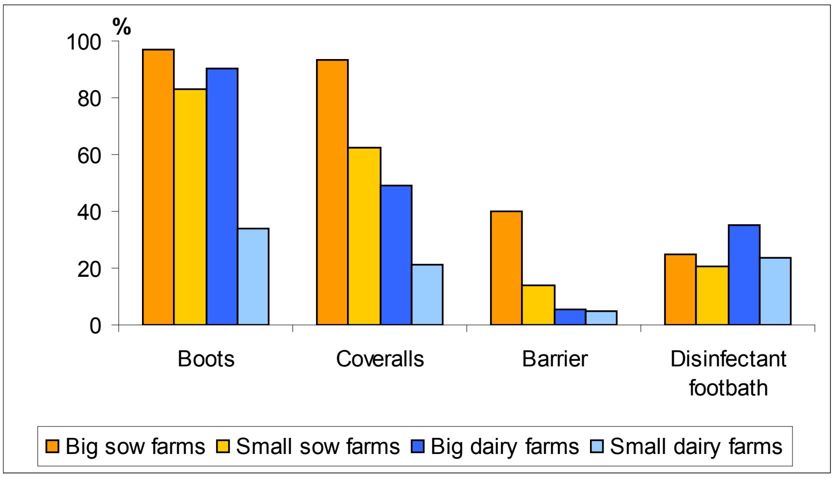

Figure 5. *Comparison of the use of biosecurity measures on large and small sow (farrowing) and dairy farms, respectively.*

The use of biosecurity measures at different-sized farms was estimated by logistic regression. Analysis of the questionnaires to the farmers revealed that biosecurity actions were more frequently used on larger than smaller farms (Figure 5). In the comparison, the largest 10% of farms had on average 55 cows or 490 sows and the smallest 10% of farms had 7 cows or 30 sows.

Sheep and goats

The number of sheep and goats in Finland is relatively small (Table 1, Table14). According to the farmer questionnaires, 4.4% of cattle farms and 1.9% of pig farms also had sheep or goats.

Sheep are mainly kept either for wool or meat production in Finland. The sheep are kept on pasture from May (or from June in the north) to November, if the weather permits. The lambs are mainly slaughtered from September to November (60%), while 20% are slaughtered in spring and 10% during the winter. Goats in Finland are mainly kept for small-scale dairy production (Rosengren et al. 2009).

Other sensitive animal populations

There is a large population of reindeer in the northern parts of Finland in the Rovaniemi PVO district. Moose (Alces alces), on the other hand, are distributed all over the country, except the most distant northern parts of Finland. In the southern parts of Finland and in Åland there is a smaller population of white-tailed deer (*Odocoileus virginianus*).

There is a fairly large population of farmed wild boar (Sus scrofa) in Finland, divided between 150 farms. The unfarmed wild boar population in Finland, however, is small, approximately only 200 but less than 1000 animals situated mainly close to the Russian border. The approximate sizes of the wildlife populations in Finland are presented in Table 14.

Table 14. Number of other FMDV-sensitive animals in Finland.

Species	Number of animals	Number of farms	Description
Goat (*Capra aegagrus hircus*)[a]	6 600	483	Most of the producers are hobby farmers
Farmed wild pig (*Sus scrofa*)[b]	not available	151	Almost half of the farms are located in Pohjois-Savo, Pohjois-Karjala, Pirkanmaa and Pohjois-Pohjanmaa
Wild pig (*Sus scrofa*)[c]	several hundred, <1000	-	Mainly near Russian border in Kymenlaakso and Etelä-Savo
Reindeer (*Genus Rangifer*)[d]	200 000 - 300 000	Reindeer husbandry is practiced by reindeer herding cooperatives (n=56)	Reindeer husbandry area covers almost the entire area of the Province of Lapland and northern part of the Province of Oulu.
Moose (*Alces alces*)[e]	91 000**	-	Almost entire country.
White-tailed deer (*Odocoileus virginianus*)[c]	ca. 30 000	-	In South Finland, originally alien species.
Roe deer (*Capreolus capreolus*)[f]	ca. 25 000	-	In South and West Finland and on the coast of the Gulf of Bothnia
Finnish forest reindeer (*Rangifer tarandus fennicus*)[c]	ca. 1 000	-	Found in Kainuu, and a small population in central south Finland

[a] TIKE 2006

[b] Finnish registry of animal holders 2009

[c] Ermala 2009

[d] Rosengren et al. 2009

[e] FGFRI 2009, data from 2008 after hunting season

[f] Finnish Central Organisation of Hunters 2007

Food industry

Slaughterhouses

In 2006 there were 17 large capacity slaughterhouses (EU establishments) in mainland Finland and one in the Åland archipelago, which slaughtered either pigs or bovines, or both. These slaughterhouses had slaughtered >2000 bovines and/or >2000 pigs per year (Table 15). In 2006 these establishments altogether slaughtered 290 000 bovines and 2.4 million pigs. Hence, they slaughtered a major proportion of the 293 789 annually slaughtered cattle and 2 401 089 pigs (TIKE 2006). The remaining pigs and cattle were slaughtered at one of the 90 low-capacity slaughterhouses approved for the slaughtering of pigs and/or bovines.

Meat can subsequently be traced back to a certain pork or beef herd or to the retail level (one step back and forward). In cases of an outbreak of animal disease, it is essential to know where each animal has been, so that animals likely to have been infected can be traced and isolated from other animals. For bovines, pigs, sheep and goats, there are species-specific directions on identity marking and registration. The identity marking and registration are monitored by inspectors from the Employment and Economic Development Centre, inspecting veterinary surgeons, and municipal veterinary surgeons. Since the beginning of 2005, appropriate identity marking and registration of livestock has been a condition of payment of animal-related subsidies.

Table 15. Slaughterhouses in Finland in 2006 (According to directives 64/433/EEC, 71/118/EEC, 77/99/EEC, 91/495/EEC, 92/45/EEC, 94/65/EC)

Establishment	Number of establishments	Description	Capacity of production
Large capacity slaughterhouses/pigs	6	approved for slaughtering of pigs	78% of pig slaughtering
Large capacity slaughterhouses/cattle	5	approved for slaughtering of bovines	50% of cattle slaughtering
Large capacity slaughter-houses/pigs and cattle	6	approved for slaughtering of pigs and bovines	21% of pig and 49% of cattle slaughtering
Low capacity slaughterhouses	90	approved for slaughtering of pigs and/or bovines	1% of pig and 1% of cattle slaughtering

Several slaughterhouses were owned by same meat production companies: there were only 13 meat production companies with large-scale slaughterhouses.

Large pig slaughtering units are located in areas with a large number of pig farms (Figure 6). Note that since 2006, pig slaughtering has ceased at two slaughterhouses in the eastern parts of Finland. Because cattle farms are more scattered around the country, slaughtering is also more spatially spread (Figure 7).
Meat production companies have different strategies in animal collection. Some companies divide Finland into different collection areas, or the whole county can be the designated collection area for one truck. Trucks are cleaned at least once a day, but usually after each batch. Vehicles vary in size between and within meat companies.

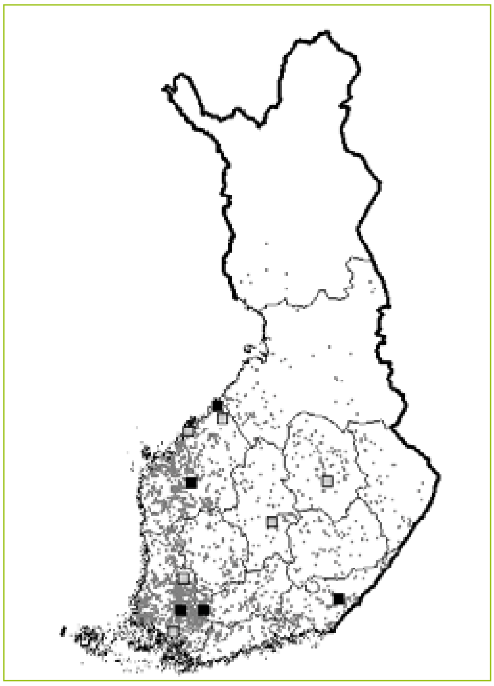

Figure 6. *Locations of the largest pig slaughterhouses in Finland in 2006. Black squares represent pig slaughterhouses (n = 6) and grey squares are pig and cattle slaughterhouses (n = 6). Each grey dot represents one pig farm (n = 3 225).*

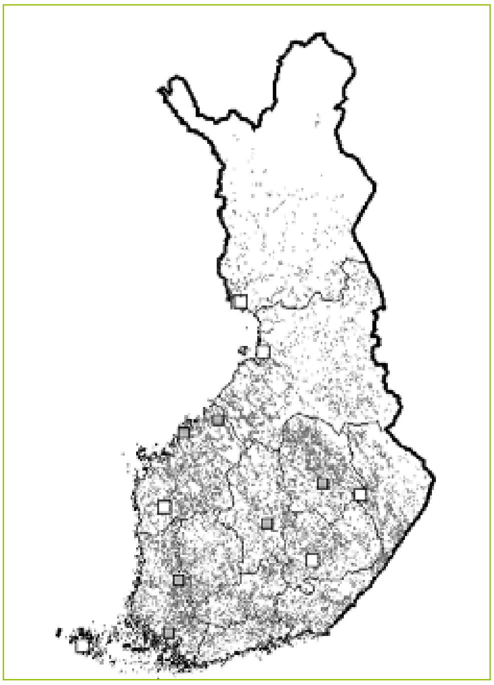

Figure 7. *Locations of the largest cattle slaughterhouses in Finland in 2006. White squares represent cattle slaughterhouses (n = 5) and grey squares are pig and cattle slaughterhouses (n = 6). Each grey dot represents one cattle farm (n = 20 211).*

Dairy plants

Table 16. Approved dairy plants in Finland in 2006 (According to directive 92/46/EEC).

Establishment	Number of establishments	Description
Large dairy	36	>2 000 000 l/year
Small dairy	64	<2 000 000 l/year

There were 100 dairy plants in Finland in 2006 (Table 16) located in areas containing a large number of dairy farms (Figure 8). Milk collection routes are quite stable. Routes are usually altered only twice a year and the same dairy tanker always collects milk in the same order. Milk is typically collected every second day from the same farm. Dairy tanker capacity varies from ca. 12 000 to 40 000 litres. Dairy tankers are cleaned after every collection route.

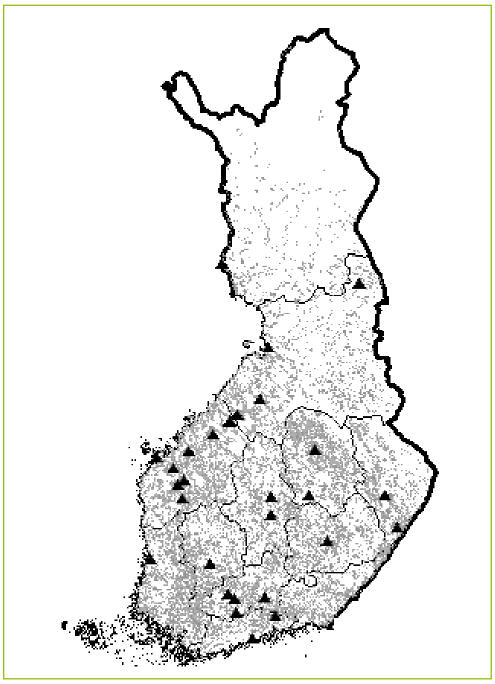

Figure 8. Locations of the largest dairies (n = 36) in Finland in 2006. Each black triangle represents one dairy plant and each grey dot represents one cattle farm (n = 20 211).

Animal transportation

Meat production companies organise pig and cattle transportation to slaughter and the transportation of pigs between farms. However, according to meat production companies and the questionnaires to pig farmers, some farmers arrange transportation between farms themselves, although this is a clear minority (<10%).

The most common way to bring pigs to farms was to use an animal transport company (52%), and the second most common method was transport by the meat production company (29%). The most common way to transport pigs between farms was to consult or turn to an animal transport company (46%) or the meat production company's transport (33%) (questionnaire to pig farmers 2007). Similar information on cattle transportation was unavailable.

Pigs and cattle in Finland are transported by entrepreneurs registered for animal transportation. Registration is mandatory, based on animal transport legislation (MAF 1429/2006). In 2006, there were 212 entrepreneurs registered in Finland for transporting animals (Finnish Animal Transporter Registry 2007). Ten percent of them had a licence to transport cattle, 9% to transport pigs and 81% had licence to transport both animals.

There were 328 EU inspections (EC 1/2005) of animal transportation in 2008. In these inspections, only two flaws concerning the origin or destination of the transport were found in the animal transport documents (Evira 2009c).

Production environment

Relief workers

The Ministry of Social Affairs and Health supervises the provision of relief workers in agriculture. The Farmers' Social Insurance Institution (Mela) is the administrator of this service. Local units composed of one or more municipalities handle the practical arrangements and employ an adequate number of relief workers. There were 135 of these local units in 2006 and 4766 monthly salary-based farm relief workers. The farm relief services include substitute assistance, an annual leave entitlement of 25 days, and subsidized help for 120 hours each year, as well as additional services at full price (Mela 2009).

The most significant sector for relief workers is milk production, but almost all other production types also regularly use relief workers. However, fattening pig farms use relief workers more seldom than other farm types. Approximately 10% of relief workers had their own farm, lived on a farm or worked on two farms simultaneously when they had been working as a relief worker in a pig farm (Raulo & Lyytikäinen 2005).

Rendering

The Finnish Food Safety Authority Evira, the MVO and the PVO, as well as Veterinary Officers at slaughterhouses supervise the processing of animal waste. Two rendering plants are approved for the destruction of high risk materials in Finland. The capacity of these plants (Honkajoki and Kaustinen) during an outbreak of FMD is estimated to be 380 000 kg/day, which corresponds to about 700 cows or 2500 pigs (Evira 2009a).

Finland is divided into three pig carcass collection areas. Cattle carcasses are only collected from areas with a high animal density (hence the northern part including Oulu and Rovaniemi PVO districts are excluded). It is still permitted to bury carcasses in the excluded northern parts of Finland.

Carcass collection was the most common way to take care of dead animals. There was little difference between production types among pig farms: 72% of farrowing herds, 76% of farrowing-to-finishing herds and 62% of finishing herds had their pig carcasses taken away by official carcass collection. Carcasses were usually stored in the same place on the farm (ca. 79%), and almost 70% of these farms had a cooled storage unit. About 20% of the respondents did not have a permanent place for the storage of carcasses.

There were only small differences between production types on cattle farms regarding carcass collection: 76% of dairy herds, 56% of beef cattle herds and 54% of suckler herds had their cattle carcasses taken away by official carcass collection. Carcasses were usually stored in the same place on the farm (ca. 30%), but almost none had a cooled storage unit. About 70% of the respondents did not have a permanent place for the storage of carcasses.

According to the questionnaires (Virtanen et al. 2008), the rendering vehicle visits a pig farm on average 5.6 times per year and a cattle farm 1.9 times per year. The number of collections is not dependent on the production type of the farm. There are different vehicles collecting pigs and cattle, and altogether there are 4 pig rendering vehicles (four independent enterprisers) and 10 cattle rendering vehicles (Lauhaluoma Ky) in Finland.

In 2008, Evira carried out a study on cattle rendering (Evira 2009b). According to the cattle register, 35221 cattle died on farms located in the carcass collection area, and

3649 of them were buried. Burying of carcasses in the collection area is illegal, but it seems that it still happens to some extent (ca. 10% in 2008).

Agricultural production advisers
There are several production advisers who can visit farms. ProAgria, a consortium of mainly co-operative-based organisations, offers production consultation for pig and cattle production in several districts throughout the country. Every large meat production company has its own production advisers, who are specialised, for example, in construction planning or in animal nutrition. These advisers also have their own districts. In addition, dairies have their own production advisers.

The FABA provides services ranging from artificial insemination and embryo transfer to genetic evaluations and breeding advice. Mating plans are prepared by breeding advisors on the herd level, and the FABA also carries out genetic evaluations of pigs. The FABA has divided Finland into four districts.

Artificial insemination
About 200 000 artificial inseminations of pigs are performed every year in Finland. Most of the work is done by licensed farmers who order semen from AI centres (Finn-Pig Ltd. or FABAsika Ltd.).

Each year approximately 700 000 artificial inseminations of cattle are carried out in Finland, and most of them are performed by AI technicians and pig farmers. In 2006 there were 727 404 AI visits to farms by 420 AI technicians (AI register). Cattle farmers perform ca. 3% of artificial inseminations by themselves, while pig farmers almost always carry out insemination by themselves. In addition, 60 AI technicians also provide a fertility service and 50 of them transfer embryos.

Economic importance of livestock production

Production and consumption quantities

Information reported in this section is mainly based on data by Niemi & Ahlstedt (2008).The amount of milk delivered to Finnish dairies has been declining during the past decade. In 2006, Finnish dairy farms produced 2 279 million litres of milk (Figure 9). Moreover, dairy and suckler cows produced 331 900 newly born calves. Milk production in Finland fell 36 million litres short of the national quota for the period that ended in 2006. Regarding the most important dairy products processed in 2006, the production of liquid milk totalled 710 million kg, yoghurts 109.1 million kg, sour milk 70.1 million kg, and creams 30.8 million kg. The consumption of liquid dairy products approximately equalled their production quantities in Finland. The production of cheese was 99.9 million kg and the consumption of cheese 100.6 million kg. The production of butter was 50.2 million kg and domestic sales amounted to 12.8 million kg. Milk powder production totalled 19.6 million kg.

The figures for the beef sector show that 85 million kg of beef was produced and 95.2 million kg beef was consumed in Finland in 2006. Altogether, 152 000 bulls and 103 000 cows were slaughtered. The average slaughter weights of cows and bulls were 264 kg and 324 kg, respectively. The average slaughter weight of bulls was almost 50 kg higher than in 2000.

In 2006 the production of pigmeat was 207.8 million kg and consumption was 180.2 million kg. This amount was obtained by slaughtering 2.4 million pigs. The average slaughter weight of fattening pigs was 84.6 kg.

On a per capita basis, the consumption of food has remained quite stable. There are consumption trends such as decline in the consumption of butter and an increase in the consumption of pigmeat since 2000, as illustrated in Figure 10. The per capita consumption of liquid dairy products (liquid and sour milk products and cream milk) also declined from 193.9 kg per capita in 2000 to 183.9 kg in 2006, but recovered thereafter to 189.2 kg per capita. Although there is both seasonal and annual variation, it is uncommon that per capita consumption of livestock products in Finland changes much from year to year.

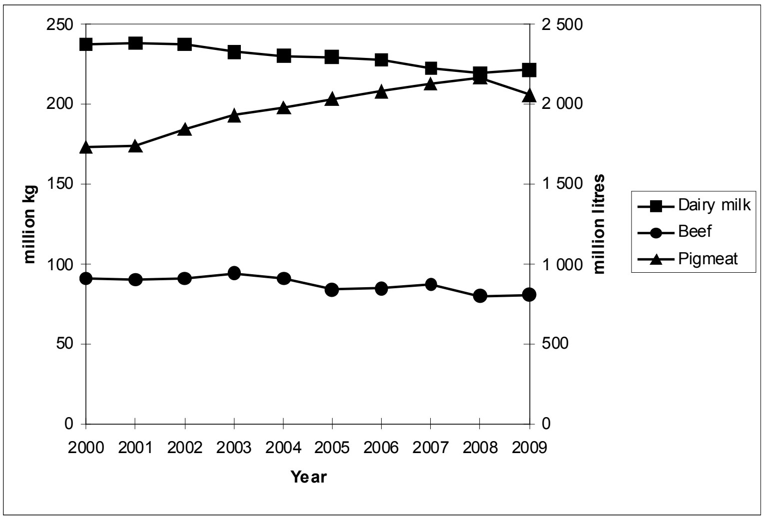

Figure 9. *Livestock production in Finland from 1999 to 2009.*
Source: Information Centre of the Ministry of Agriculture and Forestry

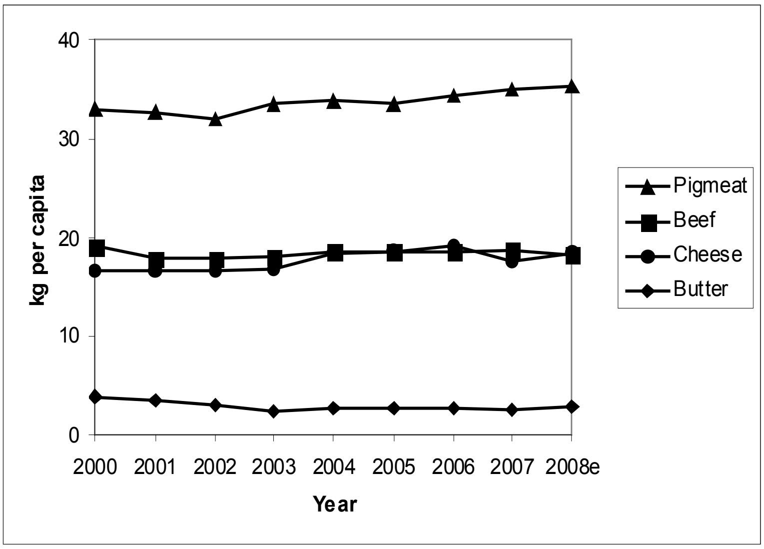

Figure 10. *Per capita consumption of cheese, butter, beef and pigmeat in Finland from 2000 to 2008 (provisional). Sources: Gallup Food and Farm Facts, Information Centre of the Ministry of Agriculture and Forestry.*

Producer and consumer prices

The market prices of livestock products in the other EU Member States influence their prices in Finland, but the Finnish prices also have special characteristics. For example, the producer prices for pigmeat and milk usually vary less in Finland than in most other EU countries.

The prices paid to the Finnish dairy producers are slightly higher than the prices paid to the producers in the EU on average. In 2006 the average quality-adjusted producer price for milk was €0.36 per litre. On top to this, producers received on average €0.07 per litre from public funds as production aid.

The average producer price for beef was €2.12 per kg, and that for bull meat was €2.50 per kg (Figure 11). In the long term, the beef prices in Finland have been 4–5% lower than the average in the EU. The producer price for all pigmeat was €1.26 per kg in 2006. The purchase price of piglets was between €54 and €55 per 25 kg piglet. The producer price for pigmeat remained stable in Finland in 2005 and 2006.

The ratio of the consumer price to the producer price for food varies according to the product. The average consumer price for light milk (typically with a 1.5% fat content) in 2006, for instance, was €0.73 per kg, which was approximately twice the producer price for milk with a 4.3% fat and 3.3% protein content, and of which 18 cents per kg of milk was left to the trade sector. The average consumer price for butter was €4.84 per kg and the price for Emmental cheese was €10.86 per kg. Regarding selected meat products, the price of beef roast was €9.9 and pork chops €7.8 per kg. Between 2000 and 2006, food prices in nominal terms rose by 10.9%, while the general consumer price index rose by 8.1%. The share of the wholesale and retail sector in the price for basic dairy products, such as light milk or Edam cheese, has grown in relation to the sale prices of the dairies (Statistics Finland 2010).

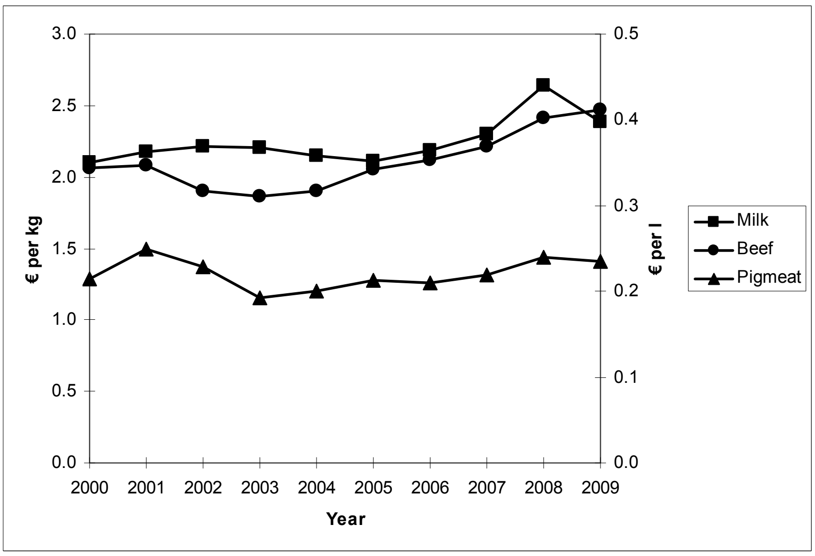

Figure 11. *Producer prices for dairy milk[1)] (€ per l) beef and pigmeat (€ per kg) in Finland from 2000 to 2009, [1)]including retroactive payment. Source: Information Centre of the Ministry of Agriculture and Forestry.*

Foreign trade

Both the import and export of food has increased over the past decade. In 2006, the value of Finnish food exports was €1 104 million whereas the value of food imports to Finland was €2 810 million. Despite the record-high exports, the deficit in the food trade balance was €1 706 million. Traditionally, the deficit has been due to the import of fruits, vegetables, coffee, alcoholic beverages and tobacco. Cheese is also a significant import article.

Most of the food imports to Finland are intra-community trade, mainly with Germany, Sweden and the Netherlands. Although import from the countries that entered the EU in 2004 has increased, their share of imports was 5.6%. As opposed to this, imports from third countries accounted for a 24.6% share.

In 2006, Russia (22%), Sweden (16%) and Estonia (10%) were the main destinations for Finnish food exports. Countries that entered the EU in 2004 accounted for only a 16% share of exports. The value of Finnish food exports was €1 104 million. In the late 1990s, the value of Finnish food rapidly increased, but from 2001 to 2005 the value of exports was quite stable.

Dairy products are the most important product group in Finnish food exports, as they represent almost one third of the total value of exports. The value of cheese exports was almost €138 million, thus representing 12.7% of the total food exports in 2006. Other important export articles include cheese, butter, sugar industry products, pigmeat, cereals and cereal products and alcoholic beverages.

The quantity of exported liquid dairy products was 30.3 million kg, 5.6 million kg more than their imports. Cheese exports were 35.8 and imports 41.5 million kg. Milk powder exports were 12.9 million kg and butter exports were 35.4 million kg. The majority of Finnish butter production is for export markets and the main export destination is Russia.

Foreign trade in beef and pigmeat in Finland is mainly carcass meat. In 2006, beef exports amounted to 2.4 million kg, of which 88% was exported to Sweden. Beef imports were 14.4 million kg and represented 15% of consumption. Beef was mainly imported from Sweden, Brazil, Ireland and Germany.

The quantity of exported pigmeat in 2006 was 48.1 million kg, and exports represented a 23% share of production. Russia, Estonia, Sweden and Japan together accounted for 74% of the carcass meat exports, of which Russia's share was 38%. Pigmeat imports to Finland amounted to 17.7 million kg, which was 10% of the consumption. During recent years, processed meat has mainly been imported from Sweden and Germany, whereas Denmark and Germany have accounted for 75–80% of carcass meat imports.

Finland exports very few live animals. However, in 2006 approximately 25 000 piglets were exported to Sweden, corresponding to about 1% of the annual pigmeat production potential in Finland.

Economic size of agricultural, food and retail sectors

The returns, costs and economic results of agriculture and horticulture are examined based on a total calculation (see Niemi & Ahlstedt 2008). Income development in primary production is examined through agricultural income, which is the total return on agriculture minus the total costs, and thus indicates the compensation for the farm family's labour and capital invested in agriculture.

In 2006, the total return on agriculture and horticulture exceeded €4 020 million for the first time since Finland joined the EU in 1995. The total costs of agriculture and horticulture were €3 118 million and the agricultural income totalled €893 million (Figure 12). The sales of agriculture and horticulture were €2 100 million, of which 39% (€812 million) came from milk production and 26% (€584 million) from other livestock production. The sales return covered only 65% of the total costs. For instance, in 2005 the average producer price plus support paid 40.6 cents per kg dairy milk, whereas the average production cost of milk was 57.2 cents per kg.

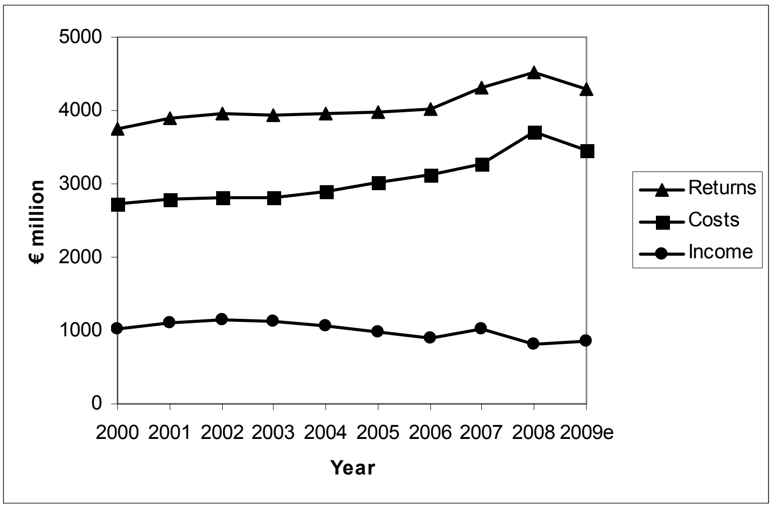

Figure 12. *The total returns, costs and agricultural income (€ million) at nominal prices in Finnish agriculture from 2000 to 2009. Source: MTT Economie Research*

The sales of groceries and daily consumer goods have increased over the past decade. In 2006 they totalled €12 404 million. Between 1995 and 2006, the sales of groceries and daily consumer goods at nominal prices increased by almost 40%.

The turnover of the Finnish food industry in 2006 was €9 200 million, of which 12% originated from exported products. The turnover per person employed by the food industry was €257 000 and the personnel employed totalled 35 900. The two largest sectors of the food industry were the meat and dairy sectors.

Milk processing markets were dominated by two major groups of companies, whereas meat processing was more fractioned in 2006. The two leading retail chains of food and daily goods had in total a 73% market share in 2006. The concentration of the retail sector and food industry has increased as the number of outlets has decreased, supermarket chains have increased their size and processing companies have merged.

5.2 Laboratory diagnostics

At the Finnish Food safety Authority Evira, animals suspected to be infected with FMDV are diagnosed from vesicle fluids or epithelium using virus isolation by RT-PCR. The sensitivity of RT-PCR is estimated to be about 95% (Rikula 2010). There is also a non-structural protein (NSP) ELISA test designed to differentiate infected from vaccinated animals (DIVA), regardless of the serotype causing the outbreak. (PrioCHECK® FMDV NS, Prionics Lelystad B.V., Paltinastraat 33, P.O. Box 2271, NL-8203 AG Lelystad, The Netherlands). There have been no problems diagnosing FMDV from reference samples with RT-PCR or ELISA tests. FMD virus must be verified from a positive PCR by sequencing the genome. This is expected to take 1–3 days. After the first preliminary positive diagnosis, the sample is sent from Evira to an FMD reference laboratory in Lindholm, Denmark or Pirbright, UK. These verifications are expected to take 4–7 days.

5.3 Administration in Finland

Veterinary administration in Finland

There are about 1800 veterinarians in Finland.

The Central Veterinary Service

Department of Food and Health of the Ministry of Agriculture and Forestry is the supreme authority that steers the quality and safety of foodstuffs through the whole food chain. The Department is responsible for the safety and quality of food and production inputs of agriculture, animal health and welfare and plant health. Legislativework is carried out as part of the Finnish Government and the EU institutions and decision making.

The Finnish Food Safety Authority Evira is the central government authority that licenses veterinary practitioners and acts as the authority ensuring compliance of veterinary practice with the legislation.

Provincial Veterinary Officers (PVO)

Finland is divided into 13 Provincial Veterinary Offices (PVO districts, Figure 13). The PVOs are responsible for monitoring, surveying and controlling animal diseases on the provincial level. Each province has its own local contingency plan, created according to the special circumstances in each province. In 2009 there were changes in provincial governments, but the spatial distribution of districts remained the same as in 2006.

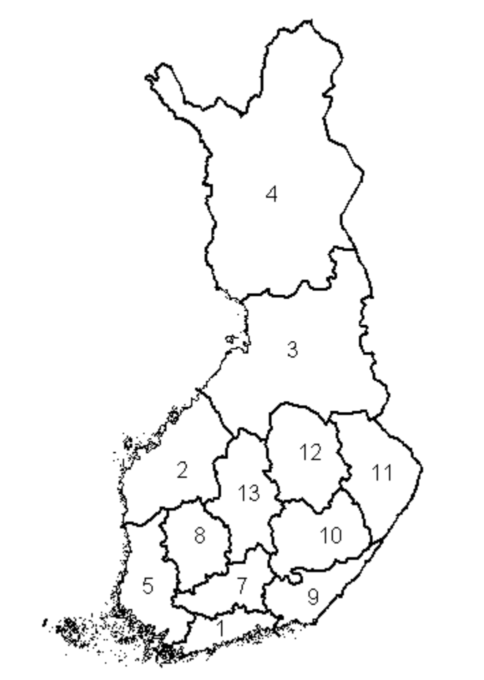

Figure 13. *The PVO districts in mainland Finland. Coding of PVO districts:*
1 = Helsinki
2 = Vaasa
3 = Oulu
4 = Rovaniemi
5 = Turku
7 = Hämeenlinna
8 = Tampere
9 = Kouvola
10 = Mikkeli
11 = Joensuu
12 = Kuopio
13 = Jyväskylä
These names indicate the location of the office of the PVO.

Municipal Veterinary Officers (MVO)

All municipalities in Finland are obliged to provide round-the-clock veterinary services covering their area. In year 2006, the treatment of production animals was taken care of by 350 municipal veterinarians in Finland.

Veterinary emergency duty districts (96 in 2006) are formed by the municipalities (431 in 2006) and they are responsible for the treatment of production animals and urgent duties concerning animal protection and contagious animal diseases.

5.4 Risk management, treatment, prevention and control

FMD is an OIE-listed disease and the control is regarded as high priority (Cox & Barnett 2009). Because FMD is a viral disease, there is no treatment for the sick animal, and as a notifiable disease it should be eradicated.

A possible FMD outbreak in Finland is dependent on the FMD situation in Europe and the rest of the world. Current control policies in Europe are based on strict import and quarantine regulations.

FMD is controlled both by European directive (2003/85/EC) and through more detailed domestic legislation (27/EEO/2006, 304/2006, 5/EEO/96, 1363/1994) and a contingency plan. The national contingency plan contains detailed descriptions of operations in the case of an FMD suspicion and after confirmation of FMD. According to the law, all veterinarians under 50 years old and veterinary students are permitted to work as veterinarians and obliged, if needed, to contribute in inspections and other veterinary work needed in case of an outbreak of FMD.

The Provincial Veterinary Officer (PVO), Municipal Veterinary Officer (MVO) and the Food Safety Authority (Evira) must immediately be notified about signs of FMD. In the case of a suspicion of FMD, a farm will be placed under restrictive measures. This includes the prevention of animals from entering or leaving the farm and all traffic to and from the farm is prohibited or strictly controlled. Samples for FMDV analysis are taken according to instructions from the competent authorities in the country (Evira). If diagnosis is confirmed, or even earlier if indicated by other evidence, animals of the susceptible species at the farm are immediately culled and the farm is cleaned and disinfected under the supervision of an official veterinarian.

Specifically trained veterinarians must carry out an epidemiologic inquiry that includes identification of the contact farms. Contact farms include all farms that in some direct or indirect way have been in contact with cloven-hoofed animals at the suspected farm, or may have acquired the infection from the same origin. All farms that have received or delivered animals from or to the suspected or infected farm during the 14 days (cattle and pigs), or 21 days for sheep, prior to the first clinical signs are regarded as contact farms. Contact farms are also farms that are situated within a radius of 1 km from the suspected/infected farm. In addition, farms that have been on the same route as the suspected/infected farm regarding, for instance, a transport vehicle or veterinarian during 2–3 days prior to the detection are considered contacts according to the Finnish contingency plan.

All contact holdings are put under restrictive measures. Immediately after an outbreak of FMD is confirmed, the competent authorities shall establish a protection zone based on a minimum radius of 3 km and a surveillance zone based on a minimum radius of 10 km around the infected farm. In the protection and surveillance zones, no animals or products thereof shall be removed from their holdings. All animals dispatched from the zone during at least the period of 21 days before the earliest detected infection must be traced. All animals in the protection and surveillance zone and on contact farms outside the zones must be counted, clinically inspected and the measures documented by an official veterinarian at the latest 7 days after the zone is established or the contact farm is traced. The farms closest to the infected farm (1 km radius) are to be inspected within 2 days. In case of clinical symptoms, samples are taken according to instructions in the contingency plan. No animals are allowed to be moved from the farms were they are kept.

The restrictive measures can be lifted at the infected farm when all suspected animals have been eradicated and disinfection of the premises has been performed. Restrictive measures can be lifted in contact farms that are not in the restrictive zones, when clinical inspection has not indicated any symptoms of FMD, and in the case of sheep and goats, a negative serological survey has been conducted and 21 days has elapsed following the last contact with an infected farm. At farms in restrictive zones the restrictive measures can be lifted when at least 15 days in the protection zone and 30 days in the surveillance zone has elapsed since the culling of animals and preliminary disinfection of the infected farm, provided that a clinical examination and serological survey, in case of sheep and goats, has given negative results.

5.5 Emergency vaccination

Vaccination against FMD has not been routinely practised in the European Union since 1991. In Finland, the use of FMD vaccines is prohibited. However, emergency vaccinations in case of an outbreak can under special conditions be decided upon separately (2003/85/EC).

Vaccination is used to diminish the clinical signs of disease and in an outbreak situation to stop or in emergency vaccination reduce the spread of the disease until it is under control. Vaccination triggers the natural immune response, in the same way as a natural infection, to produce antibodies against a specific virus and in this way recognise the viral antigens so that they can be eliminated as soon as they enter the body. Vaccinated animals show no or limited clinical signs in the case of infection (Parida et al. 2007).

The seven different FMD serotypes trigger different immune responses, which means that immunity to one serotype does not protect against another serotype (Cox & Barnett 2009). The level of protection achieved by the vaccine is dependent on both the potency of the vaccine and the antigenic relationship between the vaccine and the field strain (De Clercq et al. 2008). The possibility of subclinically infected animals is higher if the vaccine dose is small or the time between vaccination and infection is short.

The usual regime for prophylactic FMD vaccination is a booster 4–6 weeks after the initial shot, and subsequent boosts every 4–6 months or annually (Cox and Barnett 2009). Vaccination is performed with inactivated vaccines, which consist of whole virus particles that trigger the immune response (Salt 1997; Davies 2002). Current vaccines are produced in cell culture, inactivated by treatment with aziridines such as binary ethylenemine, and mixed with adjuvant (Grubman & Baxt 2004).

Finland, like the other EU countries, is a part of the EU vaccine bank that orders and delivers vaccines as the need arises. High potency vaccines (6 PD50) are recommended by the EU to be used in the case of an emergency vaccination.

Vaccination complicates the discrimination between naturally infected animals and vaccinated ones, because both groups seroconvert and serologically test positive. The NSP-Elisa tests, however, are to some extent able to discriminate between naturally infected and vaccinated animals on a herd level (Paton et al. 2006).

Emergency vaccination alternatives

In an outbreak situation there are two emergency vaccination strategies to manage and reduce the risk of the disease transmission (2003/85/EC): either suppressive vaccination (“vaccination to cull”) or protective vaccination (“vaccination to live”). In the alternative of suppressive vaccination, all animals situated in the protection zone a minimum radius of 3 km from the infected heard are vaccinated and subsequently killed and destroyed. In the case of protective vaccination, the area for vaccination is regionalised into restricted and free zones, but the area is not as strictly defined. However, around the area of protective vaccination an area of at least 10 km is formed as a surveillance zone defined by the OIE (2003/85/EC).

The goal with emergency vaccination is to reduce the rate of disease spread and also to diminish the final number of animals to be culled due to the eradication of an epidemic. The public reaction against the culling of healthy animals is also a reason to consider the option of emergency vaccination, at least if it saves animals.

The expert panel of this assessment (see the section on data sources) considered suppressive vaccination as a better option than protective vaccination in Finland. In some special cases, depending on the situation in Europe, protective vaccination could be considered in limited areas, to protect especially valuable or numerous animals.

Emergency vaccination and trade regulations

Trade regulations following an FMD outbreak and emergency vaccination are specified in detail in European directive 2003/85/EC. Moreover, the OIE and WTO (World Trade Organization) rules regarding the trade are different for no vaccination, protective vaccination and suppressive vaccination policies.

Vaccination affects the possibility to export meat and dairy products from the country. In short, an FMD-free status can be restored after at least 3 months have elapsed since the last vaccinated animal has been slaughtered. In the case of protective vaccination, the time is 6 months from the last outbreak or vaccination until the country/region is free to export products again (2003/85/EC).

If FMD occurs in a previously FMD-free country such as Finland and the disease is controlled by stamping out and serological surveillance, the FMD-free status can be regained and normal trade resumed 3 months after the last FMD case. On the other hand, if stamping-out and emergency ('suppressive') vaccination are applied, the waiting period is 3 months after the last vaccinated animal is slaughtered. Freedom from FMD must also be demonstrated with a serological survey.

If protective vaccination is used, it takes 6 months after the last case of FMD or the completion of emergency vaccination to obtain an FMD-free status. In addition, a serological survey, based on NSPs, must demonstrate the absence of infection in vaccinated animals (Figure 15).

Epidemiological criteria for the vaccination decision

In the case of a FMD outbreak, a decision must be made whether or not to use emergency vaccination. The main criteria are to be able to reduce the costs (both indirect and direct) and save animals instead of a strict stamping-out policy. Another reason to vaccinate would be to control the rapid spread of the disease and gain time in case of a lack of adequate resources. Table 17 presents the EU criteria for and against the decision to using emergency vaccination in the case of a FMD outbreak in a member state that has earlier been free from the disease.

Many factors may influence the vaccination decision (Figure 14). The emergency vaccination decision depends on the size, duration and growth of the epidemic, which on the other hand is affected by, for instance, the detection time, contacts and animal density. In the case of an epidemic, it is crucial to know the criteria to make the decision to vaccinate or not. Factors to take into consideration before the decision is made are among others:

- the number of infected herds and animals
- the expected final number of infected herds
- the effect of vaccination
- time delays to:
    - receive a confirmed diagnosis
    - obtain enough vaccine
    - contact personnel to perform the vaccinations,
    - have vaccinated all animals
    - reach a protective level in the animals

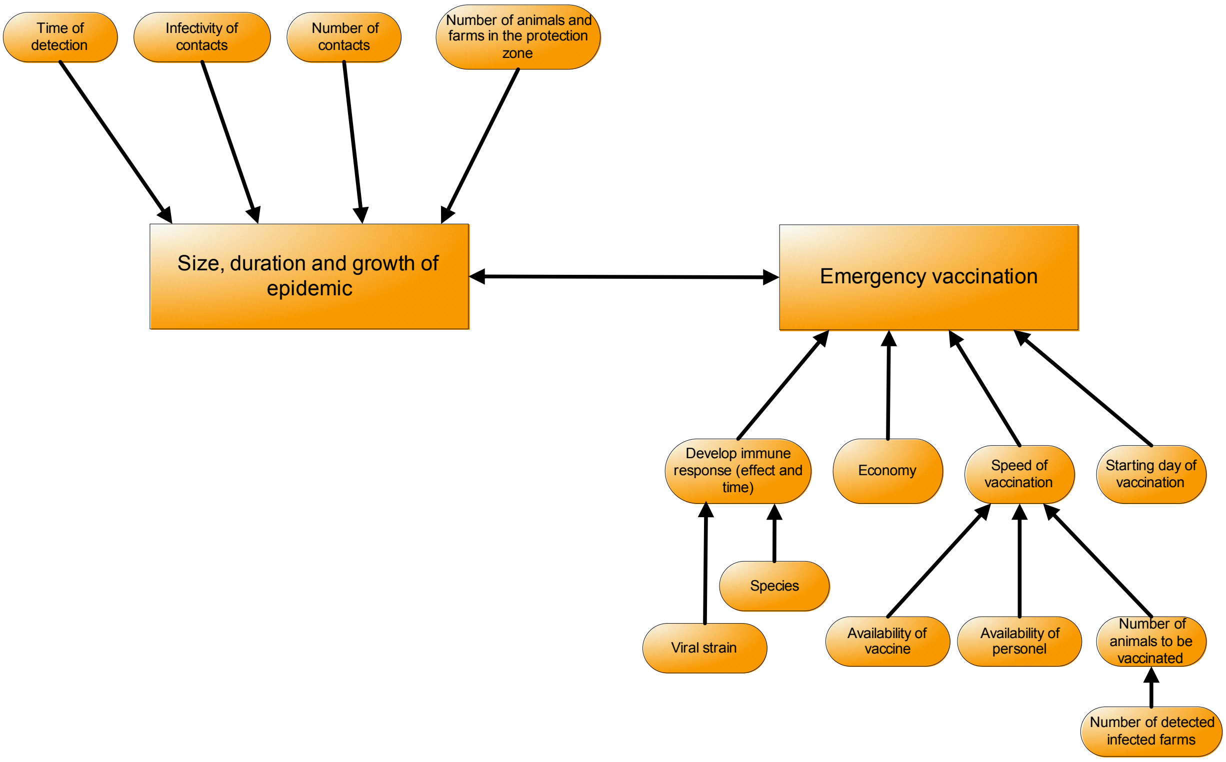

Figure 14. *Factors affecting emergency vaccination and epidemic size, duration and growth.*

Table 17. Criteria for the decision to apply protective vaccination and guidelines for the emergency vaccination programmes (2003/85/EC).

Criteria	Decision	
	For vaccination	Against vaccination
Population density of susceptible animals	High	Low
Predominant species clinically affected	Pigs	Ruminants
Movement of potentially infected animals or products out of the protection zone	Evidence	No evidence
Predicted airborne spread of virus from infected holdings	High	Low or absent
Suitable vaccine	Available	Not available
Origin of outbreaks (traceability)	Unknown	Known
Incidence slope of outbreaks	Rising rapidly	Shallow or slow rise
Distribution of outbreaks	Widespread	Restricted
Public reaction to total stamping out policy	Strong	Weak
Acceptance of regionalisation after vaccination	Yes	No
Acceptance of regionalisation by third countries	Known	Unknown
Economic assessment of competing control strategies	If it is foreseeable that a control strategy without emergency vaccination would lead to significantly higher economic losses in the agricultural and non-agricultural sectors	If it is foreseeable that a control strategy with emergency vaccination would lead to significantly higher economic losses in the agricultural and non-agricultural sectors
It is foreseeable that the 24/48 hours rule cannot be implemented effectively for two consecutive days (1)	Yes	No
Significant social and psychological impact of total stamping out policy	Yes	No
Existence of large holdings of intensive livestock production in a non-densely populated livestock area	Yes	No

(1) The 24/48 hours rule means:

(a) Infected herds on holdings referred to in Article 10 cannot be stamped out within 24 hours after the confirmation of the disease, and

(b) The pre-emptive killing of animals likely to be infected or contaminated cannot be safely carried out within 48 hours.

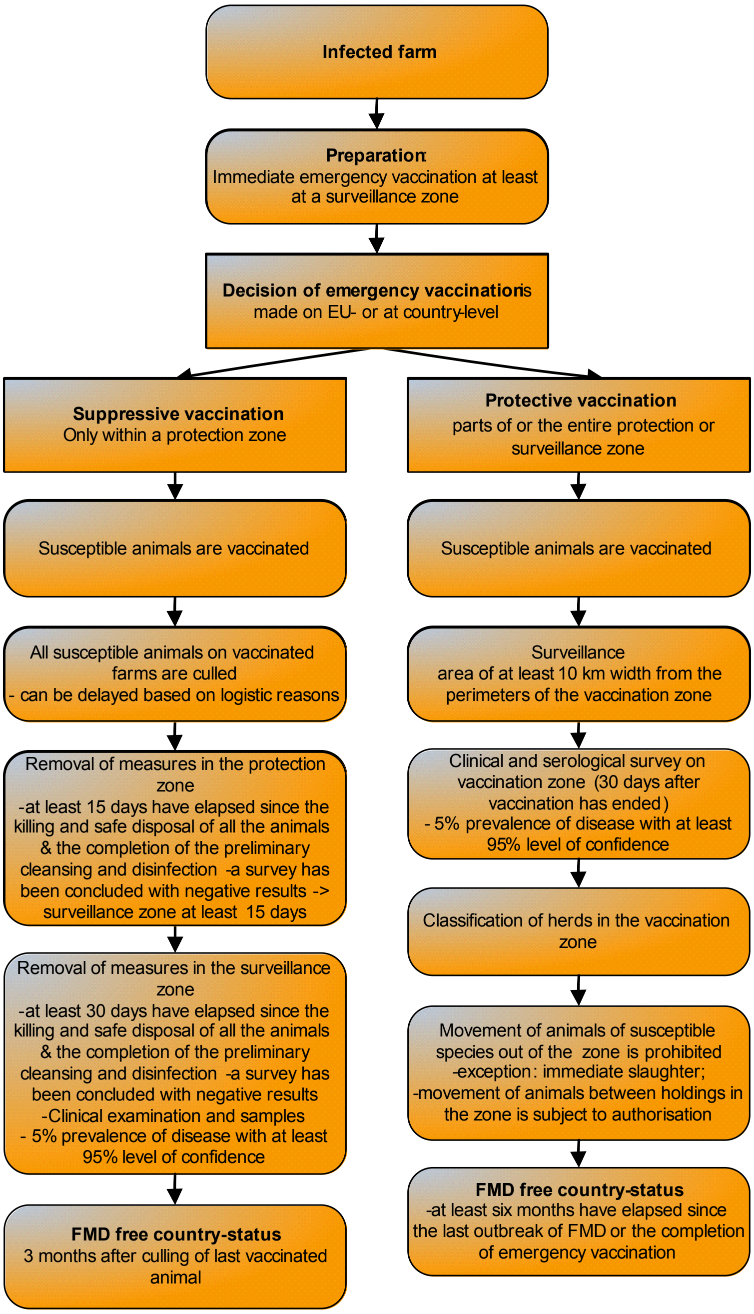

Figure 15. *Operations and consequences according to EU legislation when either suppressive or protective emergency vaccination is performed (based on 2003/85/EC).*

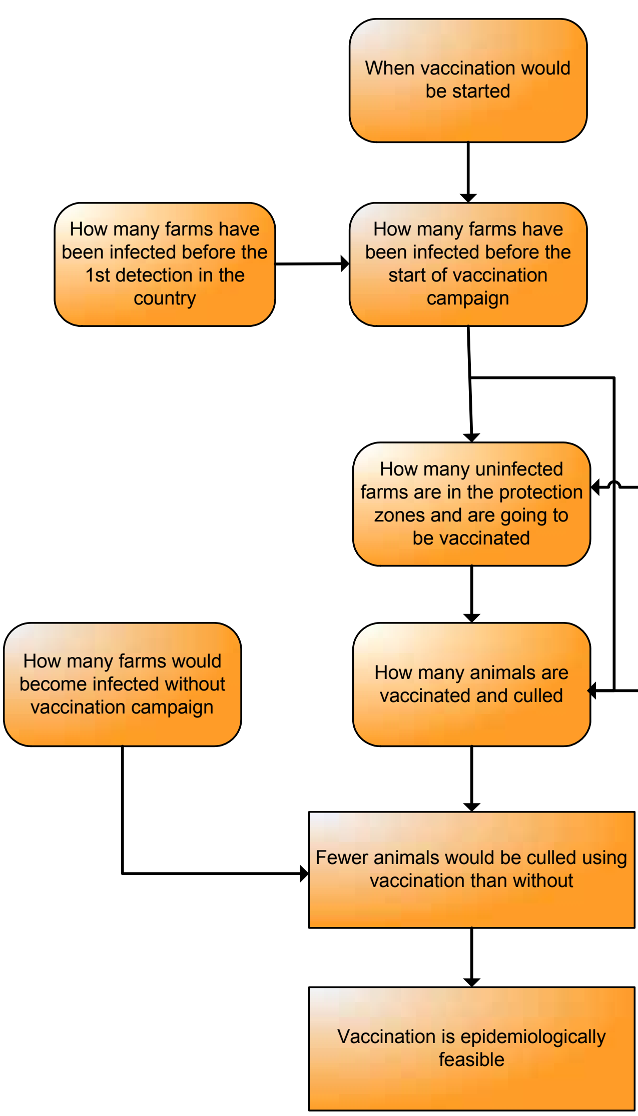

Figure 16. *Information which defines epidemiological feasibility of suppressive vaccination.*

Suppressive vaccination can be considered epidemiologically beneficial if the total number of culled animals can be reduced. This depends on how many of the farms that would become infected without suppressive vaccination have been infected before the vaccination campaign starts, how many of them are infected during the campaign and what proportion of the population is reached by the vaccination campaign. Time dynamics are important, as the progress of the vaccination campaign and the speed of development of the protective effect both influence the number of protected farms (Figure 16).

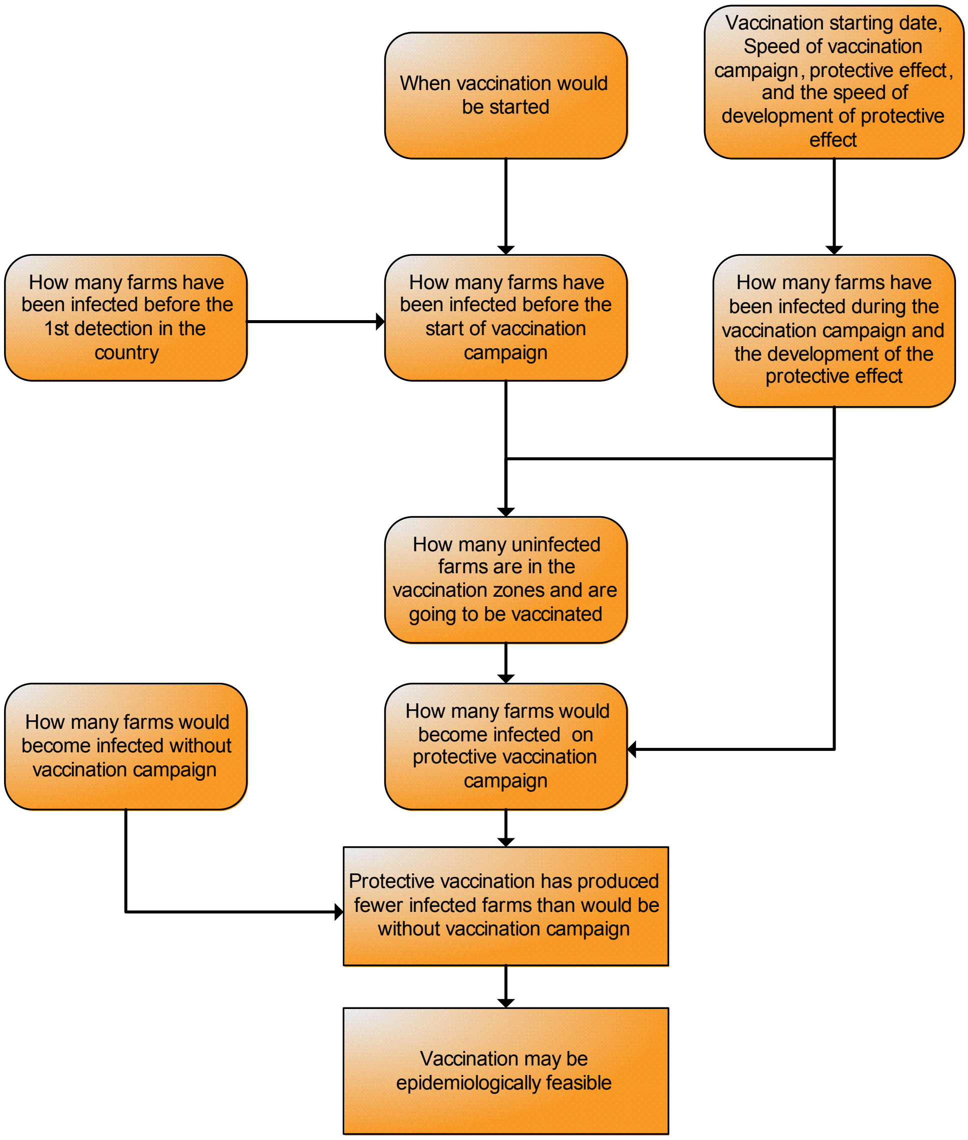

Figure 17. *Information which defines the epidemiological feasibility of protective vaccination.*

The epidemiological reasoning behind protective vaccination is different from suppressive vaccination. A protective vaccination campaign can be feasible if any of the infected farms is saved by a vaccination campaign (Figure 17).

Economic importance of FMD

Contagious animal diseases such as FMD can cause heavy losses to agricultural producers and society (e.g. Berentsen et al. 1992; Thompson et al. 2002; Mangen & Burrell 2003; Schoenbaum & Disney 2003). A survey of farm households in Cumbria, United Kingdom, for instance shows that the FMD outbreak in 2001 caused a 60% fall in revenue from traditional farm enterprises, a 17% reduction in earnings from diversified activities and a 15% fall in salaries from off-farm employment (Franks et al. 2002). Due to the threat of diseases to animals, livestock production, and in some events to human health, society puts great effort into preventing diseases from spreading.

An outbreak of a highly contagious animal disease such as FMD typically impacts on the livestock market by 1) removing animals from the market, and 2) by causing trade and market distortions. Countries can prohibit the imports of animals and animal products from the infected country or region (hereafter referred to as a trade ban). Excess supply on the domestic markets due to a trade ban tightens competition and decreases producer prices, particularly if the domestic consumption responds sluggishly to changes in prices. A decreased price gives producers an incentive to reduce production and importers an incentive to reduce imports. An outbreak can, therefore, hit producers particularly badly in export-oriented countries. Consumers may increase the consumption of meat products if their prices decrease. The outcome of such interrelated adjustments can be analysed using sector- or product-level equilibrium models of production and trade. Mangen & Burrell (2003), Schoenbaum & Disney (2003) and Paarlberg et al. (2008), for instance, examined changes in prices, trade, consumption and production when an animal disease outbreak occurs.

An FMD outbreak can reduce the income of farm businesses, their solvency and liquidity (cf. Franks et al. 2002; Saatkamp & Bruijnen 2009). Literature survey by Elbakidze et al. (2010) groups economic losses associated with FMD outbreak as follows:

- Decreased productivity and the value of livestock destroyed because of infection or because of adopted disease control policy (Bates et al. 2003).
- Task costs of operations associated with outbreak mitigation strategies (Elbakidze & McCarl 2006).
- Suppressed demand and potentially decreased consumption of directly affected meat products (Burton & Young 1996; Marsh et al. 2004; Piggott & Marsh 2004; Schlenker & Villas-Boas 2009).
- Losses associated with distortions in international trade (Paarlberg & Lee 1998). Regarding FMD, the World Organisation for Animal Health (OIE 2007) guidelines suggest that a trade ban could be lifted three months after the disease has been eradicated from a country free from FMD without vaccination.
- In some regions, losses in tourism and supporting industries could comprise a major portion of the overall losses (NAO 2002; Risk solutions 2005).
- Effects on stock prices of related companies (Henson & Mazzocchi 2002)
- Environmental impacts, including the value of lost wildlife and environmental damage from the disposal of contaminated carcasses (Sumner et al. 2005).

Economics of policies to combat FMD

Several studies have assessed policies to combat FMD. Berentsen et al. (1992) studied *routine* vaccination versus non-vaccination policies and came to the conclusion that a slaughter policy is economically superior to a vaccination policy. This was primarily because animals from regions using vaccination would not qualify for premium export markets. Mahul & Gohin (1999) studied emergency vaccination decisions and illustrated that the uncertainty related to disease spread affects the choice of disease control policy. Risk solutions (2005) studied policies to control FMD in the UK with the result that the vaccination policy was economically superior to the policy of culling (contact) herds in only one out of three of the examined regions. This was the region that resulted in the largest number of infected farms under the culling policy.

Tomassen et al. (2002) studied control measures during the early stage of an FMD epidemic in the Netherlands with the conclusion that a vaccination policy was the economically optimal control policy for densely populated livestock areas, but not for sparsely populated livestock areas. Ge et al. (2010) demonstrated for a Dutch FMD case that a flexible control policy outperforms static evaluation of pre-fixed control strategies by providing guidance to decision making during the entire control process and generating more realistic estimation of the costs of overreacting or underreacting in choosing the control options. It is common for European studies that in many regions emergency vaccination is not a particularly economic choice because of trade distortions imposed by other countries, low farm density and too slow a spread of the disease. However, in cases such as a large outbreak occurring in a farm-dense area, emergency vaccination has the potential to be an economic choice.

Vaccination and slaughter policies have also been commonly studied policies in other continents (e.g. Bates et al. 2003, Morris et al. 2001). Schoenbaum & Disney (2003) investigated the effectiveness of four slaughter and three vaccination strategies under varying scenarios of herd sizes and rates of disease spread in the United States. Their results showed that the choice of the best mitigation policy depended on herd demographics and on the rate of contact among herds. They found the slaughter of all herds within a 3 km radius from infected herds usually to be more costly than other slaughter policies, and vaccination of all herds within 10 km radius from infected herds to be more costly than controlling the outbreak with slaughter only. However, early vaccination reduced the duration of the outbreak. Kobayashi et al. (2007) analyzed policies to combat FMD in California. Their results suggested that to control FMD in the region, pre-emptive culling was not an optimal policy, vaccination, if allowed, and an increased carcass disposal capacity were able to reduce the total cost, and that dairy operations should be given preferential attention in allocating limited resources.

Garner & Lack (1995) investigated the effectiveness of combating FMD by two vaccination policies: the culling of infected herds only, or additionally the preventive culling of dangerous contact herds. Their results showed that if FMD is likely to spread rapidly then the slaughter of dangerous contacts and infected herds reduced the economic impact of the FMD outbreak. In contrast to this, a vaccination policy reduced the size and duration of an outbreak, but was uneconomic when compared to a culling only policy. Keeling et al. (2001) also found that both preventive culling and vaccination policies were effective if implemented rigorously, although culling was a more effective policy. They also argued that the spatial distribution, size, and species composition of farms influenced the pattern and regional variability of outbreaks.

Besides policies mentioned above, prior literature has addressed the effectiveness of traceability (Elbakidze 2007; Zhao et al. 2007), the timing of culling (Morris et al. 2001), and the role of regional heterogeneity in designing vaccination and culling policies (Rich and Winter-Nelson 2007). Recently, Elbakidze et al. (2010) examined early detection, enhanced vaccine availability, enhanced surveillance, and culling as part of a set of available FMD mitigation strategies. No studies have examined the economics of FMD in Finland. Regarding other highly contagious animal diseases, Niemi et al. (2008) have simulated the costs of classical swine fewer outbreaks in Finland.

6 Risk assessment

6.1 Introduction

An epidemiological simulation model was developed to simulate the spread of infectious diseases between the pig and cattle farms in Finland. The model is a type of network model, which means that the spread is simulated in real networks. The model was parameterized using data from 2006, and it describes a situation in which foot and mouth disease would have spread in Finland during that year. The network model is especially suitable to simulate the spread of FMD in Finland, because events that spread the disease occur relatively infrequently and contacts are variously correlated in time and space. The FMD spread model resembles models such as InterSpread (Sanson 1993; Mourits et al. 2002; Stevenson 2003; Velthuis & Mourits 2007), NAADSM (Harvey et al. 2007) and the earlier Finnish Classical Swine Fever (CSF) model (Raulo & Lyytikäinen 2005). The spread of the disease is simulated between farms using the Monte Carlo approach. The model has been programmed in the Matlab environment. Sampling from distributions (other than normal and uniform) is performed by functions of the Econometrics Toolbox (Le Sage 2002).

The model describes how the virus can spread between farms by different contacts. Relevant contacts are those that have occurred during an infective period on a farm. Because the model uses detailed historical data (from databases, as described later) in defining contacts, it can be considered as a network model that describes all potential networks connected with infected farms in a given time. Using registry data also means that the model is mainly a non-parametric model, because the contact processes are not parameterized but used as they are in the databases. This approach is complemented by adding parameterized data on contact types obtained from questionnaires.

All relevant modes of spread were included in the model. A description of the animal transportation network includes a description of the animal transport and farm registries that describe the time, origin and final destination of animal transportation. Related vehicle contacts are simulated according the animal transport registry. The network description of neighborhood and airborne spread is based on the coordinates of the farm. In addition, the registry of artificial insemination technicians and milk tankers describe the network of cattle and dairy farms. Other persons visiting the farm may spread FMD within the operational region of the visitor. For instance, a veterinarian can only spread FMD within the region in which he/she operates.

The frequencies of contacts are determined according to databases formed from registries or parameterized according to questionnaires (persons visiting animal holdings and other rarely occurring events). Disease will spread during the infective period and is specified by the frequency and infectivity of contacts. The spread happens within the region and to the farms according to databases and contact type specific definitions of the susceptible population.

Contact type specific infectivity and the duration of the infectious period prior to the first detection of the disease in the country are two major parameters of the model that are parameterized using existing models of the same type, namely the outbreaks in Great Britain and The Netherlands in 2001 (Stevenson 2003; Taylor et al. 2004; Velthuis & Mourits 2007). The first detection of disease was assessed by means of actual outbreaks: by estimating how long the suddenly occurring European outbreaks would have lasted before the first observation of disease was made (McLaws & Ribble 2007).

Simulation is started by sampling a random farm from the farm database. Contacts during the infective period are simulated by sampling different databases or, depending on the type of contact, some other ways. For the contacts that occurred during the infectious period, their target farms are defined in various ways, and later on, it is tested whether these contacts were causing the spread of the infection. The same approach was applied for the new infected farms during the simulation.

The detection time is speeded up by the administrative actions taken on farms other than the primary infected one: an infected farm can be detected earlier if it is located in the protection zone of the infected farm, or if it is traced as a contact farm. The detection of disease may be accelerated by the livestock producer's own intensified activity if the farm ends up in the surveillance zone, or by the general heightened awareness of the disease in the country after the first observation. These routes may shorten the detection time and infective period of a farm. Different routes are compared and the fastest route defines the detection time of the farm. Farms are subject to restrictive measures if they are traced as contact farms, or they are located in the protection or surveillance zone. No contacts are formed from the infected farms during the restrictive measures, even though the disease has not been detected. All suspicions of disease are diagnosed in a laboratory, and after a time lag the corresponding administrative operations are engaged. After positive confirmation of the infection status, the animals are killed and the initial cleaning of the farm is carried out. This is expected to end the neighborhood and airborne spread of the virus from the farm. Simulation continues until no new transmission of the FMD virus arises.

6.2 Datasources

The FMD spread model applies several databases that either describe or define the potential group of susceptible farms, relevant contacts of the farm during the infective period and/or the time when contacts have occurred. All databases were constructed using data sources from 2006.

Farm database

In Finland, it is mandatory (2008/71/EC, regulation 1760/2000; MAF 1391/2006, MAF 1296/2001) to register livestock premises. The Finnish farm registry was used as the source of data for the location and the number of cattle and pigs on the farms (registry was maintained by TIKE, Information Centre of the Ministry of Agriculture and Forestry). The registry covers the majority of the Finnish cattle and pig farm population, and a further economic incentive for registration is that registration is required to receive livestock subsidies.

The farm database combines several information sources. Identification codes were used to link data from the Finnish farm registry with the yearly notifications for EU subsidies and monthly notifications of the number of animals on the farms. The farms that did not keep cattle or pigs and did not sell or buy cattle, pigs or milk in 2006 were excluded from the database. If a farm had several animal holdings, the information on these sub-units was aggregated into one row of information. Altogether, 3.9% of farms had more than one animal holding in the registry. Different classes of animals were combined into two classes of animals: for pig farms into sows and finishers, and for cattle farms into dairy and other cattle.

Finnish farm coordinates are based on either the address, the centre of the fields of the farm or the location of central unit of the farm. Each farm was assigned to regions according to the veterinarian, relief worker, PVO, advisor, municipality and carcass collection. The proportion of different production types in the database are given in Tables 2 and 6 in the hazard identification section.

Database of animal transportation between farms

Data on the transportation of pigs and cattle are collected in the Pig Registry and the Cattle Registry, which are maintained by TIKE (Information Centre of the Ministry of Agriculture and Forestry) and Evira. The animal movement database was constructed from the official animal movement registries of 2006.

Pig transportations between farms were based on the pig registry, which contained information on the pigs sold, purchased and transported between farms in Finland. The full database of pig movements between farms contained 34 000 notifications. The linking of pig trade events was based on farm-specific marks of sold piglets and the date, which were used to link separate notifications of farms either selling or buying pigs. By linking the notifications of farmers with those of pig traders, it was possible to link over 90% of the pig transportations with the transport vehicle.

Cattle movement database was constructed by linking two notifications of an animal with the same identification number: the first from the farm from which it was transported and the second from the farm that received it. Because the information on the trader could not be linked with these events, linking of the vehicle with the transportation event was not possible and the database therefore contains no information on transportation vehicles. The full database of cattle movements between farms contained 70 200 notifications.

Domestic animals traded in Finland are mostly transported by entrepreneurs registered for animal transportation. Registration of the vehicle and the case/event is obligatory, based on animal welfare legislation (MAF 1429/2006).

Slaughterhouse transportation database

Data on the transportation of pigs to slaughter were directly retrieved from the pig movement registry and contained over 68 000 notifications of pig deliveries to slaughterhouses.

Data on the transportation of cattle to slaughter were directly retrieved from the cattle movement registry and contained over 92 000 notifications. Neither registry contained information on the transportation vehicles, so detailed information on vehicle movements could not be included in the slaughterhouse transportation database.

AI technician movement database

Artificial insemination technicians mostly visit dairy farms. The Finnish Agriculture Calculation Centre holds a registry that contains the daily movements of every AI technician operating in Finland. AI technicians are obliged to register the farms they have visited and the time and the date of visit to the centre. Because the registry contains the farm identification numbers and times of the visits, it was possible to construct a database that contained every route of AI technicians during 2006. The database contained 536 900 notifications of AI technician visits.

Dairy logistics database

The dairy industry provided us the routes of each dairy tanker for weeks 22 and 50 in 2006. A dairy tanker typically visits a farm every second day and routes are changed approximately twice a year, during spring and autumn. These routes were adequate data sources to construct the dairy logistics. The database contains over 90% of farms classified as dairy farms in the country. The dairy industry plans the logistics of the tankers, so the order of visits within a day could also be included in the dairy logistics database. Database contained the collection routes of 12 690 dairy farms.

Questionnaires to farmers

Two postal questionnaire surveys, one directed to Finnish cattle farms and the other to Finnish pig farms, were conducted in the spring of 2007. The aim was to obtain information on the contacts of the farms that is not registered elsewhere. To estimate the frequencies of contacts, the farmers were asked about the number of visits per year that may lead to contacts with other farms. Data for 2006 obtained from the questionnaire were applied to estimate the unknown frequency of contacts. Both questionnaires consisted of 6 printed pages.

A wide variety of people visit farms, including animal caretakers, holiday substitutes, agricultural advisers, artificial inseminators, veterinarians and others. The frequencies of visits by people to cattle and pig farms or production units were estimated from a questionnaire study performed during 2007. The number of posted questionnaires, 2 699, covered 13.1% of Finnish cattle farms (n = 20 652). The recipient farms were randomly selected from the whole Finnish cattle farm population. Another questionnaire was send to pig farmers (n= 1 118) that covered 34.6% of the Finnish pig farms (n = 3 228) (National Farm Registry 2006). Sampling in this questionnaire was partitioned, as all farms that belonged to the highest 10% fraction according either the number of sows or finishers received the questionnaire (13.6% of the Finnish pig farm population). The rest of the questionnaires were send randomly to 21% of the other pig farms. There were 1180 respondents among the cattle farmers (response rate of 44%) and 571 respondents among the pig farmers (response rate of 51%).

Questionnaire to veterinarians

To estimate how many farms a veterinarian visits during a day and how the farm production type would influence this frequency, a questionnaire was sent (in 2007) to 350 municipal veterinary officers in Finland, of whom 134 (38%) returned the questionnaire. The questionnaire was completed like a diary, where the practitioners reported their daily visits to farms during two five-day periods. They were asked to report which farms (pig, cattle or other) they visited during a 2-week interval.

Expert panel

By using an expert panel, relevant information was gathered regarding information required in the assessment of an emergency vaccination policy and the decision rules. An expert panel was gathered on 24 April 2009 to evaluate the measures that affect emergency vaccination, the time lags before some events during the vaccination would be either started or completed, and what would influence the vaccination decision. The expert panel consisted of 7 veterinarians with an expert knowledge of vaccination, disease transmission, epidemiology, laboratory diagnostics/methodology and/or virology. The experts were asked to answer and evaluate some questions and statements regarding the decision to vaccinate, the time and the delays in detection, diagnosis and vaccination that would occur if FMD infection were to appear in Finland. The experts completed the form before a discussion, and the same form was also completed after the discussion, which was a modification of the Delphi method. Based on the expert opinions, the parameters used in the calculation of vaccination results were revised.

Other sources

Other sources were applied when needed to define parameters that were not estimable from the previous mentioned sources. This additional information was required to parameterise vehicle movement patters when animals were transported to slaughter and when cattle were transported between farms. The carcass collection of both pigs and cattle, and operation of relief workers were also parameterised using additional information.

A telephone questionnaire to slaughterhouses was performed to define how many farms a vehicle would visit per day transporting either animals to slaughter or cattle to another farm.

Cattle carcass collection data from one week in Finland were used to estimate the spatial range of carcass collection vehicles and the number of cattle farms visited on one route. For pig carcass collection, the average number of visited farms during a route was estimated from the statistics for the whole of 2006.

Official statistics of the Farmers' Social Insurance Institution were used as a parameter indicating how much a relief worker might work on a single farm during a year.

Assumptions and exclusions

- After the primary infected farm is detected, FMD-infected animals are identified based on clinical signs only (McLaws & Ribble 2007). This assumption also includes the fact that at least some animals on the farm will always show clear clinical signs and will be detected.
- Laboratory tests always confirm a positive case.
- Sheep and goats, which might have less visible clinical signs, are excluded from the model.
- The Åland archipelago, which is not a part of mainland Finland, is excluded from the model.
- Each Finnish farm is assumed to be an equally probable candidate for the primary infected farm in the country.
- Animal transportation vehicles and milk tankers are cleaned at least once a day; thus, we assumed that a day is an adequate limit for vehicles
- All visitors are assumed to remain infective for the rest of the day if they have visited an infected farm.
- Every relevant contact will be traced.
- Restrictive measures, protection and surveillance zones will prevent all animal transportation away from infected farms, zones and traced contact farms.
- The infective period will end at the time when initial cleaning has ended on the infected farm.
- The spread of infection to another production sector is possible by veterinarians, AI technicians and relief workers, as well as airborne and neighbourhood spread
- Spread to another production sector is also possible via the animal transportation of some meat companies that may occasionally mix cattle and pigs during transportation.
- Quantitative assumptions are given in model description (Tables 18-21).

6.3 FMD spread model – The simulation process

The simulation process has five distinctive phases: 1) an initial phase that is required once per iteration, 2) estimation of the infective period of a farm, 3) estimation of the infective contacts, 4) the selection of a new infective farm and 5) if there are no new infected farms, the end phase of the iteration.

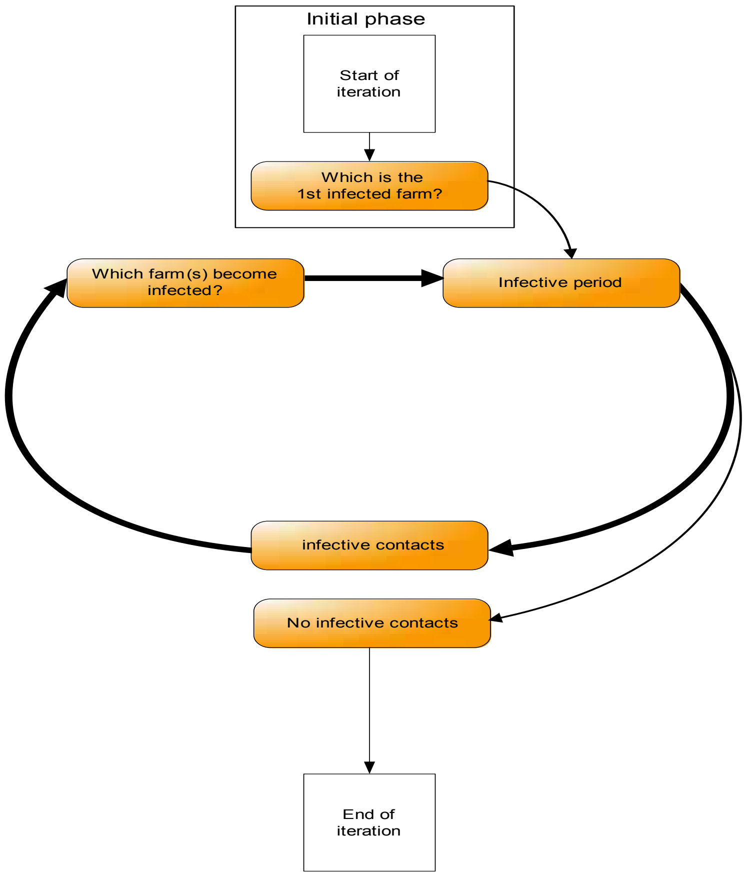

Figure 18. *The basic process describing the simulation principle of the Finnish FMD model. Iteration starts by randomly selecting the first infected farm in the country. After knowing the length of the infective period and the identity of the farm, it is possible to define the infective contacts (see details later). By selecting new infective farms (end points of infective contacts), the iteration continues until no new infective contacts are formed.*

Initial phase

One farm is sampled randomly from the Finnish farm population to be the first infected farm of the iteration (Figure 18). In this assessment, the iterations were started on 15 March 2006 and the contacts of the first infected farm were simulated for the following infective period (Figure 18). Some of the contacts are sampled directly from the databases and are thus dependent on the date of starting the iteration. In the initial phase of an iteration, all parameters used in equations estimating the number of visits to a farm (Table 20, Figure 21) are simulated by sampling from a covariance-variance matrix and estimated parameters of the model (Appendix 2, Table 20). The level of other country-level parameters containing uncertainty due to information sources is also sampled at the start of the iteration.

Infective period of a farm

The length of the infective period is given as an input parameter for the first infected farm, but for the following infected farms it is simulated by comparing different routes that could put a farm under restrictive measures and/or allow it to become detected according to EU legislation. For the first infected farm it is assumed that the detection is always initiated by a suspicion of FMD. For other infected farms there is no closed form to define the length of the infective period, because it is also dependent on other events such as which farms have already been detected as infected during the iteration (Figure 19). If a farm is infected by a detected farm, it can be traced as a contact farm. If it is in the protection or surveillance zones of an already detected farm, it can be detected earlier than by suspicion. Events defining the infective period are simulated conditionally: this means that an initial condition has to be met before the next event could be simulated. Because different operations take time, there are time lags between events (Table 18).

The infective period of a farm has two phases: In the first phase all contact types can be infective and the farm is not under restrictive measures. When restrictive measures are effective for the farm, only neighbourhood and airborne spread remain as infective pathways, until the farm has been initially cleaned (Figure 19).

Table 18. The duration of an infective period, time lags and parameters used to simulate events relevant in the determination of the infective period of a single infected farm during an iteration.

Parameter	Initial condition	Duration of period or time-lag (days)	Event following after the end of period or after the time-lag
Latent period	Virus has been introduced to the farm	4	Clinical signs are possible on infected farm
Non-infective period	Virus has been introduced to the farm	2	The start of infective period
The day of suspicion of farms infected before 1st detection	Virus has been introduced to the farm	20	The end of first phase of infective period of farms under suspicion*
The day of suspicion of farms infected after the 1st detected farm in the country	Virus has been introduced to the farm	14	The end of first phase of infective period of farms under suspicion*
Time lag of diagnosis of primary infected farm	Farm has been suspected to be FMD positive	1-3	Positive diagnosis of FMD
Time lag of sending samples of farms in protection zones	Farm is in the protection zone	0-7	Laboratory has received samples
Time lag of sending samples of farms in surveillance zone	Farm is in the surveillance zone	0-7	Laboratory has received samples
Time lag of tracing	Farm is diagnosed as FMD positive	0-7	Connected farms can be traced
Time lag of sending samples of traced contact farms	Farm is traced as a contact farm of a farm diagnosed as FMD positive	0-7	Laboratory has received samples
Time lag of diagnosis of farms after 1st detected farm in the country	Samples have been sent due to clinical screening or protective zone serological screening or due to farmer notification or activity	0-1	Positive diagnosis of FMD
Time lag of eradication**	Farm has been diagnosed as FMD positive	1-7	Animals of infected farm have been culled
Time lag of initial cleaning**	Culling on the farm has been completed	1-8	Initial cleaning of farm has been completed, the end of second phase of infective period

*under suspicion are meant here only those farms which are not detected by administrative operations, namely due to zone and contact farm inspections

**McLaws & Ribble 2007

The following definitions are used in the model:

Infective period: The infective period begins on the starting day of the infective period (see below). When a farm is under restrictive measures, the infective period of all contact types except neighbourhood and airborne spread will end. The infective period of neighbourhood spread and airborne spread lasts until the initial cleaning of the farm has been completed.

Introduction of virus: The day when the virus has entered a specific farm.

Starting day of the infective period: The infective period starts two days after the introduction of the virus on the farm.

The day of suspicion of FMD: The day when a farm is placed under suspicion of having FMD without contact tracing or inspections based on the location of the farm in the zone around a farm with a detected infection.

The day of positive diagnosis: For the primary infected farm, a positive diagnosis is assumed to be obtained 1–3 days after suspicion, because confirmative diagnosis is to be carried out before the farm is culled. On suspected farms and those infected following the primary infected farm, the decision to cull would be made according to the first positive indication of FMD. For the later infected farms, following the primary infected farm, the day of a positive diagnosis also depends on whether the farm is traced as a contact farm of an infected farm, or is located on the protection or surveillance zone around a positively diagnosed infected farm.

The day of restrictive measures = Restrictive measures are put in force on those farms located in the surveillance or protection zone around an infected farm that has been diagnosed to be FMD-positive. Farm tracing is contact type-dependent and has a time lag (0–7 days). After the traced farms are put under restrictive measures, all other contact types, except neighbourhood spread and airborne spread, are assumed to be non-infective after this time point.

The end of eradication: Eradication is performed X days (Table 18) after the day of positive diagnosis. The time lag is defined according to recent epidemics in the EU (McLaws & Ribble 2007) (Table 18). The end of eradication is the day when the eradication is completed.

The end of initial cleaning: Initial cleaning is completed X days (Table 18) after the day of eradication. The time lag is defined according to recent epidemics in the EU (McLaws & Ribble 2007). The end of the initial cleaning is the endpoint of neighbourhood and airborne spread.

Duration of outbreak: The time in days from the first infection until the last infected farm is initially cleaned.

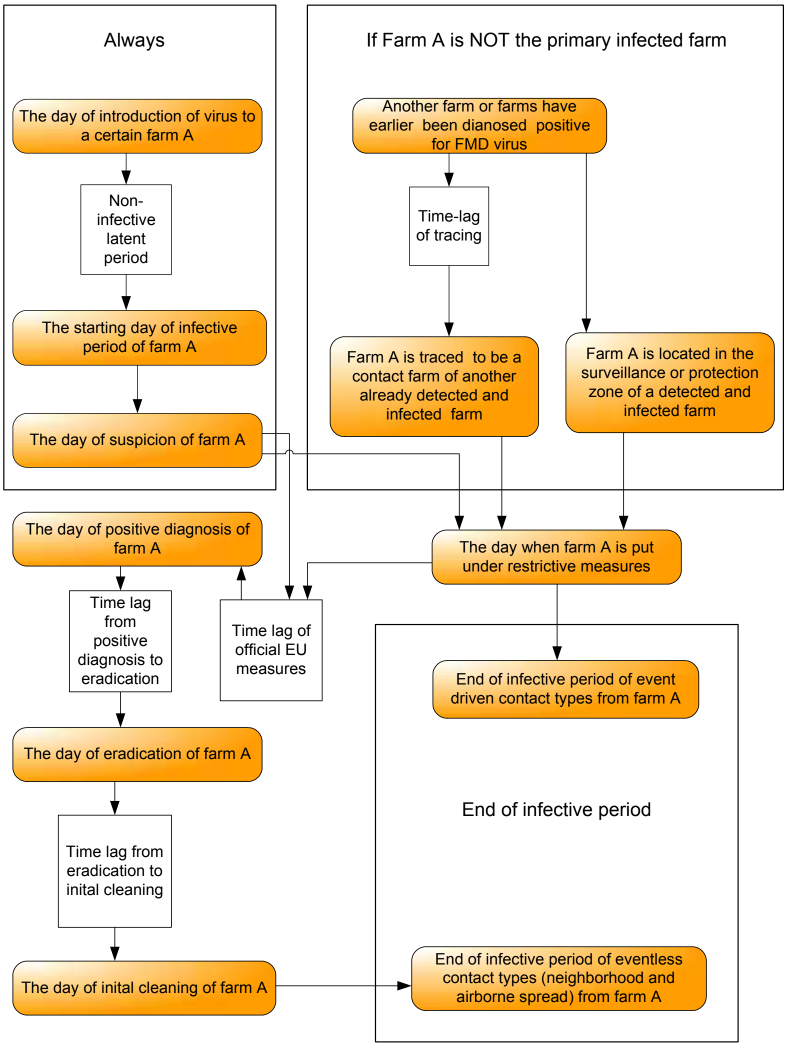

Figure 19. *The events that define the infective period of an infected farm.A farm can always become detected by suspicion. If a farm is not the first infected farm in the country, it is also possible that a farm becomes detected either by the tracing of contact farms of already detected farms, or by location in the protection/ surveillance zones of other infected farms. The detection process has several time-lags due to time limits in EU legislation and resulting from other processes that require resources or efforts. See Table 18 for applied values of time lags and periods preceding the events. The infective period partially ends when restrictive measures are in force and finally when farm is initially cleaned.*

Simulation of spread from infected farm(s)

Infectivity and contacts during the infective period define the number of new farms becoming infected from an already infected farm (Figure 20). If new farms become infected, infective contacts of these farms are then simulated and iteration continues. When the infective period of a farm is known, it is possible to sample those events from databases. This sampling also partly defines the contact farms. If the contacts following a visit to an infected farm are not explicitly known, for instance if information on the order of events is lacking within a day, the order of events (contacts due to a visit) is randomly simulated to estimate the contacts and contact farms. If events such as visits to the farm are not sampled from the database, they are estimated by equations (Figure 21). Each visit is then further simulated to estimate the contacts, their timing and contact farms from the population of susceptible farms (Table 19). Neighbourhood and airborne spread are tested separately for each farm in the susceptible population, which is determined by the distance from an infected farm (Table 19).

Steps applied in the simulation of a certain contact type are as follows:

1. Estimate or sample visits to an infected farm(s), (Figure 21, Table 19 and Table 20);
2. Estimate or sample potential contacts due to every visit to an infected farm (if applicable) (Figure 21);
3. Estimate contacts from the potential contacts (Figure 21);
4. Test which contacts are infective (Bernoulli trials) (Figure 22 and Table 21);
5. If the number of infective contacts is less than the number in the susceptible population, sample contact farms that will become infected (Table 19).

The steps are repeated for each contact type to estimate all farms that a single farm would infect. If same farm is infected by several farms or by several different contacts, the fastest route of spread is taken into account. When there are no more new infections during the iteration, the iteration ends (Figure 20).

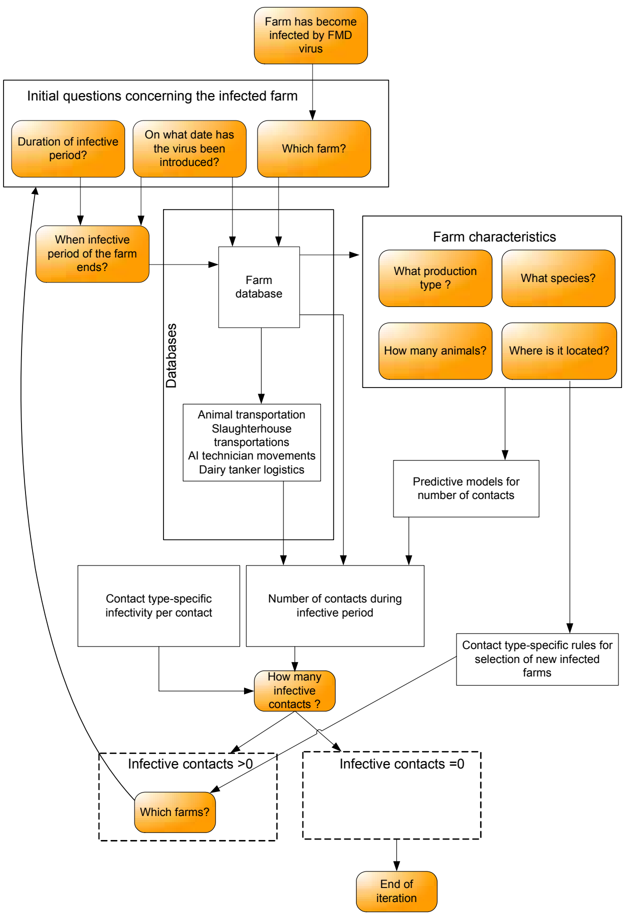

Figure 20. *The information used to simulate the infective process of a farm. Different information sources and characteristics of the infected farm influence how many contacts within an infective period an infected farm would promote and which farms would become infected. The number of infected farms is also dependent on the infectivity of the contact types.*

The following definitions are used in the model:

Contacts are estimated for the infected farm or farms and only for the infective period (see the simulation of the infective period above). A contact is an event during the infective period that links farms and can potentially cause the transmission of FMD to the extent that it could cause new outbreaks among the population of susceptible farms.

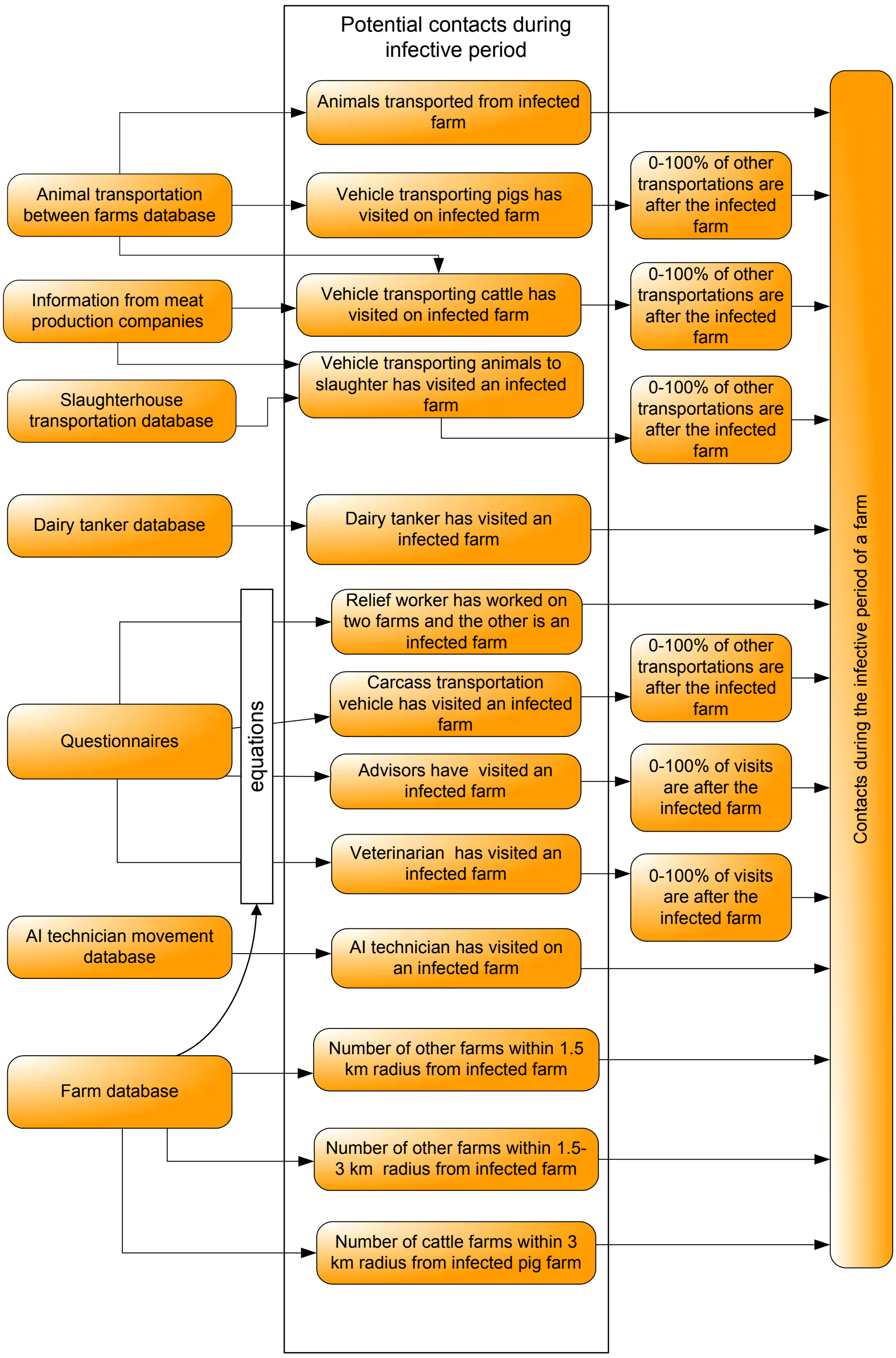

Figure 21. *Schematic description how different information sources will affect potential contacts by different contact types of a certain infected farm and how these are related to the contacts during the infective period. See parameters and definitions in Tables 19 and 20.*

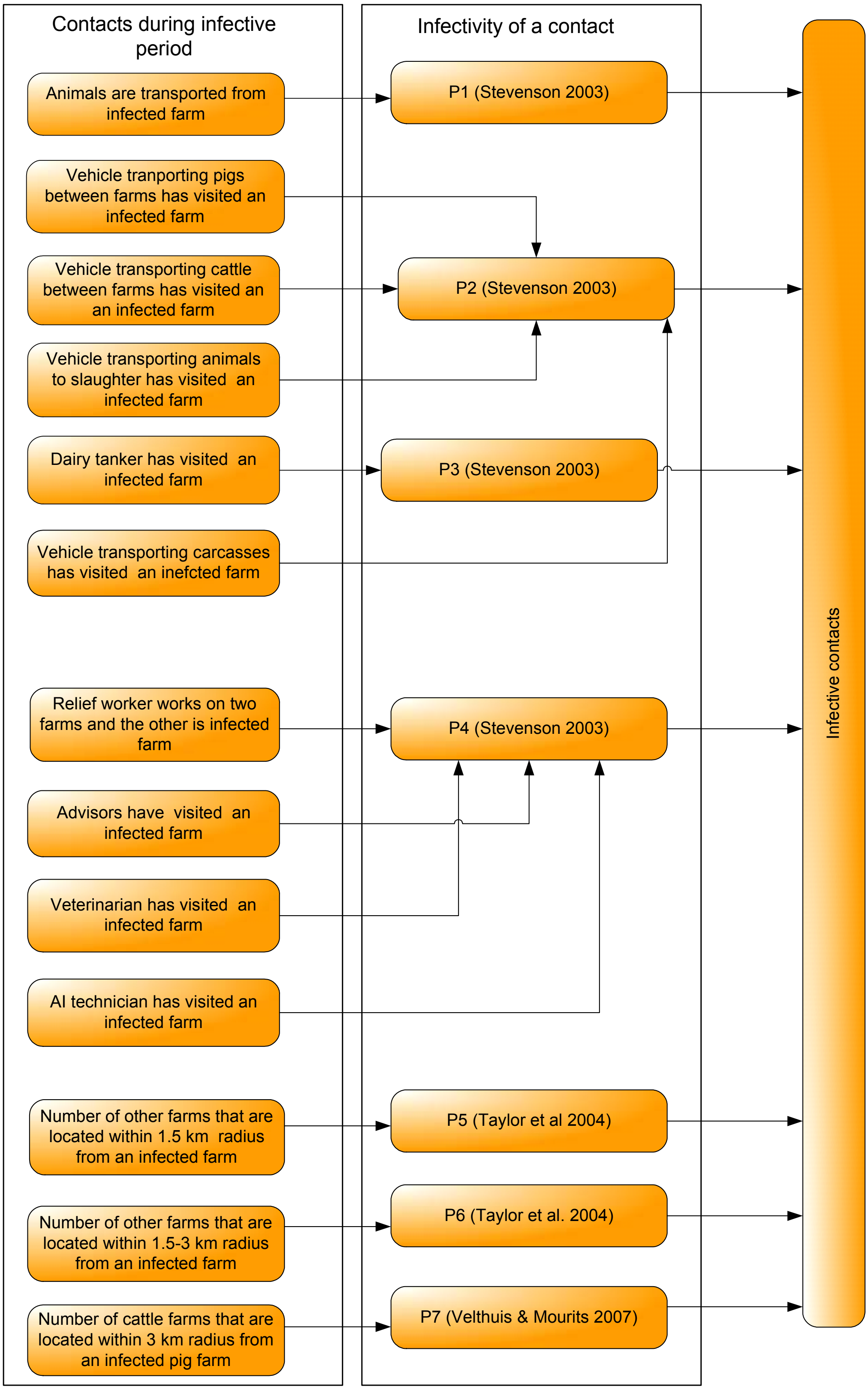

Figure 22. *Different contact types have a different infectivity per contact Contacts during the infective period and the infectivity of contact types together define which contacts are simulated to be infective. Because different contact types may infect the same farms, the number of infected farms may be smaller than the number of infective contacts. See parameters and definitions in Tables 19, 20 and 21.*

Potentially infective contact types: all those types of contacts that are assumed to be able to transport the virus to another farm (Figure 21). Those operators who only visit the farm but not the animal holdings were not regarded as infective contact types. Potentially infective contact types can be divided into two categories: event-driven contact types, where the transmission can be tested for a specific event such as a visit to the animal holdings, and eventless contact types (neighbourhood and airborne spread), where there are no distinctive events leading to transmission (Table 19, column 4).

Infectivity of contact types: probability that one contact of a certain contact type from an infected farm would introduce an adequate dose of virus to another farm and initiate an outbreak of FMD on that farm. Values for infectivity were retrieved from epidemiological literature (Table 21).

Visits to the farm: Visits of any contact type during the infective period to a certain farm. The number of visits is defined directly by a database, and is sampled for the infective period of the farm (Table 19) or estimated by equations (Table 20). If equation or parameter is used as a value for the number of visits per year, the number of visits during the infective period is sampled by a binomial distribution, Bin(number of visits per year, t/365), where t is the length of the infective period.

Potential contacts due to a visit: Farms visited by a vector on the same day that it has visited an infected farm. Potential contacts are contact-type dependent and are either directly sampled from a database or estimated according to questionnaires and other data sources (Figure 21).

Contacts due to a visit: The farms that either a vehicle or a person has visited on the same day AFTER a visit to an infected farm. This is the proportion of potential contacts (0-100%), if not known specifically (Figure 21).

Infective contact: a contact that promotes an FMD outbreak on another farm. This is defined by performing a Bernoulli trial for contacts due to visits by using the infectivity of a contact type as the probability rule of the trial. If the random number is less than the probability rule, then a contact promotes a new infected farm.

Susceptible farms: Those farms that can be potentially connected with the infected farm during the infective period. The definition of susceptible farms is dependent on the contact type and the identity of the infected farm (due to the location and membership of different operational regions) (Table 19).

Contact farms: Those farms that can acquire the infection if a contact turns out to be infective in a Bernoulli trial. The definition of contact farms is dependent on the contact type, and the identity of infected farm (due to the location and membership of different operational regions). Contact farms are sampled from the contact type-specific population of susceptible farms by a fraction defined by infective contacts, if not specified in the databases (Table 19).

Table 19. Potentially infective contact types in the FMD model, spatiality, temporality and the rule for defining susceptible and contact farms during the infective period of an infected farm.

Vector	Incident leading to transmission of infection	Spatiality of network	Source for temporal events	Susceptible farms	Contact farms
Pigs or cattle	Transportation of live pigs or cattle between farms from an infected farm	Animal transportation database	Animal transportation database	Year 2006, animals are transported from infected farms	Same as susceptible farms
Vehicle	Vehicle, transporting pigs or cattle between farms, has visited an infected farm earlier on the same day	Animal transportation database	Animal transportation database, in addition cattle: farm database, slaughterhouse transportation database	Year 2006, pigs: same transportation vehicle and day, cattle: same slaughterhouse, day and closeness	Sampled from susceptible farms
Vehicle	Vehicle transporting pigs or cattle to slaughter has visited on an infected farm earlier on the same day	Slaughter transportation database	Slaughter transportation database	Year 2006, same slaughterhouse and day of slaughter	Sampled from susceptible farms
Dairy tanker	Same vehicle transporting milk to dairy has visited on an infected farm earlier on the same day	Dairy logistics database	Dairy logistics database	Year 2006, same dairy tanker after a visit to the infected farm	Same as susceptible farms
Carcass collection vehicle	Carcass collection vehicle has visited on an infected farm earlier during the collection route	Carcass collection regions, distance from infected cattle farm within defined region	Simulated Poisson process	Pigs: same carcass collection region, Cattle within a given distance from an infected farm	Sampled from susceptible farms
Advisor	Visit to the production unit on another farm after a visit on the production unit of an infected farm earlier on the same day	Depending on the operational region of the visitor	Simulated Poisson process	Same operational region as infected farm	Sampled from susceptible farms
AI technician	AI technician has visited production unit of an infected farm earlier on the same day	AI technician movement database	AI technician movement database	Year 2006, same AI technician after a visit to the infected farm	Same as susceptible farms
Veterinarian	Veterinarian has visited the production unit of an infected farm earlier on the same day	Depending on the operational region of the visitor	Simulated Poisson process	Same operational region as infected farm	Sampled from susceptible farms
Substitute worker	Substitute worker operates in two farms during the same day and one of them is infected	Depending on the operational region of the visitor	Simulated Poisson process	Same operational region as infected farm	Sampled from susceptible farms
Unknown	Neighbouring pig farms within 1.5 km	Farm database	Eventless	Proximity from infected farm below the given value	Same as susceptible farms
Unknown	Neighbouring pig farms within 1.5-3 km	Farm database	Eventless	Proximity from infected farm within given values	Same as susceptible farms
Unknown	Neighbouring pig farms within 3 km	Farm database	Eventless	Proximity from infected farm below the given value	Same as susceptible farms

Table 20. Number of visits per year and number of potential contacts per a visit for those contact types where potential contacts during the infective period are estimated by a equation or a parameter.

Contact type	Number of visits per year	Number of potential contacts per visit
Relief worker, pig farm [a, c]	31	0-1
Relief worker, cattle farm [b, c]	31	0-1
Carcass transportation, pig farm [d]	Bin(Poisson $(0.376Z_{max}+2.035)^2$, 0.66)	0-11
Carcass transportation, cattle farm [e]	Bin(Poisson $(0.026N_{dai}+0.003N_{oth}+1.507)^2$, 0.27)	0-14
Advisor, pig farm [d]	Bin(Poisson $(0.376Z_{max}+2.035)^2$, 0.34)	0-2
Advisor, cattle farm [e]	Bin(Poisson $(0.026N_{dai}+0.003N_{oth}+1.507)^2$, 0.73)	0-2
Veterinarian, pig farm	Sow herd = 7.5; Mixed Herd =7.9; Finisher herd = 4.2	0-2
Veterinarian, cattle farm	$0.30N_{dai}+0.02N_{oth}+1.53I_{dai}+1.53$	0-2

[a] The probability that a pig farm uses a relief worker = $\exp^{(0.171+0.871I_f+0.792I_m+0.660Z_{max})}/[1+\exp^{(0.171+0.871I_f+0.792I_m+0.660Z_{max})}]$

[b] The probability that a cattle farm other than a dairy farms uses a relief worker was 10%

[c] The probability that a relief worker has two farm at the same time is sampled from beta(21,110)

[d] Carcass collection and advisors for pig farms are simulated together: the total number sampled from a Poisson distribution is divided by binomial sampling between advisors and carcass collection

[e] Carcass collection and advisors for cattle farms are simulated together: the total number sampled from a Poisson distribution is divided by binomial sampling between advisors and carcass collection

Symbols: I_f = Indicator of farrowing farm, I_m = indicator of farrowing-to-finishing farm, Z_{max} = standardised sum of pigs and cattle on the farm, N_{da} = Number of dairy cattle on the farm, N_{oth} = Number of other cattle on the farm, I_{dai} = Indicator of dairy farm, random distributions: Bin = binomial distribution, Poisson = Poisson distribution

Table 21. Infectivity (probability of transmission of disease / one contact) of contact types in the Finnish spread model when used in the risk assessment of FMD.

Parameter	Value	Contact types	Citation
P1	0.4	Direct animal contact	Stevenson 2003
P2	0.15	Animal transportation vehicles, Carcass collection vehicles	Stevenson 2003
P3	0.005	Dairy tanker	Stevenson 2003
P4	0.01	Relief worker, Advisor, Veterinarian, AI technician	Stevenson 2003
P5	0.063	Neighbourhood spread up to 1.5. km	Taylor et al. 2004
P6	0.025	Neighbourhood spread within 1.5-3 km	Taylor et al. 2004
P7	0.00438	Airborne spread from pig farms	Velthuis & Mourits 2007

Note: Airborne spread from a cattle farm to other cattle farms is included in P5 and P6 –Taylor et al. (2004) estimated the spread among cattle farms.

Epidemiological simulations

The results are based on 100 000 iterations, which ensures that each Finnish cattle and pig farm has acted as the first infected farm at least once during the simulation. The average and variance of the iteration run are stabilized during the run (Figures 23 and 24), indicating that the Monte Carlo run is adequately long to define the country and PVO district level results for the expected value and variance. A preliminary study of three different days also indicated that the starting dates of iterations did not influence the results at the country level.

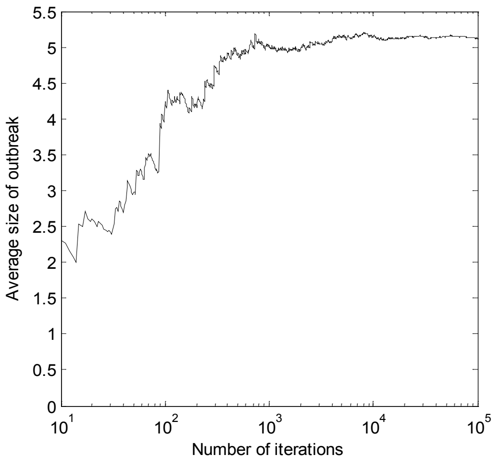

Figure 23. *Effect of the number of iterations on the estimated mean epidemic size.*

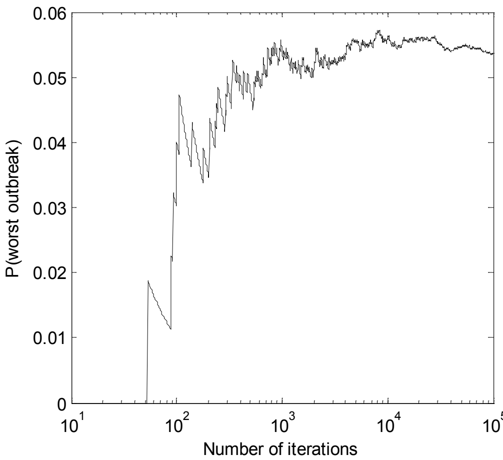

Figure 24. *Effect of the number of iterations on the probability of the worst-case scenario.*

Output of epidemiological simulation

The simulation model produces two basic output files: one with summary results for each iteration and another that contains the information on each farm that has been infected during iterations and events relevant to define the infective period of the farm.

The summary file contains the number of the infected farms, the duration of the outbreak, and the identity, type and location of the primary infected farm and parameter values containing uncertainty.

A detailed file contains the identity of the infected farm, the infection date, the date when the farm was put under restrictive measures, the day when animals on the farm had been culled and the day of initial cleaning. It also contains information on the farm that has caused the infection and what contact type led to the infection.

These results can be linked with farm-specific data (such as location and farm production type) and also with the information calculated afterwards from the databases.

Parameters of the vaccination decision

In the spring of 2009, an expert panel was gathered to collect the views of Finnish experts on the circumstances that would influence the decision to conduct emergency vaccination in Finland.

Time lags regarding the vaccination decision are based on the expert panel (held 24 April 2009) and the scientific literature. After the vaccination decision there is a time lag before the vaccination can be started. Vaccination is possible only after the type of virus has been identified and the vaccine for that type is produced in adequate quantities. After the first observation of FMD, the virus type has to be determined. Samples would be sent to Great Britain or Denmark. According to the experts, the typing of the FMD strain would be confirmed 6–14 days after the first suspicion of disease, meaning 3–11 days after the confirmation of suspicion. After typing of the virus, it should be possible to manufacture the vaccine. Vaccinations could begin no earlier than 14–18 days after the first confirmed diagnosis. If the disease were to be found earlier in other European countries, a vaccine could be delivered one week earlier.

Vaccination teams would be gathered. The expert panel estimated that 10–25 (maximum 50) teams could be assembled. Vaccination would protect 80% of uninfected, vaccinated farms 10 days after vaccination closure. Since the holdings in protection zones are under restrictive measures, vaccination would protect farms from receiving the virus from undetected infected farms from the same protection zone or nearby areas.

The expert panel considered that Finland would use commercial vaccines that would require 10 days after the vaccination to produce the maximum protection in 80% of cases. The experts did not consider it possible to use more effective vaccines in Finland due to the lack of availability.

The expert panel suggested that suppressive vaccination would be started when there would be at least 18 detected outbreaks and protective vaccination would start when there would be at least 30 detected outbreaks. As a precondition for starting emergency vaccination, the experts wanted to be 80–90% certain that the disease would spread out of control without vaccination.

6.4 Economic simulation model

Principle

Previous research has provided important viewpoints regarding the economic effects of an animal disease outbreak, such as 1) modelling domestic, export and import demand for the main livestock commodities. Moreover, epidemiological models can simulate the distribution of the size and duration of the disease outbreak, and the outcomes of these models can be consistently integrated with economic models. In terms of economic research, our contribution is to extend the existing approaches towards two aspects that are crucial in determining optimal mitigation policies. We extend the analysis by 2) treating the management of an animal stock explicitly, by taking into consideration the dynamic and biological nature of production and irreversible consequences of production decisions and 3) accepting that the duration of the market shock is unknown, a priori. The examination of the issues listed above is of wider interest, because they are relevant for various market shocks.

Our analysis elaborates that the risk of a trade distortions affects the producer and the consumer, by adjusting their decisions and market prices during and after an outbreak. However, if a large outbreak occurs, animal production can quickly decrease due to extensive disease eradication measures. Producers on uninfected farms are unable to change aggregate production volumes quickly, because it takes time to raise reproductive and fattening animals and because long-term investments in an animal stock with a high yield potential are sunk costs. Models of agricultural product markets often operate at the annual level or assume a static economic equilibrium where production and the animal stock are fully adjusted at little or no adjustment cost. In these models, the market most often fully clears at relatively small changes in market prices, compared to relatively large price fluctuations on markets distorted by an animal disease. Applications of market-level economic models of a shorter time span than one year (e.g. Mangen & Burrell 2003; Paarlberg et al. 2008) are rare.

Models should consider future events to produce consistent results for the volume and the value of production over time. For instance, culling animals prematurely incurs irreversible costs. Despite the sunk costs and dynamics of the animal stock, the optimal adjustment of production would be relatively straightforward if the size and the duration of the epidemic event were known beforehand. Unfortunately, the duration of an epidemic and the duration of the trade distortions can vary considerably.

Our approach allows producers to adjust their animal stock through inter-temporal decision-making. Moreover, we argue that production adjustments, or the lack of adjustments, must be modelled endogenously by using a structural-form stochastic dynamic optimisation framework. In this way, it is possible to cater for the rigidity of production more explicitly than by using econometric estimates. The main source of economic losses in a highly contagious animal disease outbreak, i.e. the negative price shock from the markets due to trade bans, requires the modelling of demand and supply in a sufficiently short time span to reflect the actual time scale in which production and trade decisions are made under uncertainty (Figures 25 and 26).

The economic effects of FMD are estimated in two steps by using a partial-equilibrium model and partial budgets. Firstly, it is estimated how an outbreak impacts on the number of animals kept on farms. These estimates are used to quantify the direct costs of an outbreak, which are mainly financed by tax-payers. Direct costs include cost incurred by measures such as culling and rendering infected animals and material, disinfection and cleaning of infected premises, tracing and surveillance of susceptible farms, administrative work, operations in national and local crisis centres, emergency vaccination and other official measures. Secondly, information on the animal stock and duration of an outbreak is used to quantify impacts on uninfected farms affected by restrictive measures and on livestock.

Market effects are estimated with a dynamic partial equilibrium model, which maximises the societal value of the livestock sector and thus minimises the societal costs of an FMD outbreak. The partial-equilibrium model simulates how an FMD outbreak and the related trade distortions would affect the dairy, beef and pork production, export, import and market in Finland. Export demand equations are further separated into intra-community trade with Finland and third-country trade with Finland for products that have sufficient trading quantities in the dataset. This procedure allowed us to examine the role of trade restrictions imposed by third countries. In addition, milk was divided into six different product groups (liquid milk, cream, cheese, butter, yoghurt, milk powder), and each group of products behaved as a separate product. The pig market was simulated with the model documented by Niemi & Lehtonen (2010). Another model was developed to simulate dairy and beef markets.

The models simulate dairy, beef and swine markets at the monthly level. This is an exceptionally short time frame for a partial-equilibrium model, because these models usually operate at an annual level. The short time span is of special importance, because losses are incurred in quite a short period. For instance, models operating at an annual level are fully adjusted to each new market price and marginal cost situation to minimise the losses and they are therefore likely to underestimate losses incurred in the short term.

The starting point for this study is that there are limited options to adjust production. For instance, production can be significantly increased only after several months or even years. Milk and meat prices are the key production and consumption decisions of factors (Figure 26). Hence, the decision problem is dynamic in nature, and dynamic optimisation better suits analysis of the problem than static optimisation.

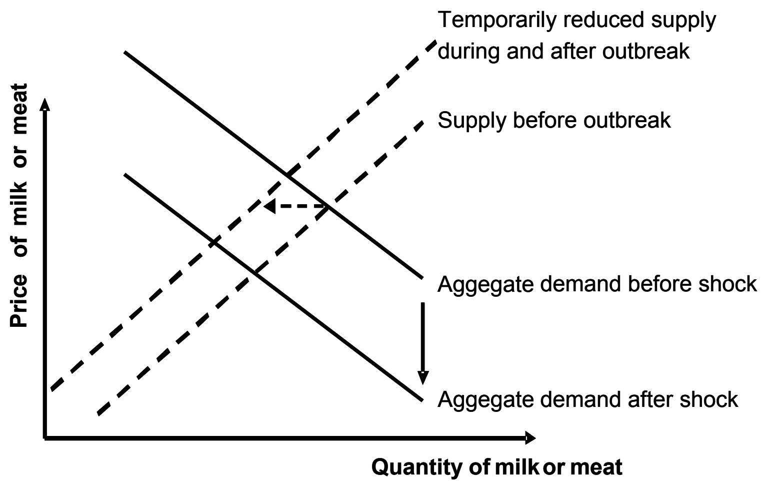

Figure 25. *Principal changes in the livestock market when a disease outbreak results in a shift in the export demand curve and hence the aggregate demand curve for domestic products, and temporarily reduces the supply of livestock products.*

Demand equations for six dairy products, beef and pigmeat export, import and domestic demand were estimated using three-stage least squares (Zellner & Theil 1962) procedure provided by Le Sage (2002). This method corrected for estimation bias caused by the endogeneity of Finnish product prices, i.e. the price variable having strong links to other variables in the model, and simultaneity of export, import and domestic demand.

The partial equilibrium model simulates the utility obtained by domestic consumers from imported and Finnish products and returns obtained by producers from the domestic and export markets. The model accounts for costs incurred due to changes in the use of production capacity in livestock production, distortions in the standard production process, an increased need to produce replacement animals and the effects of changes in the removal of animals. Both production and consumption are allowed to adjust according to the new markets situation emerging after the discovery of FMD in Finland. Biological factors that constrain rapid changes in the production quantity in the very short term are taken into account. For instance, milk production and piglet production can be increased only after a time. In each simulation, the actual duration of trade distortions is unknown, but its expected duration is known (Figure 27).

It is assumed that information about the presence of FMD in Finland halts the exporting of pigmeat, beef and milk production from Finland to third countries. Moreover, the expected duration of halted exports is assumed to follow OIE regulations. Hence, trade will be distorted on average three months after disinfection of last detected infected farm. In contrast to this, intra-community trade is assumed to continue according to EU regulations.

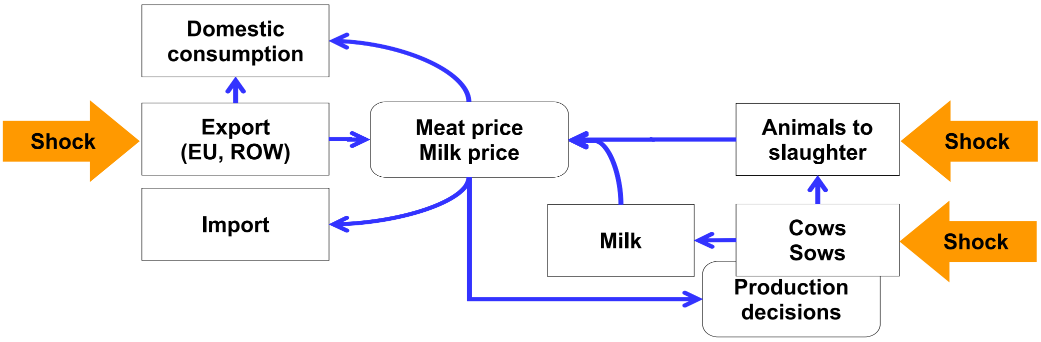

Figure 26. *The partial-equilibrium model simulates simultaneous and interrelated changes in production decisions and production quantities, import, export and domestic consumption decisions and market prices over time, and the implications of a disease (shock) on these as well as on the animal stock.*

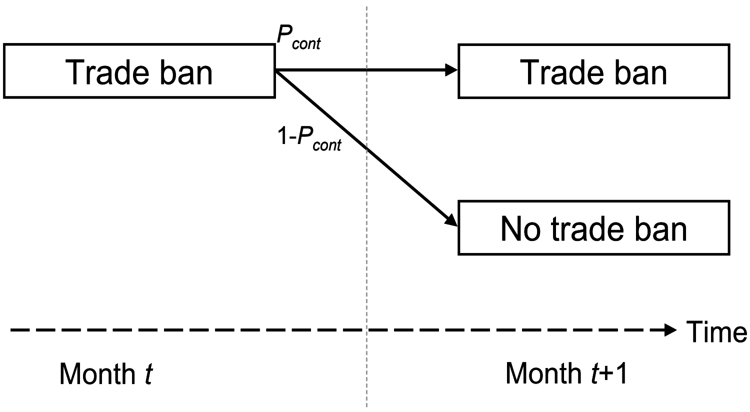

Figure 27. *The duration of a trade ban is unknown beforehand in the partial-equilibrium model, and the probability of a trade ban being lifted before the next month is represented by 1-P_{cont}.*

Key parameters for FMD in economic simulation

Direct costs

The material resources for each task were estimated according to procedures characterised by the terms of reference for veterinary officers with regard to an FMD outbreak in Finland. Labour requirements, the expenditures of which are paid from public funds, were estimated using data provided by Risk Solutions (2005). These data indicate the labour resources needed for field operations during hypothetical FMD epidemics of different sizes in the United Kingdom. Estimates of the labour required by a national crisis centre were based on a Finnish study (Niemi et al. 2008) and consultation with officials. Unit prices for each resource were collected from official statistics or requested from officials and companies capable of executing measures. Values given in Table 22 were used to calculate the direct costs.

Table 22. Values used to compute the direct costs.

Unit of measure	€ per unit[1)]
Infected farm, maximum for a farm-type dependent fixed cost	119 576
Per fattening pig in an infected farm	175
Per sow in an infected farm	572
Per dairy cow in an infected farm	1 550
Per heifer in an infected farm	1 211
Per suckler cow in an infected farm	1 296
Per growing cattle in an infected farm	1 726
Per farm in a protection zone	638+6 028*duration in months
Per farm in a surveillance zone	425+468*duration in months
Per contact farm	1 130
Vaccination, excluding the cost of culling vaccinated animals	892 per farm+8.53 per animal

[1)] Including the value of culled animals, if applicable.

Indirect costs

Production costs in milk and beef production were mainly based mainly on ProAgria (2006), but supplemented by information from other publications such as Heikkilä (1999, 2006). The cost structure of suckler cow production was based on updated information similar to that provided by Heikkilä (2005). Piglet production costs for the year 2006 used in the dynamic programming model were provided by the rural advisory organization ProAgria (2006). Feed costs were based on the assumption that pigs are fed according to Finnish feeding recommendations (MTT 2006) and they grow according to a structural-form growth model by Niemi (2006). Feeds used in the analysis were barley, soybean meal and premix. Their prices were based on 2006 prices. Extra feed costs due to production disturbances were estimated using information from the Finnish feeding recommendations (MTT 2006).

Processing costs and the division of market returns to different stakeholders in the food chain as well as information on the protein and fat composition of dairy products were needed for the model. These parameters were based on Lehtonen (2001) and Statistics Finland (2008).

Own-price elasticity estimates for six dairy products, pigmeat and beef as used in the analysis are given in Table 23. Moreover, it was assumed that extreme price fluctuations are eliminated through marketing contract arrangements between the Finnish food industry and retail. The common practice is that food deliveries to retail are contracted for four to six upcoming months. Moreover, the food industry has a limited storage capacity that can be used to smooth out extreme fluctuations in the markets. On the other hand, processing capacity is also limited in volume. The storing capacity was indirectly taken into account as a buffer that reduces the impact of the trade shock in the short term. Moreover, the impact of the limited milk product processing capacity was taken into account by imposing a constraint such that the manufacturing of each milk product cannot exceed the maximum historical amount in 1995 to 2007.

Table 23. Elasticity estimates used in the model and their standard errors (SE).

	Intra-community exports		Third-country exports		Imports		Domestic demand	
	Estimate	SE	Estimate	SE	Estimate	SE	Estima-te	SE
Pigmeat	-0.968	0.283	-0.512	0.169	0.872	0.828	-0.138	0.064
Beef	-1.016	0.213	-2.631	0.213	0.939	0.936	-0.376	0.191
Liquid milk	-6.261	0.499	-6.261	0.499	6.804	1.842	-0.157	0.083
Creams	-4.574	0.391	-4.574	0.391	0[1)]	0[1)]	-1.925	0.626
Butter	-1.768	0.661	-0.249	0.373	0[1)]	0[1)]	-0.168	1.062
Yoghurt	-0.327	0.302	-0.327	0.302	0[1)]	0[1)]	-0.464	0.183
Cheese	-2.326	0.623	-0.154	0.749	0.555	0.624	-1.594	0.475
Milk powder	-1.300	1.218	-1.866	0.769	0.009	0.367	-1.523	0.525

[1)] The parameter was restricted at zero.

The economic simulation process

The model was developed in Matlab version 7.8.0.347. Pigmeat markets were simulated with one partial-equilibrium model and milk and beef markets with another model, as pig and cattle production are in an economic sense not particularly strongly related to each other. Partial-equilibrium models were calibrated for the average monthly figures for the year 2006. Simulations were performed for a standardised set of epidemiological scenarios to determine the value of the epidemic size and duration. Thereafter, these results were incorporated with epidemiological simulations and direct and indirect costs incurred in each iteration were estimated by using previously simulated value results.

7 Results

The results are based on 100 000 iterations. They are divided into three groups based on the final size of the epidemic: 1) a sporadic outbreak = no further spread 2) a typical outbreak = 2–17 farms will become infected, 3) the worst-case outbreak = at least 18 infected farms at the end of iteration. The typical and worst-case outbreaks represented 67.8% of iterations (Table 24).

Table 24. The distribution of simulated outbreaks.

Outbreak type	Number of infected farms	Average number of infected farms	Duration from infection to disinfection (weeks)	% of all iterations
Sporadic	1	1	3.5	32.2
Typical	2-17	5	5	62.3
Worst case	>=18	29	8	5.5

Sporadic outbreak

Sporadic outbreaks occurred in 32.2% of the iterations. The farm was initially cleaned on average 3 days (95% of the infected farms were cleaned after 7 days) after the positive diagnosis. The duration from the first introduction of the virus until disinfection was on average 3.5 weeks. The number of animals on infected farms was obviously dependent on the production type of the farm (Table 26).

Sporadic outbreaks had the largest indirect influence due the administrative obligations associated with an outbreak when the first infected farm was in Vaasa, Turku or Oulu PVO district. In outbreaks starting from these PVO districts, the number of uninfected farms within the protection and surveillance zone of the single infected farm was on average 3 to 8 times higher than when sporadic outbreaks occurred in Rovaniemi district (Table 25). In addition, about 20 traced contact farms would not have become infected. The number of traced contact farms varied little between PVO districts. The proportion of sporadic outbreaks in the different PVO districts varied between 27.3–38.6%, so an epidemic outbreak was more probable than a sporadic outbreak in every PVO district (Table 25).

Table 25. Mean number of uninfected farms in the given PVO district that are located in protection and surveillance zones or have been traced as contact farms in the case of a sporadic outbreak. The 95th percentile is shown in parentheses.

PVO district	Number of farms			P(no outbreak) %
	In Protection zone	In Surveillance zone	Traced contacts	
Helsinki	3 (8)	26 (50)	20 (56)	38.2
Vaasa	11 (25)	62 (109)	20 (51)	30.1
Oulu	7 (24)	34 (104)	23 (57)	30.0
Rovaniemi	2 (7)	8 (23)	20 (49)	34.6
Turku	7 (15)	50 (92)	20 (57)	38.6
Hämeenlinna	5 (12)	42 (75)	20 (57)	38.2
Tampere	4 (10)	35 (65)	18 (53)	37.7
Kouvola	5 (13)	40 (75)	20 (59)	32.2
Mikkeli	3 (8)	28 (51)	20 (54)	30.2
Joensuu	5 (13)	35 (71)	19 (53)	31.6
Kuopio	7 (15)	51 (92)	22 (57)	27.3
Jyväskylä	4 (11)	25 (47)	16 (49)	33.5

Note: Only farms outside the zones are estimated as traced contact farms

In sporadic outbreaks, the number of animals on the infected farms was low. There were differences among PVO districts, as in some districts it is quite unlikely that there would be any pigs on infected farms. Among cattle farms the relative differences between districts were low. Variability within PVO districts was large, as the 95th percentile could be 5–6 times larger than the expected value. By contrast, the range between expected values and the 95th percentile of dairy cattle was only two-fold (Table 26).

Table 26. Number of animals on infected farms in sporadic outbreaks that occurred in a given PVO district.

PVO district	Sporadic outbreak											
	Sows		Piglets		Finishers		Dairy cows		Other Cattle		Total	
	mean	<95%	mean	<95%	mean	<95%	mean	<95%	mean	<95%	mean	<95%
Helsinki	3	23	17	131	37	248	11	39	17	77	87	467
Vaasa	7	48	40	274	69	432	11	39	22	89	152	686
Oulu	1	0	6	0	11	0	14	38	24	100	53	159
Rova-niemi	0	0	0	0	2	0	11	31	36	90	36	96
Turku	13	80	74	456	115	568	6	29	15	84	227	914
Hämeen-linna	6	48	34	274	48	385	10	36	17	79	113	613
Tampere	3	19	17	108	18	105	10	36	18	78	65	258
Kouvola	3	17	17	97	33	216	9	32	17	78	78	353
Mikkeli	2	0	11	0	10	5	8	31	21	99	50	166
Joensuu	1	0	6	0	8	0	11	34	21	88	44	151
Kuopio	1	0	6	0	7	0	13	38	22	87	49	173
Jyväskylä	2	0	11	0	10	45	8	29	22	88	52	192

Losses in a sporadic outbreak

In the sporadic outbreak scenario, the median total loss was simulated at €22.8 million. In 95% of iterations, simulated losses were less than €23.5 million per outbreak. The majority of losses were paid by producers, and the direct costs of an outbreak were considerably smaller than the indirect costs. In fact, producer losses were larger than the total loss, because consumers were able to gain a little from an outbreak. In the median case, consumers gained €68.4 million, whereas producers lost €91.0 million.

The variation in losses caused by a sporadic outbreak was quite small, as these outbreaks were quite equal in their duration and other size measures. Regional differences between PVO districts in their simulated losses in the case of a sporadic outbreak were small. For almost every PVO district, the median loss caused by a sporadic outbreak and the upper 95% percentile results were the same as reported in Table 27 for the entire country.

Table 27. Mean, median, 5th and 95th percentiles of the change in economic surplus of producers, consumers, taxpayers (public funds) and society as a whole in millions of euros due to a simulated sporadic FMD outbreak.

	Producers	Consumers	Public funds	Total
<5%	-90.0	67.8	-0.2	-22.5
Median	-91.0	68.4	-0.3	-22.8
Mean	-91.5	68.9	-0.3	-22.9
<95%	-93.8	70.6	-0.5	-23.5

Typical outbreak

A typical outbreak was the most common outcome, as it was achieved in 62.3% of iterations. An outbreak lasted 5 weeks from the first introduction of the virus and 5 farms were typically infected. The infected farms were initially cleaned approximately 2 weeks after the first suspicion (Table 28).

The size and duration of an outbreak varied only slightly between PVO districts in which the outbreak had started (Table 29). Typical epidemics could spread out of the PVO district, but it was more probable that further spread of FMD would occur in the same PVO district where the outbreak had started. There was a tendency that typical outbreaks would in some districts stay in the PVO district, while in other districts it tended to spread to another PVO district (Table 37).

Table 28. The size (number of infected farms) and duration (days) of a typical outbreak.

	Number of infected farms	Number of infected production units	Duration of outbreak*
Mean	5	5	36
Median	4	4	35
95th percentile	13	14	51

*From the first infection until the disinfection of infected farms

Table 29. The outcomes of typical outbreaks in PVO districts in Finland.

PVO district	Number of infected farms (qty)		Number of infected production units (qty)		Duration of outbreak (days)	
	Mean	95th	Mean	95th	Mean	95th
Helsinki	5	12	5	13	35	50
Vaasa	5	14	6	15	36	51
Oulu	5	13	5	13	36	50
Lappi	5	13	5	13	35	50
Turku	5	13	5	15	35	50
Hämeenlinna	5	12	5	13	35	49
Tampere	5	13	5	14	35	49
Kouvola	5	14	6	15	37	51
Mikkeli	6	14	6	15	37	52
Joensuu	5	14	5	14	36	52
Kuopio	5	14	6	14	36	52
Jyväskylä	5	14	6	14	36	51

Although typical outbreaks were similar-sized in different PVO districts, the consequences were quite different: a typical outbreak starting in the district of Vaasa caused 3 times more uninfected farms in protection zones and 4 times more in surveillance zones than in typical outbreaks starting in the district of Rovaniemi (Table 30). In addition, with the uninfected farms in zones, the number of traced contact farms was also 4 to 5 times higher than in a sporadic outbreak, but the differences between PVO districts were small (Table 30).

Table 30. Mean number of uninfected farms in protection and surveillance zones and traced contact farms when a typical outbreak started in a given PVO district. In parentheses are given 95th percentiles.

PVO district	Number of farms				N protection/ N infected	N surveillance/ N infected
	Infected	In protection zones	In surveillance zones	Traced contacts		
Helsinki	5	16 (52)	97 (300)	95 (254)	3.2	19.4
Vaasa	5	40 (107)	160 (416)	92 (216)	8.0	32.0
Oulu	5	28 (88)	99 (308)	102 (245)	5.6	19.8
Rova-niemi	5	13 (44)	41 (164)	90 (211)	2.6	8.2
Turku	5	24 (67)	130 (342)	103 (243)	4.8	26.0
Hämeen-linna	5	19 (51)	104 (264)	88 (220)	3.8	20.8
Tampere	5	19 (59)	106 (303)	96 (243)	3.8	21.2
Kouvola	5	22 (60)	115 (290)	109 (258)	4.4	23.0
Mikkeli	6	19 (58)	103 (287)	107 (256)	3.2	17.2
Joensuu	5	23 (63)	99 (272)	97 (233)	4.6	19.8
Kuopio	5	27 (75)	138 (360)	105 (251)	5.4	27.6
Jyväs-kylä	5	19 (57)	86 (262)	99 (248)	3.8	17.2

Note: Only farms outside the zones are estimated as traced contact farms

Typical outbreak involved much larger numbers of animals than a sporadic outbreak. The animal production in different PVO districts varied, and thus in several districts it was not probable that large numbers of pigs would be involved in the outbreak (Table 31). Differences between PVO districts in the expected number of cattle on infected farms were small.

Table 31. Number of animals on infected farms in a typical outbreak that has started in a given PVO district.

PVO district	Typical outbreak											
	Sows		Piglets		Finishers		Dairy cows		Other Cattle		Total	
	mean	<95%	mean	<95%	mean	<95%	mean	<95%	mean	<95%	mean	<95%
Helsinki	49	253	279	1 442	332	2 232	88	288	104	422	851	4 088
Vaasa	49	295	279	1 682	307	1 960	110	322	136	528	884	4 055
Oulu	8	0	46	0	39	0	109	299	130	529	328	974
Rovaniemi	3	0	17	0	14	0	92	259	120	519	249	783
Turku	131	727	747	4 144	806	474	66	254	104	523	1 855	8 986
Hämeen-linna	43	190	245	1 083	267	267	84	263	92	396	729	2 819
Tampere	26	150	148	855	174	1 070	87	280	119	489	553	2 333
Kouvola	27	129	154	735	186	998	102	299	104	405	575	2 184
Mikkeli	10	18	57	103	72	119	99	278	118	430	354	924
Joensuu	5	0	29	0	40	0	98	271	127	467	299	741
Kuopio	9	0	51	0	55	0	109	296	146	575	371	989
Jyväskylä	10	23	57	131	56	170	94	274	121	420	337	883

Losses in a typical outbreak

In the typical outbreak scenario, the median total loss was simulated at €25.3 million. In 95% of iterations, simulated losses were less than €31.4 million per outbreak. Hence, the median loss was larger and losses also varied more than in the sporadic scenario. In the median case, consumers gained €73.5 million, whereas producers lost €97.5 million. In 95% of iterations, the costs paid by public funds fell below €4.1 million (Table 32).

Differences between regions in the mean losses were still quite small, whereas 95th percentile losses were more volatile. Outbreaks beginning in different regions were able to reach €30 million in losses (Table 33).

Table 32. Mean, median, 5th and 95th percentiles of change in the economic surplus of producers, consumers, taxpayers (public funds) and society as a whole in millions of euros due to a simulated typical FMD outbreak.

	Producers	Consumers	Public funds	Total
<5%	-91.5	68.9	-0.4	-23.1
Median	-97.5	73.4	-1.1	-25.3
Mean	-99.3	74.8	-1.5	-26.0
<95%	-113.1	85.2	-4.1	-31.4

Table 33. Mean and the 95th percentile change in society's economic surplus (million €) due to a typical FMD outbreak according to the PVO district.

	Mean	<95%
Helsinki	-25.6	-30.8
Vaasa	-26.4	-32.0
Oulu	-26.0	-31.3
Rovaniemi	-25.5	-29.9
Turku	-25.9	-31.4
Hämeenlinna	-25.6	-30.7
Tampere	-25.7	-31.0
Kouvola	-26.1	-31.6
Mikkeli	-26.2	-31.4
Joensuu	-26.0	-31.2
Kuopio	-26.1	-31.6
Jyväskylä	-25.9	-31.1

Worst-case outbreak

The proportion of worst-case outbreaks was 5.5% of 100 000 iterations. The number of infected farms ranged from 18 to 134, and outbreaks lasted 2–4 weeks longer than typical outbreaks on average (Table 34). The number of animals on infected farms was typically much larger than in typical outbreaks.

Table 34. The size (number of infected farms) and duration of a worst-case outbreak.

	Number of infected farms	Number of infected production units	Duration of outbreak*
Mean	29	30	57
Median	25	25	55
95th percentile	54	55	77

*From the first infection until disinfection of infected farms

The probability of worst case epidemics in different PVO districts varied from 2.4–8.9%. The number of uninfected farms in protection and surveillance zones was larger, but relative differences between different PVO districts were smaller than in typical outbreaks. In protection zones there were be 3.8–6.8 farms per infected farm in a worst-case outbreak, but in a typical outbreak there were 3.2–8.0 uninfected farms per infected farm. A similar tendency could be seen in surveillance zones, where worst-case outbreaks produced 16.8–24.6 uninfected farms in surveillance zones per infected farm, while a typical outbreak produced 8.2–32.0 uninfected farms in surveillance zones per infected farm (Tables 30 and 35). The number of traced contact farms was approximately 4 times higher in a worst-case outbreak than in a typical outbreak. Differences between PVO districts were relatively small (Table 35).

Table 35. Mean number of farms in protection and surveillance zones when a worst outbreak started in a given PVO district.

PVO-district	Number of farms			Traced contacs	P(Worst) %	N protection/ N infected	N surveillance/ N infected
	Infected	In Protection zones	In Surveillance zones				
Helsinki	29	134 (269)	686 (1361)	475 (904)	2	5	24
Vaasa	29	203 (402)	733 (1433)	359 (666)	6	7	25
Oulu	29	166 (326)	629 (1279)	442 (836)	4	6	22
Rovaniemi	28	133 (348)	503 (1223)	430 (858)	3	5	18
Turku	29	127 (272)	524 (1151)	360 (678)	5	4	18
Hämeen-linna	27	121 (234)	578 (1200)	422 (756)	3	4	21
Tampere	28	133 (294)	622 (1413)	430 (813)	4	5	22
Kouvola	29	127 (260)	573 (1137)	430 (770)	6	4	20
Mikkeli	30	119 (256)	547 (1094)	418 (757)	9	4	18
Joensuu	30	134 (265)	527 (1159)	393 (722)	7	4	18
Kuopio	29	158 (318)	664 (1305)	429 (763)	7	5	23
Jyväskylä	28	126 (283)	538 (1180)	428 (849)	5	5	19

Note: Only farms outside the zones are estimated as traced contact farms

In worst-case outbreaks the proportion of iterations in which the whole outbreak stayed in the same district as the primary infected farm was lower than in a typical outbreak in every PVO district (Table 37). This means that the worst outbreak was less dependent on the production structure of the PVO district of the primary infected farm. The strongest tendency of the worst outbreak to remain within the PVO district of the primary infected farm was in Vaasa and Turku PVO districts. The lowest tendency to remain within one PVO district appeared to be in Helsinki, Hämeenlinna, Tampere, Jyväskylä, Rovaniemi and Kouvola PVO districts, and thus the further spread from these PVO districts to other PVO districts was more probable.

In worst outbreaks, differences between PVO districts in the number of cattle on infected farms were small, while there were clear differences in the number of pigs that would be eradicated (Table 36). The largest quantities of pigs on infected farms were in those outbreaks that started in Turku PVO district, where the total number of animals on infected farms was also be 2–3 times higher than if the outbreaks started elsewhere.

The number of pigs on uninfected farms that would be in protection and surveillance zones varied more between PVO districts than the number of cattle. In Turku PVO district, the number of pigs on uninfected farms within these zones was 5–9 times higher than in Joensuu and Mikkeli PVO districts. By contrast, the highest mean number of cattle on uninfected farms of the zones in a PVO district was less than two times higher than in the PVO districts that on average had the lowest number of cattle in the zones (Table 38).

Table 36. Number of animals on infected farms when a worst-case outbreak started in a given PVO district.

PVO district	Worst outbreak										Total	
	Sows		Piglets		Finishers		Dairy cows		Other Cattle			
	mean	<95%	mean	<95%	mean	<95%	mean	<95%	mean	<95%	mean	<95%
Helsinki	200	1 590	1 140	9 063	919	7 408	660	1 424	1 127	2 854	3 753	20 631
Vaasa	271	2 097	1 545	11 953	1 462	10 486	632	1 224	1 015	2 530	4 780	24 209
Oulu	70	30	399	171	287	282	614	1 166	1 029	2 536	2 297	4 788
Rovaniemi	197	2 371	1 123	13 515	902	7 682	532	1 060	1 159	2 912	3 673	22 025
Turku	519	3 562	2 958	20 303	2 598	17 679	555	1 156	785	2 184	7 203	39 374
Hämeen-linna	174	1 233	992	7 028	882	6 824	556	1 035	953	2 375	3 415	15 314
Tampere	172	1 177	980	6 709	863	5 588	606	1 169	959	2 184	3 447	14 001
Kouvola	25	37	143	211	108	355	623	1 133	934	2 034	1 793	4 042
Mikkeli	19	27	108	154	137	355	574	1 108	866	1 972	1 620	3 456
Joensuu	18	2	103	11	132	200	590	1 136	945	2 319	1 706	3 674
Kuopio	46	53	262	302	232	424	608	1 171	1 137	2 628	2 271	4 858
Jyväskylä	53	113	302	644	317	767	572	1 119	905	2 238	2 024	4 907

Table 37. The proportion of iterations in which all infected farms were situated in the same PVO district as the primary infected farm in typical and worst outbreak scenarios.

PVO district	Proportion (%) of outbreaks which remain in PVO-district	
	Typical	Worst
Helsinki	66.4	21.7
Vaasa	91.5	71.7
Oulu	82.5	45.4
Rovaniemi	82.7	39.1
Turku	86.0	73.4
Hämeenlinna	71.5	33.8
Tampere	71.2	36.2
Kouvola	75.8	44.6
Mikkeli	75.5	54.3
Joensuu	81.4	56.9
Kuopio	85.1	59.5
Jyväskylä	74.5	39.7

Table 38. The mean number of animals on uninfected farms in protection and surveillance zones when an outbreak started in a given PVO district under the worst-case scenario.

PVO district	Protection		Surveillance zones		Total mean
	Pigs mean	Cattle mean	Pigs mean	Cattle mean	
Helsinki	9 700	3 700	44 000	19 200	82 600
Vaasa	13 600	7 200	37 800	25 200	82 500
Oulu	4 500	6 700	14 300	24 000	43 800
Rovaniemi	5 700	4 800	10 800	18 300	34 300
Turku	15 100	3 200	42 300	12 900	76 900
Hämeenlinna	7 900	3 400	33 300	16 400	62 300
Tampere	9 700	3 800	40 400	17 600	71 300
Kouvola	3 700	3 900	16 700	17 400	41 600
Mikkeli	2 100	3 800	9 600	17 200	33 800
Joensuu	1 900	4 800	7 800	18 200	39 200
Kuopio	3 300	5 900	11 800	24 700	38 600
Jyväskylä	3 400	4 300	12 900	17 600	20 600

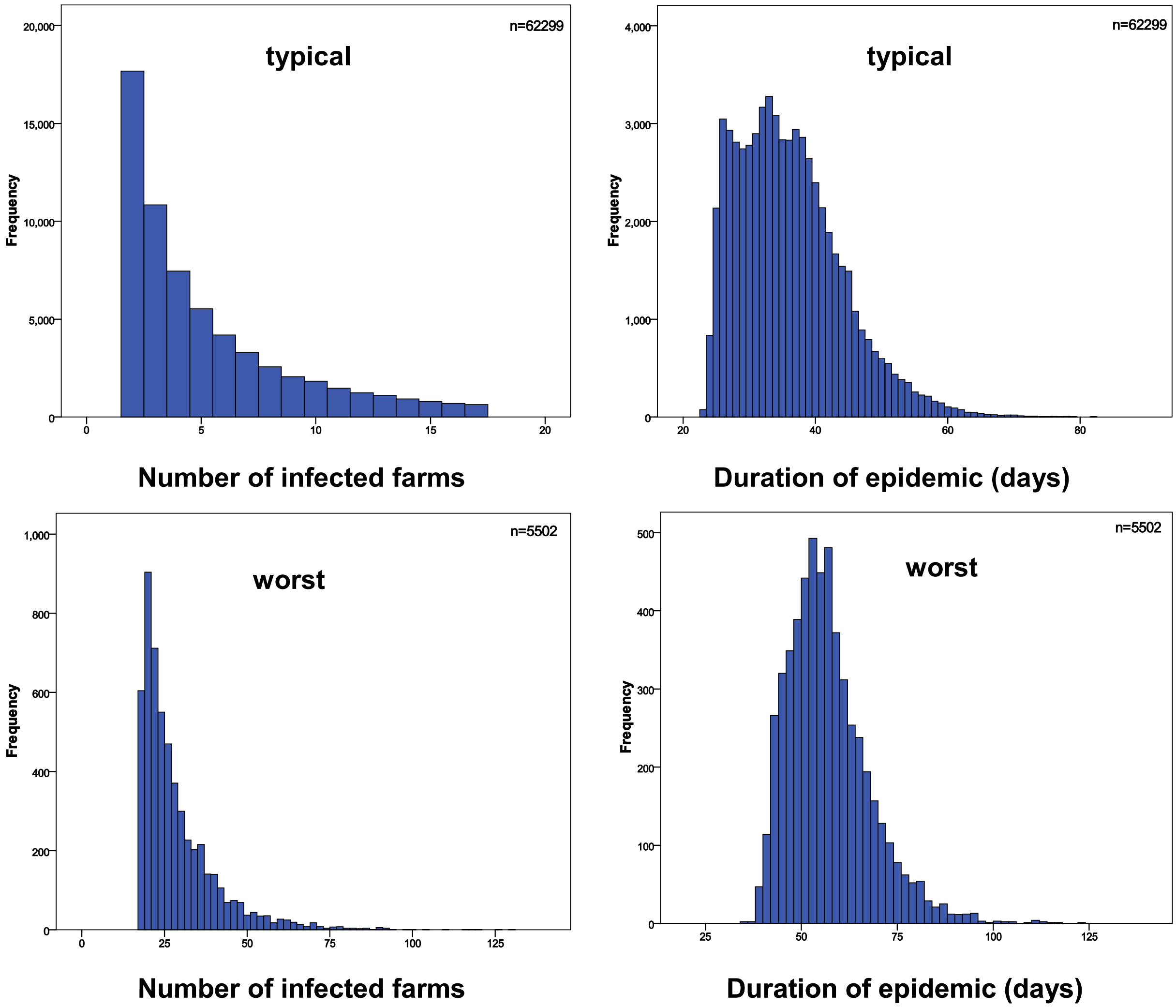

Figure 28. *The distribution of size and duration of a typical outbreak (n = 62299) and a worst-case outbreak (n = 5502). Note that the scale is different for typical and worst outbreak histograms.*

Losses in the worst-case outbreak

In the worst-case outbreak, the median total loss was simulated at €36.5 million. In 95% of iterations, simulated losses were less than €52.4 million per outbreak. In the median case, consumers gained €85.8 million, whereas producers lost €113.7 million. Hence, the losses were larger and losses also varied more than in the sporadic scenario. The loss distribution overlapped with the distribution obtained for the typical outbreak, but not with distribution obtained for the sporadic scenario. Median costs paid by public funds were simulated at €7.9 million, but two times higher losses were also possible. In relative terms, public expenditures were boosted by the worst-case scenario more than the economic effects of consumers on producers. Higher variation in public expenditures was mainly because public expenditures were quite strongly related to the number of infected farms, whereas losses to producers were mainly related to the duration of trade distortions (Table 39).

Differences between regions were more prominent in the worst-case scenario than in other scenarios. The highest median loss was simulated for outbreaks beginning from Vaasa PVO district. When considering the 95th percentile, outbreaks beginning from Vaasa, Oulu, Joensuu and Kuopio districts were able to result in more than €53 million in losses, whereas outbreaks beginning from Hämeenlinna or Tampere district did not result in losses higher than €49 million (Table 40). These results were explained by differences in outbreak size and duration.

Figure 29 illustrates the accumulation of the total loss over time in the worst-case scenario. More than 50% of final outbreak costs are already incurred by the time the first farm has been detected. In a few cases, losses are accumulated until about two months have elapsed, whereas in most cases no further losses are accumulated after some 3 to 4 weeks time following the detection of the first case. The costs of an outbreak are sunk costs after it has occurred. Even if the costs are realized afterwards, they cannot be recovered, as the infection – and the costs – cannot be cancelled. In less than 5% of worst-case outbreaks, i.e. in fewer than 0.25% of all iterations, no preventive measures could save costs when approximately 60 days have passed after the first farm has become infected. This pattern is not fully captured by Figure 29, because in a few cases the very end of the iteration can boost the losses and thus shift the 95% curve in Figure 29. There are some differences between iterations in their pattern of accumulation of losses. The observed epidemic size makes a difference to the accumulation curve. The more infected farms have been observed by a specific date, the more extra losses are expected to be incurred before the last farm has been disinfected. The information value of the number of detected farms is at the largest around 40 days after the first infection.

Table 39. Mean, median, 5th and 95th percentiles of the change in the economic surplus of producers, consumers, taxpayers (public funds) and society as a whole in millions of euros due to a simulated worst-case outbreak of FMD.

	Producers	Consumers	Public funds	Total
<5%	-103.9	77.9	-4.8	-31.0
Mean	-117.7	88.6	-9.4	-38.5
Median	-113.7	85.8	-7.9	-36.5
<95%	-145.7	109.3	-18.9	-52.4

Table 40. Mean and the 95th percentile change in society's economic surplus (million €) due to a worst-case FMD outbreak according to the PVO district.

	Mean	<95%
Helsinki	-38.1	-51.8
Vaasa	-39.7	-54.8
Oulu	-39.2	-53.8
Rovaniemi	-37.4	-51.1
Turku	-38.3	-51.6
Hämeenlinna	-37.1	-47.5
Tampere	-38.2	-48.6
Kouvola	-37.6	-50.9
Mikkeli	-37.2	-50.9
Joensuu	-38.3	-53.7
Kuopio	-39.0	-53.5
Jyväskylä	-37.5	-50.0

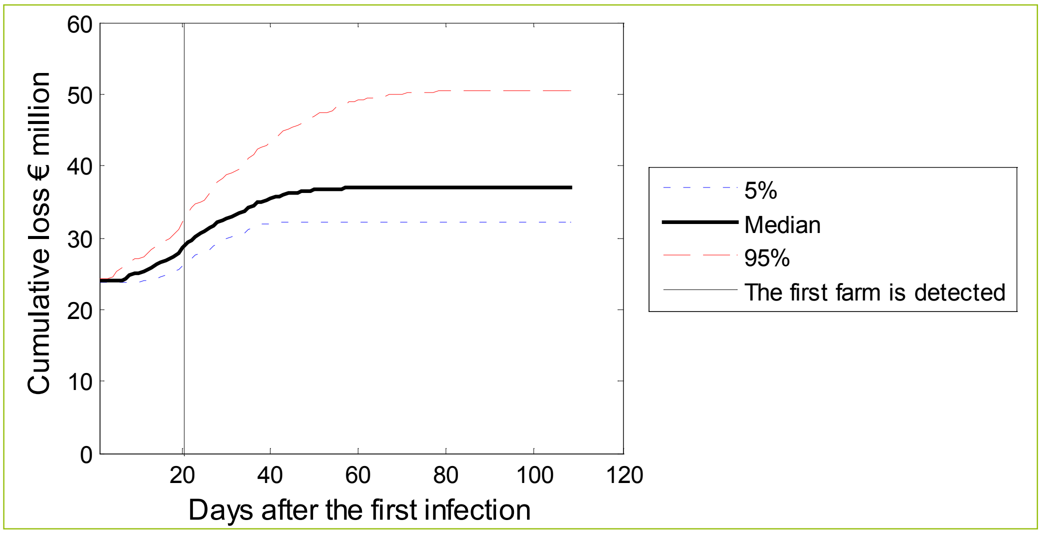

Figure 29. *Accumulation of societal losses in the event of a worst-case outbreak.*

Major determinants for losses

In the event of a worst-case scenario, the direct costs of an outbreak were quite prominent, whereas in other scenarios they generally represented only a fraction of the losses. Direct losses were quite strongly related to the number of infected farms. Each infected farm contributed, on average, €0.33 million in additional losses. The direct cost could soar for a number of reasons. The effort required to clear the infected premises is quite labour-intensive and therefore costly. Moreover, the culling of animals kept in infected farms, disinfection measures taken at the farm and the loss of value of animals were more costly the more animals were involved. The costs of maintaining surveillance and protection zones were high, especially when a large number of farms were located in these zones, such as in herd-dense areas, and when the outbreak was long-lasting. Direct costs were the highest in the worst-case scenario, where both the number of infected farms and the number of farms located in a surveillance or protection zone or traced as a contact herd were the highest.

The number of infected premises also contributed to the total loss, but less than indirect losses did. Each infected farm contributed on average €0.56 million in additional losses to society. To a large extent, economic losses resulted from distortions in the foreign trade of pigmeat, beef and dairy products. When information about the introduction of FMD into Finland was obtained, third-country exports were halted. This resulted in difficulties in marketing pigmeat and dairy products because the Finnish dairy and pig sectors were exporting a considerable share of their products outside the EU. Producer prices fell and market revenues to the dairy and pig sectors decreased, because domestic consumers were unable to increase their food consumption as much as excess supply in the domestic markets would have required. This problem could partly be solved by increasing intra-community trade and by adjusting the processing quantities of dairy products each month. Given the short time perspective, these adjustments were insufficient to prevent prices from falling.

Producer prices for pigmeat fell by 20 to 25 cents per kg (16-20%), whereas the producer price for beef fell only modestly, generally less than 5%. The most important contributor was milk production, where simulated losses amounted to approximately €8 per 100 kg milk (-18%) and the producer price for milk fell close to prices paid in countries such as Germany. The importance of milk production is mainly because of the larger economic size of the dairy sector when compared to the pig or beef sectors, and because of the export orientation of fatty milk product manufacturing. The losses in milk exports were mainly due to distortions in the trade of high-fat-content dairy products such as cheese or butter.

The supply shock caused by a sporadic or typical outbreak was generally small, because the outbreak was quite small. Worst-case outbreaks also had quite a limited impact on the number of animals and large number of animals were not removed from the markets due to FMD. If the disease had removed a large number of animals from the markets, it would have changed the result a little. When the supply of milk and meat decreased, market prices were able to recover slightly, both during and after the export shock. Although market losses of the worst-case outbreak were reduced by an elevated number of animals removed from the markets, they were also increased by the prolonged duration of trade distortions when compared to other scenarios.

As market prices in Finland were falling due to trade distortions, consumers were able to benefit in the short term. The benefit per consumer was deemed small, because it was divided between a large number of people. In the worst-case scenario, the 95th percentile result implied a benefit of only €20 per consumer. The loss per farm enterprise was larger, as farms are fewer in number than people. When producer losses were normalized by agricultural income, an outbreak was able to reduce the agricultural income by 10% to 16%, depending on the scenario and the value that was being examined. However, the impact on pig and cattle farms would be more significant, because only 36% of Finnish farms have cattle or pigs. It is likely that the profit margin of livestock farms would have been negative in the year when the outbreak occurred.

Consumers and retailers were able to benefit from the trade shock, e.g. by substituting the consumption of imported cheese with Finnish cheese. Hence, Finnish production was able to increase its market share in the domestic markets, even though Finnish products are not identical to imported products. A similar result was obtained for pigmeat. When market prices for pigmeat fell, domestic consumers were able to substitute part of their imported meat consumption with domestic pigmeat. This was important for pig production, as imports were approximately 20% of production. In contrast to this, changes in the consumption of beef were negligible, because beef is exported in small amounts and exported products are mostly of a type that does not have adequate markets in Finland.

Impacts on production

As noted above, the direct impact of an outbreak on production was quite small. In a median of all simulations (n = 100 000), restrictive measures were imposed on less than 1% of cows and sows in Finland. In 95% of iterations, the outbreak resulted in less than a 0.13% immediate decrease in milk production and less than a 0.08% immediate decrease in piglet production. Distortions due to restrictive measures affected a larger number of animals. In 99% of iterations, protection zones controlled a maximum of 1.3% of milk production and 2.3% of piglet production, and surveillance zones controlled a maximum of 4.7% of milk production and 9.3% of piglet production. Hence, in worst-case epidemics, a larger share of pig production than milk production can be under restrictions. These figures also illustrate that pig production is spatially more concentrated than milk production. Pig farms are on average larger and fewer in number than dairy farms.

Despite large market losses and the reduced ability of the food processing industry to pay for livestock products, adjustments in production were small. Slaughter weights of fattening pigs were virtually unchanged in the short term. Adjustments in feeding were not considered as an important adjustment method, as it could result in distortions in the production process. For instance, the production potential of dairy cows could be reduced due to inadequate feeding. Hence, the most important modes of adjustment in the model were changes in the number of inseminated and removed cows and sows and changes in milk processing.

The sluggish adjustment was mainly driven by biological constraints in production and the short expected duration of trade shocks. In the event of pig production, producers had incentives to increase the number of inseminations to quickly recover the sow stock (Figure 30). Hence, when an outbreak occurred, piglet production was able to recover close to pre-outbreak figures within approximately 18 months. A similar result was obtained for milk production, but the time span was longer due to longer biological production cycle. When an outbreak and trade shock are expected to be short (less than one reproductive cycle of cows or sows), it is unlikely that producers would adjust their animal stock, because it would require costly investments to remove animals prematurely from the stock and to recover the animal stock later on. However, if the trade shock were be expected to continue for more than six months in the pig sector, or for more than 9 months in the milk sector, then producers would gradually start using their adjustment options. The least productive sows and cows would be prematurely removed from the stock and inseminations of gilts would be reduced.

As noted above, adjustments in primary production are small. In a large or long-lived outbreak, they could play a role in determining losses. For instance, consider a hypothetical FMD outbreak where either 1% or 5% of dairy cows would be removed from the stock due to the outbreak (e.g. due to animal welfare reasons), and the trade shock would be expected to last on average 4.5 months. It would then take approximately two years for the cow stock to recover to the pre-outbreak level and the milk price would be stabilised only after almost 3 years. The cow stock would be unable to recover quickly, partly because the number of heifers that could be inseminated immediately is limited. Even if the cow stock recovered after two years, not all these cows would be producing milk by that time. As the milk price is affected by milk production and the trade shock, prices could fluctuate for several years. In beef production, the effect could last even longer, as it takes almost two years to fatten beef cattle after they have been born. Besides the above-mentioned pattern, Figure 30 illustrates that if a large number of animals is removed from the market, producer prices can recover above the pre-outbreak level after the trade ban has been lifted.

The storing of livestock products was examined as a potential method to reduce economic losses caused by the trade shock. The storage capacity would be used up in a few weeks and the potential for increasing meat and milk product inventories was limited. Based on statistical time-series regarding the volume of monthly milk production and pigmeat inventories in Finland, and information obtained from stakeholders, the storage capacity corresponds to one to two months of production. Approximately 75% of the storage capacity is in use at all times. Hence, there is very limited extra storage capacity in the Finnish meat and dairy industry.

Because approximately half of milk fat produced in Finland is exported and it is mainly exported to third countries, there would quite a severe temporary excess supply of milk fat in Finland. Without any adjustments in milk processing, more than two million kilograms of excess cheese and butter per month would have been entering the domestic market. Hence, the manufacturing of butter and cheese was reduced during the trade shock and the production of some other more profitable products was increased (Table 41). However, these adjustments were unable to eliminate the problem of excess supply in the short term. The disease was not assumed to alter the demand for livestock products in Finland. The relationship between price and quantity demanded was assumed to be fixed. All changes observed in the markets were solely due to the export shock and changes in prices.

The result that the manufacturing of creams for the domestic market increases by 42% due to the trade shock is probably because the demand for cream is better able to respond to changes in market prices than other products. For instance, the demand for liquid milk is almost unaffected by its price. Increased manufacturing of cream with a high fat content is one way to mitigate market losses. Moreover, cream exports have represented quite a small percentage of production in Finland, so that relative changes in the cream market can be quite large. However, is questionable whether dairies would be interested in selling creams at discounted prices in the domestic market for a long time. Another important option to reduce market losses is to increase the manufacturing of milk powder, which can be stored and exported after the lifting of the trade ban. This option could be attractive because it reduces the amount of water to be stored with the product. The problem with milk powder is that the processor's margin from selling milk powder is generally smaller than that of selling other dairy products.

Table 41. The monthly production of dairy products (1000 t) when exports are halted or are not halted and the impact of halting exports on the economic surplus to the consumer, producer and society[1]).

Product	Monthly production		Change	Exports	Change in economic surplus, million €		
	Not halted	Halted	%[2])	% production[3])	Consumers	Producers	Total
Liquid milk	60.6	61.1	1	0.3	-2.1	2.5	0.4
Creams	2.7	3.9	42	7.7	0.1	2.7	2.8
Yoghurt	16.5	17.1	3	9.8	-1.0	1.5	0.5
Butter	4.6	4.3	-6	51.5	-8.6	3.8	-4.8
Cheese	7	6.6	-7	35.1	-6.5	4.5	-2.0
Milk powder	2.3	2.6	12	74.3	0.1	0.1	0.2
Total	-	-	-	-	-18.1	15.1	-3.0

[1]) The results are produced for an outbreak that has a negligible direct impact on animals kept on farms, such as a sporadic outbreak.
[2]) Percentage change in production when exports become halted.
[3]) Percentage share of export from production when exports are not halted.

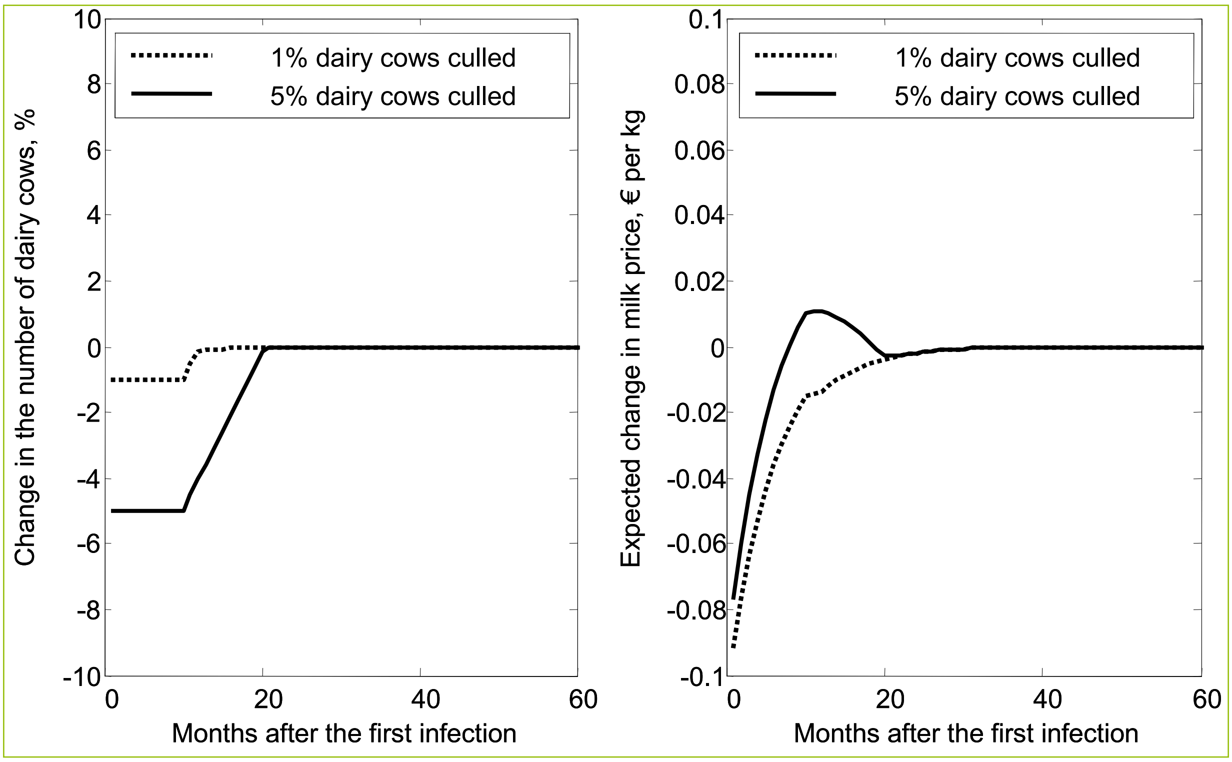

Figure 30. *Expected change in the number of dairy cows in the stock and in the producer price of milk compared to the pre-outbreak price (zero impact) due to an outbreak that directly removes either 1% or 5% of cows from the market and for which the export shock is expected to last for 4.5 months.*

The effect of the production sector and location of the primary infected farm on the consequences of a typical and worst outbreak

To study the effect of the production sector on the course and consequences of an outbreak, farms were divided into two categories according to whether they mainly had pigs or cattle. The lowest probability of a typical outbreak was in the Turku PVO district when outbreak started either from the pig or cattle production sector. By comparison, the highest probability of the worst-case scenario would be if an outbreak started on a cattle farm in the PVO district of Turku (Figure 31).

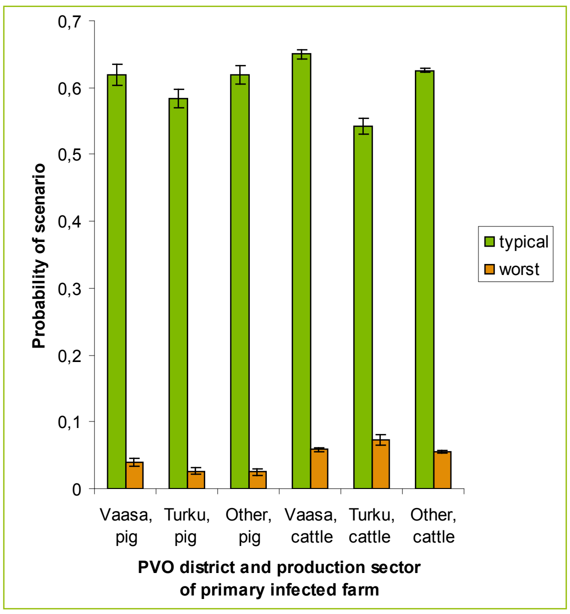

Figure 31. *The effects of production sector and location of primary infected farms on the probability of a typical and worst-case scenario.*

If the primary outbreak were to start from a farm mainly having pigs, the probability of the outbreak remaining solely within the pig production sector would be lower than the probability that an outbreak starting in the cattle production sector would remain in the cattle sector only (Figure 32). The location of the primary infected farm also seemed to influence the probability, as Turku had the highest probability for an outbreak starting in the pig sector and the lowest probability for an outbreak starting in the cattle sector. In the worst-case outbreak, the probability of the outbreak remaining within one production sector was generally lower than in a typical outbreak (Figure 32).

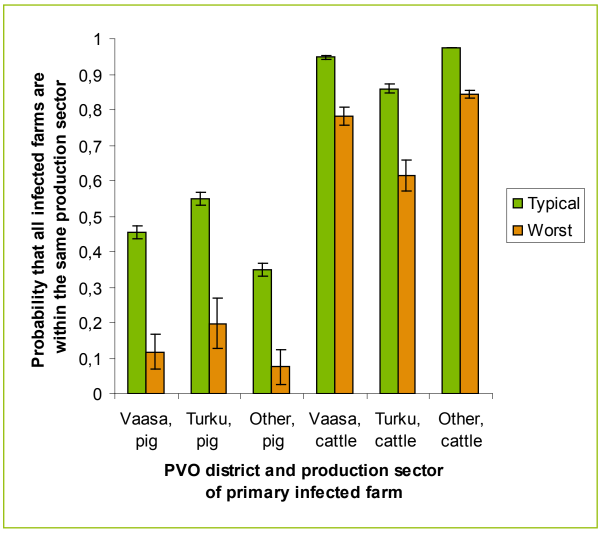

***Figure 32**. The effects of outbreak magnitude, production sector and location of primary infected farm on the probability that all infected farms are in the same production sector. Vaasa and Turku districts are examples of districts with a dense animal population and "other" includes the rest of Finland. Error bars indicate the 95% confidence limits for the expected value.*

The production sector of the primary infected farm had clearer influence on the proportion of infected farms operating in the same production sector as the primary infected farm. In the pig sector, the proportion was highest in the Vaasa and Turku PVO districts, while in the cattle sector the location had little influence on the proportion, and almost all infected farms were in all cases cattle farms (Figure 33). In worst-case outbreaks, the proportion of infected pig farms was lower than in typical outbreaks if the primary infected farm was in the pig production sector (Figure 33).

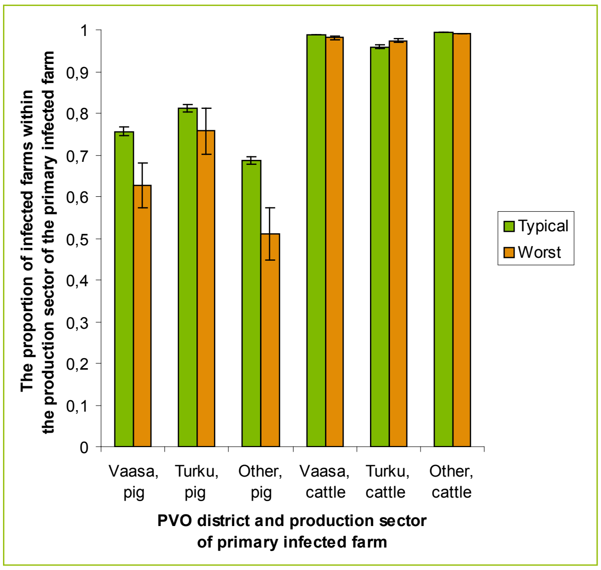

***Figure 33.** The effects of outbreak magnitude, production sector and location of primary infected farm on the proportion of infected farms that are in the same production sector as the primary infected farm. Vaasa and Turku districts are examples of districts with a dense animal population and "other" includes the rest of Finland. Error bars indicate the 95% confidence limits for the expected value.*

The location of the primary infected farm and the size of the outbreak influenced the proportion of infected farms that were located in the protection zone of another infected farm. In typical outbreaks, the proportions were lowest if an outbreak started in Turku or Rovaniemi PVO districts. In worst-case outbreaks, this proportion clearly declined in all other PVO districts except for Turku (Figure 34).

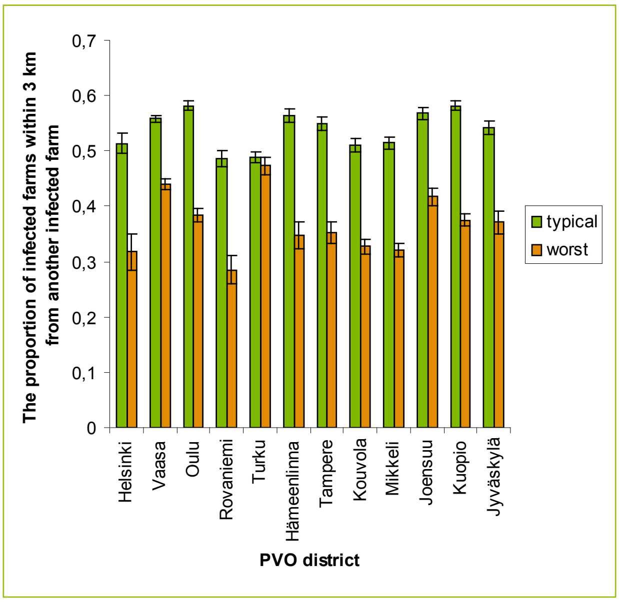

Figure 34. *The effects of outbreak magnitude and location of primary infected farm on the proportion of infected farms located in protection zones.*

The proportion of infected farms located in the surveillance zone of another infected farm was higher in worst-case scenarios than in typical outbreaks. In a typical outbreak the lowest proportion was observed when it had started in the Rovaniemi PVO district (Figure 35).

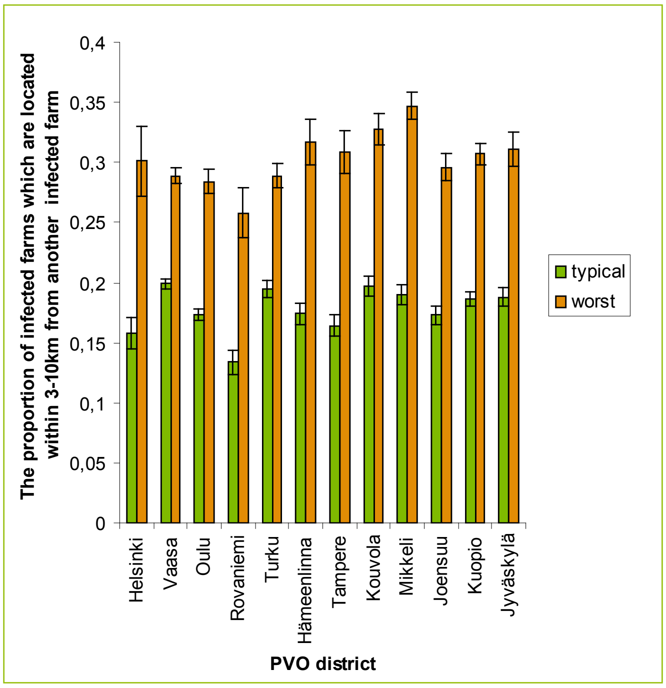

Figure 35. *The effects of outbreak magnitude and location of the primary infected farm on the proportion of infected farms located in surveillance zones.*

The production sector and location of the primary infected farm also influenced the quantity and distribution of the production sector of uninfected farms that are in protection and surveillance zones in typical outbreaks. The highest number of uninfected farms in administrative zones was achieved when an outbreak had started in Vaasa PVO district. Most farms would in this case be operating in the cattle production sector. In Turku PVO district the proportion of the pig sector affected would be slightly higher than the cattle sector if an outbreak started in the pig sector. Overall, the lowest number of uninfected farms under administrative zones would be for an outbreak starting in a PVO district other than Turku or Vaasa. If the outbreak started in the cattle sector, most uninfected farms in the zones would be cattle farms (Figure 36).

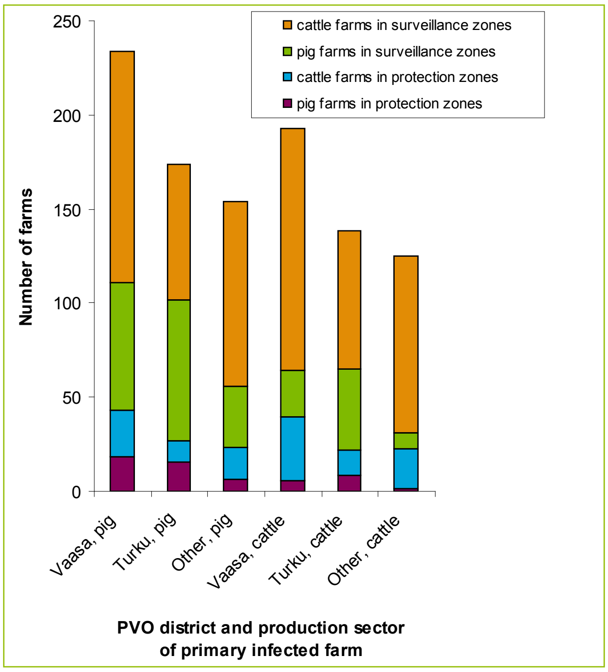

Figure 36. *The effects of production sector and location of the primary infected farm on the number and production sector of uninfected farms in protection and surveillance zones in a typical outbreak.*

In worst-case outbreaks, the lowest number of uninfected farms in administrative zones was observed when an outbreak started in the Turku region and the highest when an outbreak started in the Vaasa PVO district. The division between production sectors is similar to that in typical outbreaks (Figure 37).

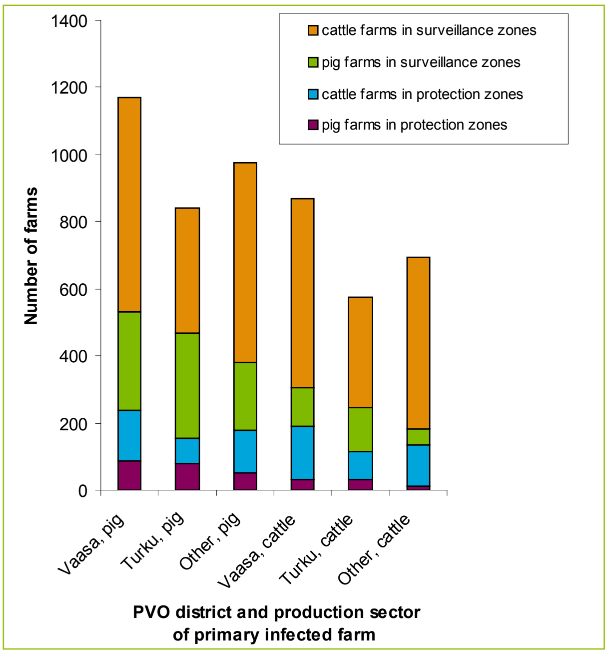

Figure 37. *The effects of production sector and location of the primary infected farm on the number and production sector of uninfected farms in protection and surveillance zones in a worst outbreak.*

The number of traced, uninfected contact farms was highest for an outbreak starting from a PVO district other than Turku and Vaasa and when the primary infected farm is operating in the pig production sector. The worst-case scenario would produce approximately four times more traced, uninfected contact farms than a typical outbreak (Figure 38).

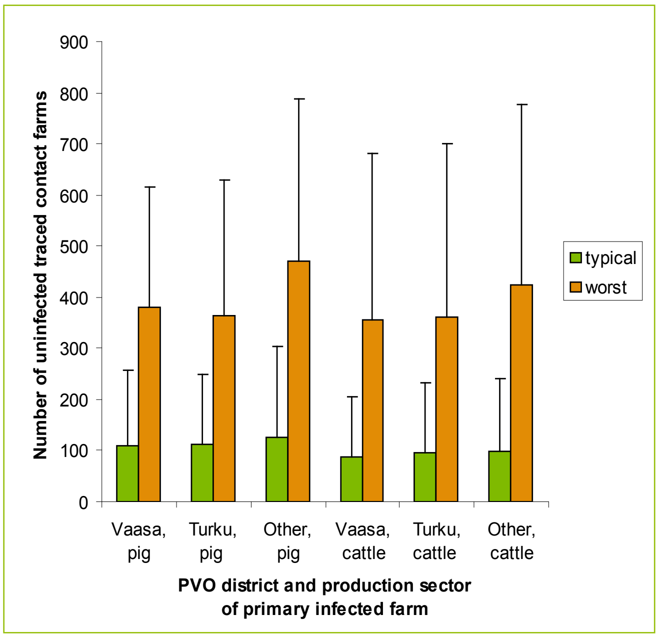

Figure 38. *The effects of outbreak magnitude, production sector and location of primary infected farm on the number of traced, uninfected contact farms. Error bars indicate the 95th percentile of the outcomes.*

Factors influencing the probability of a worst-case outbreak

Generalized linear models (binomial family, logit link) were developed to predict the probability of a worst-case outbreak in simulations. Two separate models were developed:

1. when characteristics of the primary infected farm are known, and
2. when the rate of new detected FMD cases is additionally known.

The final model was selected by minimizing Bayesian information criteria (BIC). Individual predictors were also excluded from the model if the Wald test gave a larger than 5% probability that the parameter value is not different from zero.

The probability of a worst-case outbreak can be estimated for an individual case by applying the following transition of the model:

- Predicted probability of worst-case outbreak = 1- [exp(equation)/ (1+exp(equation)]

The models were developed using the GENLIN application (generalized linear model, see for instance McCullagh & Nelder 1989) of the PASW Statistics 18.0 statistical package (SPSS Inc., IL, USA).

a) The predictive value of information on the characteristics of the primary infected farm

The model in equation 1 (Table 42) corresponds to a situation when only information concerning the first infected farm is known. The generalized linear model indicated that knowledge of the characteristics of the primary infected farm will improve the ability to predict a worst-case scenario. A less probable worst-case scenario appears to be if "other cattle farm" is the primary infected farm, as all other production types have a higher probability of developing a worst-case outbreak. If a farm is located in either Vaasa or Turku PVO district, it has a slightly higher probability of inducing a worst-case outbreak. Similarly, if a farm is located in a risky region, the probability of a worst-case scenario appears to be higher. Naturally, the probability of a worst-case outbreak increased with increasing number of contacts (Table 42). The parameter was standardized within the farm type before analysis and standardized [(value – mean of farm type)/ standard deviation of farm type], so it actually represents how one standard deviation of number of contacts will influence the outcome within a farm type. Prior to standardization, each contact type was weighted applying coefficients (see details in Appendix 1). Typically, dairy and sow herds had the highest weighted contact numbers (Table 43) and the highest probabilities of a worst-case outbreak (Table 44).

Table 42. Parameters and their significance in equation 1.

Parameter	Explanation	Value	SE	Wald chi-square	P
Intercept		5.778	0.199	888.0	0.000
Sow farm	indicator of a farrowing and farrowing-to-finishing farm	-1.872	0.201	86.7	0.000
Finisher farm	indicator of a finisher farm	-1.077	0.224	23.0	0.000
Dairy farm	indicator of a dairy farm	-2.724	0.193	199.0	0.000
Beef cattle farm	indicator of a beef cattle farm	-1.465	0.202	52.5	0.000
Suckler farm	indicator of a suckler farm	-0.662	0.215	9.5	0.002
Vaasa PVO district	indicator of a farm being in the Vaasa PVO district	-0.098	0.037	7.2	0.007
Turku PVO district	indicator of a farm being in the Turku PVO district	-0.321	0.520	38.1	0.000
Located in most risky regions	Indicator that a farm is located in the six regions with the highest probability of a worst-case scenario (probability 16.80-27.5%)	-1.760	0.084	437.5	0.000
Located in risky regions	indicator that a farm is located in regions where the probability of a worst-case scenario is between 10.8%-16.7%	-0.836	0.044	364.1	0.000
Contacts	standardized square root of the sum of weighted contacts within the farm type during 30 days before suspicion	-0.929	0.017	3039.9	0.000

Table 43. Number of contacts of the primary infected farm with different farm types. Column 0 corresponds to the mean number of contacts during 30 days before the first detection of FMD (See Appendix 1).

Production type	Number of weighted contacts		
	- 1SD	0	+1 SD
Sow farm	5.5	17.1	35.5
Finisher farm	2.6	8.8	18.6
Dairy farm	12.0	28.7	52.7
Beef farm	0.5	6.5	19.3
Suckler farm	0.0	3.0	10.8
Other farm	0.0	1.3	4.8

SD = standard deviation

Table 44. The effects of location, number of contacts and production type of the primary infected farm on the predicted probability of the worst-case outbreak.

Parameters	Farm type of primary infected farm					
	Sow	Finisher	Dairy	Beef	Suckler	Other
Vaasa PVO district	P(worst)	P(worst)	P(worst)	P(worst)	P(worst)	P(worst)
weighted contacts -1 SD	0.01	0.00	0.02	0.01	0.00	0.00
weighted contacts mean	0.02	0.01	0.05	0.01	0.01	0.00
weighted contacts +1 SD	0.05	0.02	0.12	0.04	0.02	0.01
Turku PVO district						
weighted contacts -1 SD	0.01	0.00	0.03	0.01	0.00	0.00
weighted contacts mean	0.03	0.01	0.06	0.02	0.01	0.00
weighted contacts +1 SD	0.07	0.03	0.14	0.04	0.02	0.01
Other parts of the country						
weighted contacts -1 SD	0.01	0.00	0.02	0.01	0.00	0.00
weighted contacts mean	0.02	0.01	0.05	0.01	0.01	0.00
weighted contacts +1 SD	0.05	0.02	0.11	0.03	0.01	0.01
Most risky regions						
weighted contacts -1 SD	0.04	0.02	0.10	0.03	0.01	0.01
weighted contacts mean	0.10	0.05	0.22	0.07	0.03	0.02
weighted contacts +1 SD	0.23	0.12	0.41	0.16	0.08	0.04
Risky regions						
weighted contacts -1 SD	0.02	0.01	0.04	0.01	0.01	0.00
weighted contacts mean	0.04	0.02	0.10	0.03	0.01	0.01
weighted contacts +1 SD	0.11	0.05	0.22	0.07	0.03	0.02

Note: probabilities for risky and most risky regions are estimated when they are located in the category "other parts of the country".

The model had sensitivity of 48.0% and a specificity of 16.7% in predicting the simulated worst-case scenario if cut-off value of 0.1 was used for separation of the outcomes into worst-case and other outbreaks. The predictive value of the model has a linear relationship with the simulated probability and distinctively improves the prediction of the worst-case outbreak above the general simulated probability of a worst-case outbreak. When the predicted probability reaches 0.4, the relationship with simulated probability becomes unstable (Figure 39).

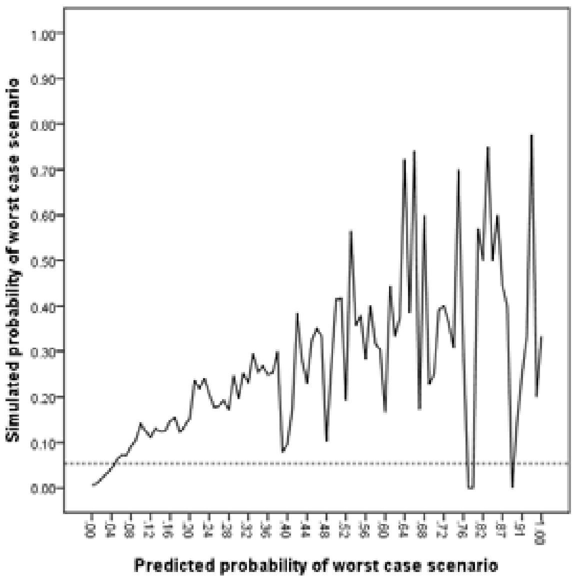

Figure 39. *The relationship of the predicted and simulated probability of a worst-case scenario (n = 100 000), when only predictors related with the primary infected farm are used in the prediction. The dashed line indicates the average probability of the worst case in simulations.*

b) Predictive value of the equation when the speed of new detections is also known

This corresponds to a situation after the first detection. The most important predictor of equation 2 is how quickly new FMD positive cases are found after the first detected case. The more quickly the new cases are found, the more probable the worst-case outbreak would be. In addition, information related to the primary infected farm still has some predictive value: the location of risky regions, being a dairy farm and having more contacts will all increase the predicted probability of worst-case outbreaks (Table 45). The sensitivity of the predictions is 76.7% and the specificity 58.7% if cut-off value of 0.2 is applied for the separation of outcomes into worst-case and other outbreaks. Predicted and simulated probabilities from equation 2 have a much better correspondence with the simulated values than those from equation 1 (Figure 40).

Table 45. The parameters and their significance in equation 2.

Parameter	Explanation	Value	SE	Wald chi-square	P
Intercept		8.616	0.242	1266.0	0.000
Dairy farm	indicator of a dairy farm	-0.588	0.233	6.4	0.011
Vaasa PVO district	indicator of a farm being in the Vaasa PVO district	0.181	0.053	11.7	0.001
Located in most risky regions	indicator that a farm is located in one of the six regions with highest probability of worst-case outbreak (probability 16.80-27.5%)	-0.804	0.148	29.7	0.000
Located in risky regions	indicator that a farm is located in a region where the probability of a worst-case outbreak is between 10.8%-16.7%	-0.582	0.068	73.1	0.000
Speed of detection of new cases	mean number of new cases detected during a day	-10.444	0.123	7267.6	0.000
Contacts	standardized square root of the sum of weighted contacts within the farm type during 30 days before suspicion	-0.270	0.024	124.3	0.000

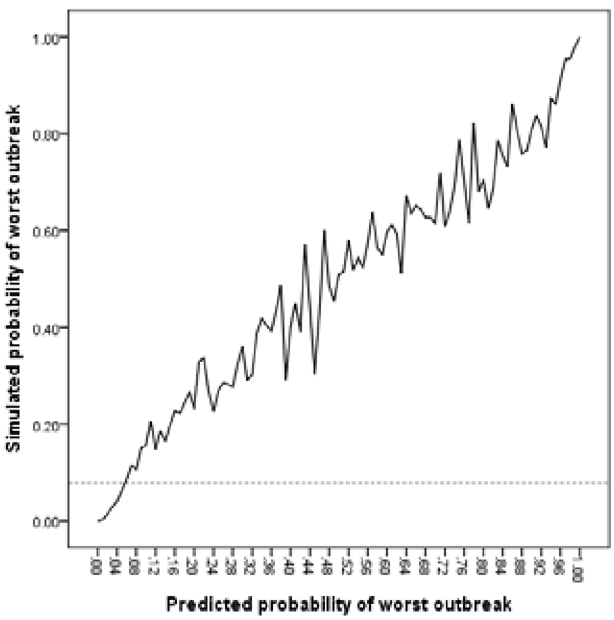

Figure 40. *The relationship between the predicted and simulated probability of a worst-case outbreak, when predictors related to the primary infected farm and the speed of detection of new cases are used in prediction.*

The dashed line indicates the average probability of a worst-case outbreak in the simulations. The number of iterations was 67 522. Sporadic outbreaks were excluded in the analysis, because the speed of detection of new FMD cases after the first case would in this case always be zero.

Table 46. Effects of the speed of detection of new cases, production type, number of contacts and location of the primary infected farm on the probability of a worst-case outbreak.

Parameters	Farm type of primary infected farm		Farm type of primary infected farm	
	Dairy	Other	Dairy	Other
Speed of detection of new cases	0.5 new cases/day		0.8 new cases/day	
Vaasa PVO district	P(worst)	P(worst)	P(worst)	P(worst)
weighted contacts -1 SD	0.04	0.02	0.47	0.33
weighted contacts mean	0.05	0.03	0.54	0.39
weighted contacts +1 SD	0.06	0.04	0.60	0.46
Other parts of the country				
weighted contacts -1 SD	0.04	0.02	0.51	0.37
weighted contacts mean	0.06	0.03	0.58	0.44
weighted contacts +1 SD	0.07	0.04	0.65	0.50
Most risky regions				
weighted contacts -1 SD	0.09	0.05	0.70	0.57
weighted contacts mean	0.12	0.07	0.76	0.63
weighted contacts +1 SD	0.15	0.09	0.80	0.69
Risky regions				
weighted contacts -1 SD	0.08	0.04	0.65	0.51
weighted contacts mean	0.10	0.06	0.71	0.58
weighted contacts +1 SD	0.12	0.07	0.77	0.64

The speed of detection of new cases appeared to have a large influence on the predictive value: an increase from 0.5 to 0.8 new cases per day increased the probability of the worst-case scenario by over ten-fold. The probability of the worst-case scenario was additionally increased by being a dairy farm and located in a risky region, and contacts had an important effect on this probability (Table 46).

Disease spread and other events in the "worst-case" scenario

Typically, the 18th infected farm was observed within 38 days after the introduction of the FMD virus, but the variation in the detection time was large. In the worst-case outbreaks, a large proportion of farms (on average, slightly more than half) had already been infected before the first detection (Figure 41). The latest infections were found to take place within the first two months after the first detection of FMD, but usually within 1-1.5 months. The average size of epidemics without vaccination should be a little less than 30 farms (18–52, 90% range). In addition, nearly 150 farms would be within protection zones (50–300, 90% range). The number of premises and animals in surveillance zones would be about five times more than in protection zones.

A simulated outbreak of foot-and-mouth disease has three stages. Before the first detection of FMD, the infection rises exponentially, after the first detection the spread of the disease slows down slightly, and two weeks later most of the spread has already occurred and further spread is slow (Figure 41).

The proportion of infected farms under restrictive measures grows very quickly after the initial detection, and the speed of new detections will exceed the speed of spread soon after the first detection of FMD. The speed of detected infected farms is slower than the speed of infected farms under the restrictive measures (Figure 42). The speed of detection will depend on inspections of the contact premises and the protection zones, and could require large resources to be carried out within a week, as suggested in the EU directive. The speed of detection of FMD cases will exceed the speed of spread within a week after the first detection (Figure 42).

Usually, in worst-case outbreaks, there would on average be slightly less than one new case per day (expected value = 0.82) for a period of 35 days. This would mean that a new infected farm would be found almost every day after the first positive diagnosis. There would also be approximately 3–4 new uninfected farms in protection zones that need to be inspected, and 14–16 new farms in surveillance zones. In addition, there would be 10–11 traced contact farms. This information can be used to scale the contingency plan so that adequate resources are available in all cases.

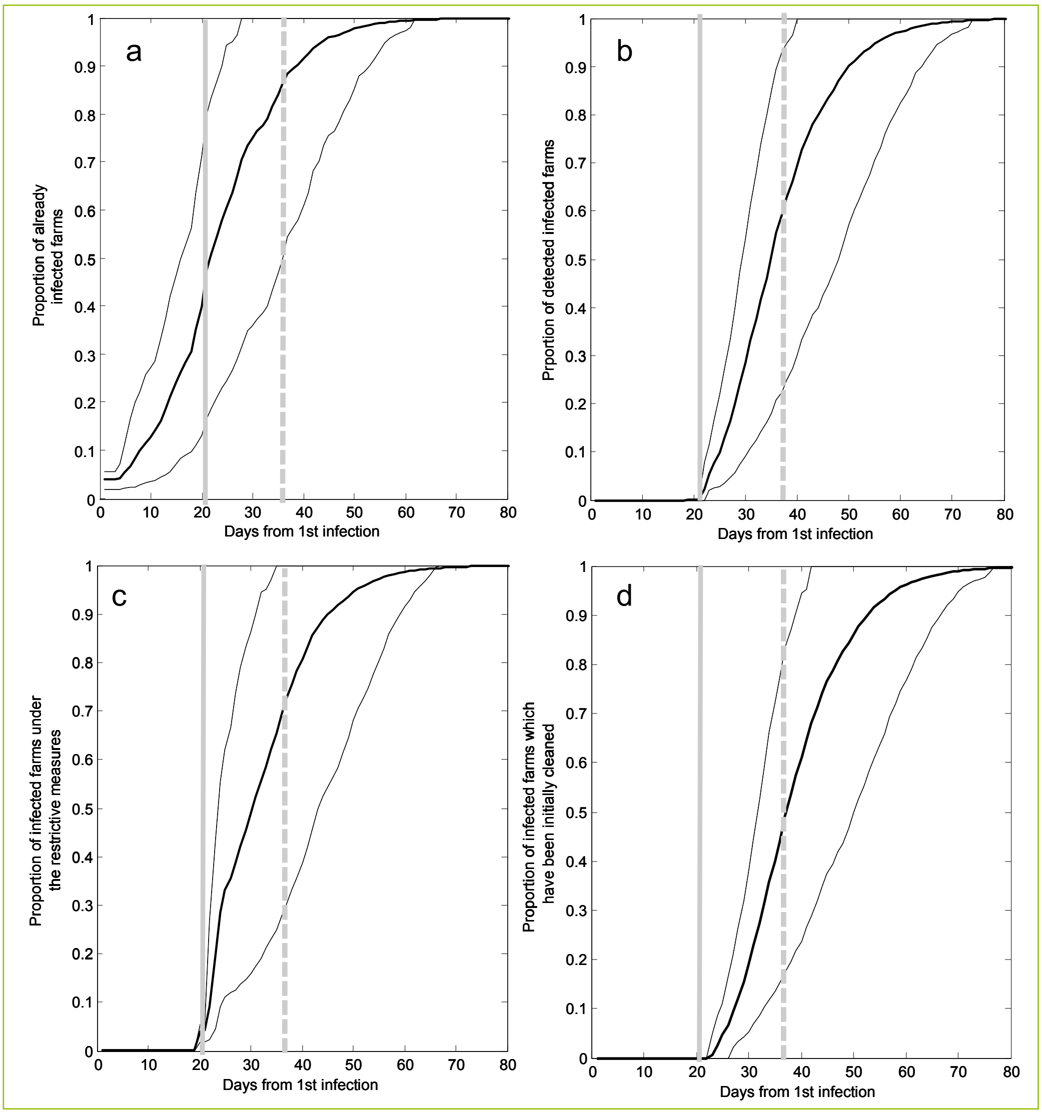

Figure 41. *Proportion of the final number of farms a) infected, b) detected, c) under restrictive measures and d) initially cleaned as a function of time from the first infection in the country.*

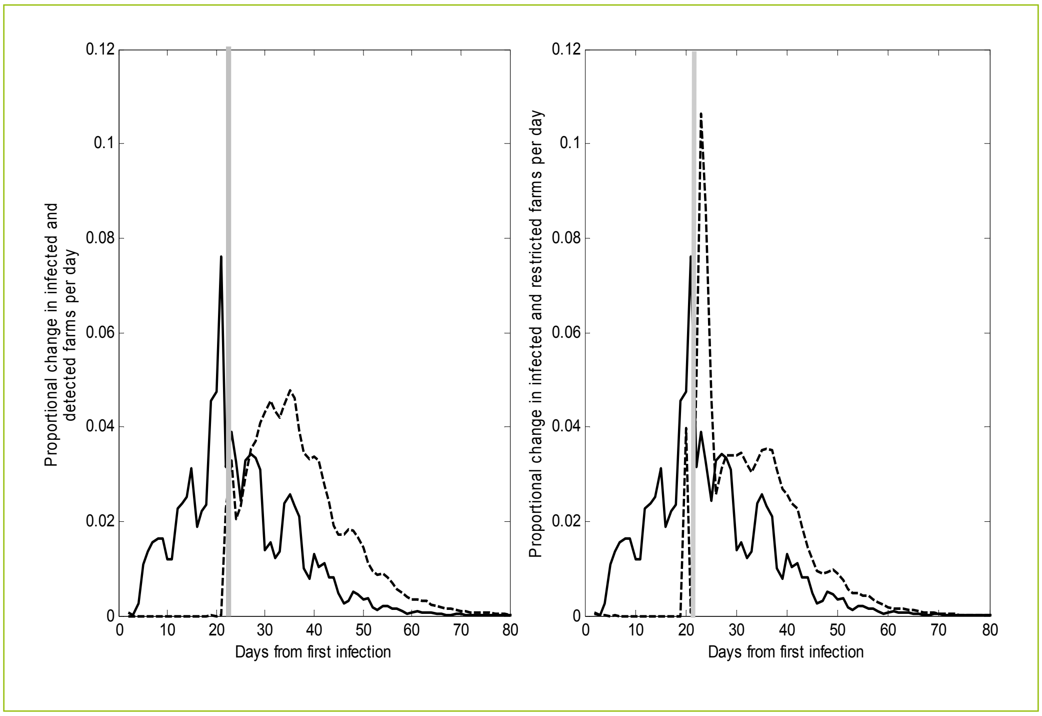

Figure 42. *The speed of spread of infections (solid line) compared against speed of detections (dashed line) on the left and against the speed of restrictive measures on infected farms (dashed line) on the right. Gray lines indicate the time of first detection.*

Vaccination scenarios

It is assumed in the calculations that vaccination would be performed in every zone, regardless of the phase of administrative operations within the zone. Four scenarios were assessed:

1. Suppressive vaccination in protection zones, applying the threshold defined by the expert panel;
2. Suppressive vaccination in protection zones at the earliest possible stage, if Finland was the first country in Europe to be infected;
3. Suppressive vaccination in protection zones as early as possible, when the disease occurs at the same time in some other parts of Europe;
4. Protective vaccination in the protection or the protection and surveillance zones of the epidemic.

1. Suppressive vaccination in protection zones applying the threshold defined by the expert panel

The expert panel defined that vaccination would be started when there would be at least 18 infected farms in the country. During a real outbreak, only a proportion of the infected farms are known, and thus the vaccination decision should be made on the basis of this "incomplete" information. On day 38 (when the 18^{th} infected farm should have been observed in the worst-case scenario), 90% of the farms that would acquire the infection without vaccination would already be infected (Figure 41). If vaccination would take two weeks, 95% of the final size of the epidemic would have been reached even before the start of vaccination. Using standard vaccines (Woolhouse 2003), a full protective effect would require 10 days. Suppressive vaccination in protection zones would bring a total of nearly 180 culled farms (29 infected/culled and 150 suppressive vaccinated/culled). It is highly unlikely that any outbreak would be prevented if the vaccination was performed at that time.

From an economic perspective, this option is also not rational. The costs of vaccinating 150 farms and culling nearly 180 farms, and the production losses due to the reduced animal stock would clearly exceed the potential savings from the reduced duration and size of an outbreak. As it takes time to vaccinate animals and for the vaccine to have a full protective effect, it is highly unlikely that there would be even minor benefits from vaccination.

2. Suppressive vaccination in protection zones at the earliest possible stage, if Finland was the first infected country in Europe

According to the expert group, the vaccinations could begin no earlier than two weeks after the first detection. At that time, nearly 90% of the farms that will become infected will already have been infected (Figure 41). Infected farms are found after a time lag, so only 60% of the infected premises would have been identified at that time (Figure 41). Due to restrictive regulations, however, more than 70% of infected premises would already be under restrictive measures, and thus most of the infectivity and contacts would be prevented. Thus, at the time of starting the vaccinations, there 10% of farms would be uninfected. If the targeting of vaccination was perfect (full protection of vaccine is assumed to be 80%), only 8% of the final number of infected farms could be protected by vaccination, without any time lags for the protective effect. Unfortunately, this seems unlikely, because only 39.1% of infected farms are captured by protection zones in the worst-case scenarios. This means that 60% of the farms that should be vaccinated are not captured by suppressive vaccination of protection zones. If this is taken into account, only 2-3% of outbreaks will be protected by suppressive vaccination of all protection zones. This actually means that on average there could be 0.5–0.6 protected farms (at most 3) due to vaccination, because the average number without vaccination was 29 farms (maximum 134).

A vaccination campaign would last 2–3 weeks, and full protection with available vaccines would require a 10 further days. Full protection would be achieved a month after the initiation of vaccination (Figure 43). At this time there would be no further spread, even without the vaccination, but some protection would be gained during the vaccination campaign. Thus, the protective effect would probably only be half of the anticipated number of 0.5-0.6 protected farms, meaning that a realistic range of expectations would be 0.2-0.3 farms. When this is compared to the total number of culled farms (29 culled farms without vaccination / 177 culled farms with vaccination), it indicates that vaccination increases the number of culled farms considerably. Typically, the number of culled animals with vaccination would be more than four to six times higher under a suppressive vaccination policy than when it is not applied (Figure 44).

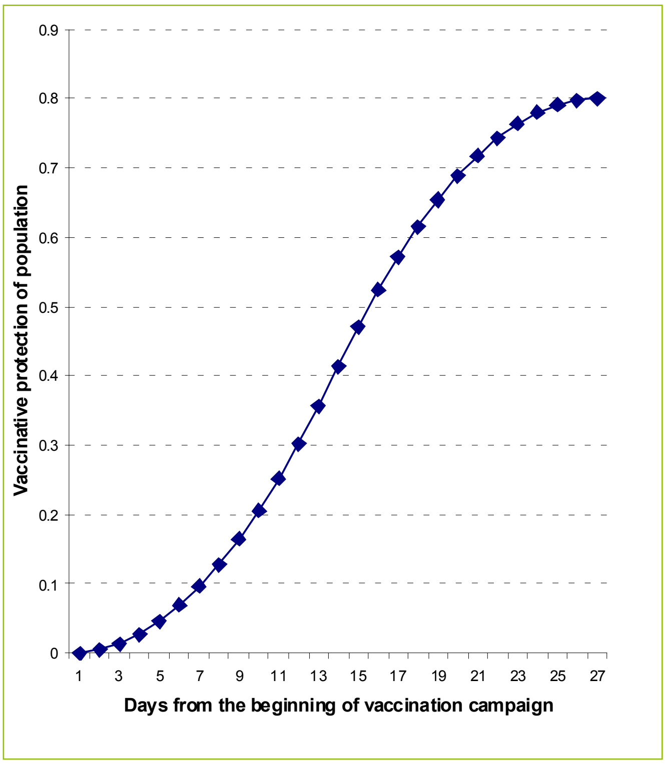

Figure 43. *Theoretical efficiency of protecting a population against FMD spread in a susceptible population that has been vaccinated within two weeks after the vaccination decision.*

The protective efficiency of vaccination is assumed to be 80%. A full protective effect on a vaccinated farm is assumed to be achieved 10 days after vaccination.

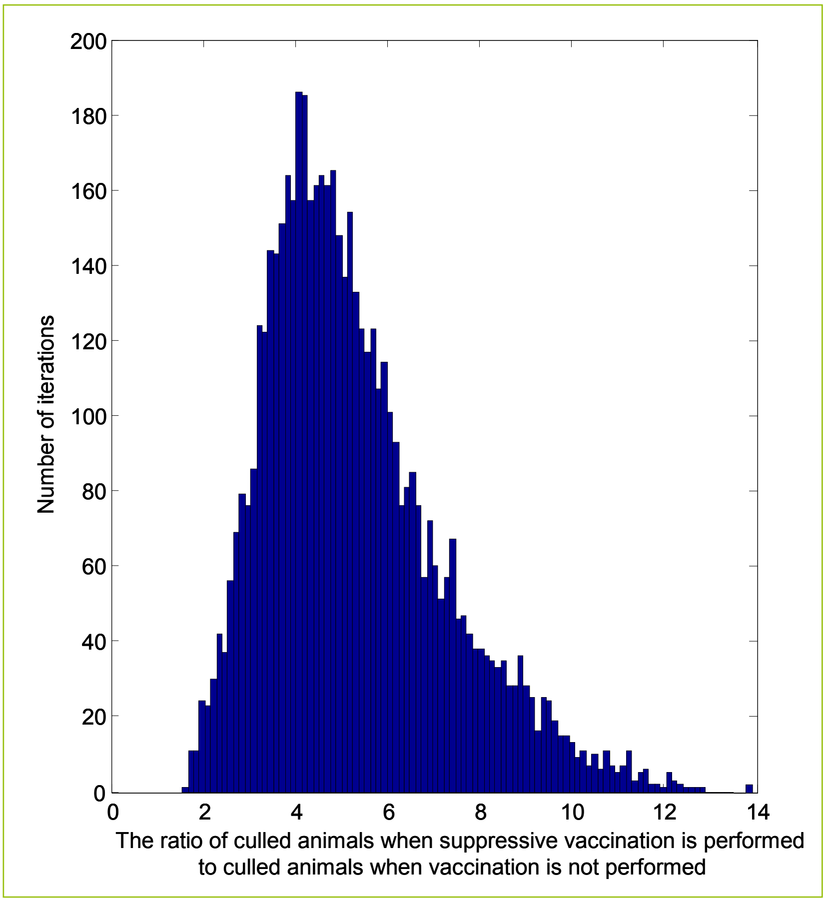

Figure 44. *The distribution of the ratio of culled farms with suppressive vaccination to culled farms without vaccination in scenario 2.*

From an economic point of view, it is likely that this option would not be a rational choice. Less than 10% of iterations in the worst-case scenario had the potential for cost savings if vaccinations would be started two weeks after the first detection, carried out in one day, and if full (80%) protection would be obtained on the day after vaccination. However, as noted above, it takes time to carry out vaccinations. If vaccinations were started two weeks after the first detection and the campaign would take two weeks, less than 1% of iterations *in the worst-case scenario* would have the possibility of generating savings worth on average €3.6 million. If a further ten days is required to reach a protective effect, it would be only 0.1% of iterations in the worst-case scenario (i.e. 5 iterations out of 100 000). In each step, the scenarios with the potential for savings were larger than average in terms of the number of infected farms and longer in duration. Hence, the potential benefits are due to cases where vaccination is able to reduce the duration of trade distortions. However, this effect is obtained by assuming that vaccinated herds can be culled with no delays and that vaccination does not increase administrative effort that would prolong trade distortions.

3. Suppressive vaccination in protection zones, as early as possible, when the disease occurs simultaneously in some other parts of Europe

In this scenario, the vaccine would be available a week earlier than in scenario 2, since the vaccine production could have started before the disease is even detected in Finland. Only 70% of the infected farms that would become infected without the vaccination are already infected at the time the vaccination is started, but most of these farms are already under restrictive measures. Using the same assumptions as in scenario 2, the expected values for farms whose outbreak would have been prevented would be 3 times higher. This means that at most the expected benefit from a vaccination campaign could be a couple of farms, if the outbreak would reach about 100 farms without vaccination, which is a highly unlikely scenario. Typically, the number of prevented outbreaks would be approximately one. The total benefit of vaccination would be the sum of all farms that would not become infected due to vaccination and the farms that would be in their protection zones. In general, this scenario will more probably lead to a larger proportion of animals being culled than when the policy is not applied.

From an economic perspective, this scenario behaves similarly to the previous one, except that vaccination takes place a week earlier than in the previous scenario. Here, the median and the mean return on the vaccination decision is also negative. Hence, in most cases it is not profitable to implement this vaccination policy.

If vaccination would be started within a week after the first detected case, the campaign would take two weeks and further ten days would be required to reach a protective effect, then only 0.4% of iterations would have the potential for cost savings. Epidemics in iterations that had the potential for savings were larger than the average epidemic, when the epidemic size is measured in terms of the number of infected farms and its duration.

4. Protective vaccination in the protection or the protection and surveillance zones of the epidemic

If protective vaccination is timed as in scenarios 2 or 3, vaccination seems to have only a small preventive effect. If protective vaccination is applied similarly as in scenario 1, it would not prevent any further spread of FMD.

Larger areas would require more resources for vaccination, which makes it practically more difficult to perform. If the vaccination would cover a wider area, i.e. around each infected detected farm, all farms within a 10 km radius would be vaccinated, the number of vaccinated farms would be about six times higher than that in the suppressive vaccination scenarios. The preventive effect could be larger than the effect of suppressive vaccinations if vaccination is carried out over a larger area, as 69.3% of infected farms are captured by protection and surveillance zones together during a worst-case outbreak. In addition, the buffer zone surrounding the vaccination area would also increase even further the number of farms affected by protective vaccination.

The economic justification for protective vaccination is dependent on the impacts of the decision to vaccinate on foreign trade in livestock products. According to the OIE regulations (OIE 2007), protective vaccination increases the duration of the trade ban by three months. It would take six months after the rendering of the last infected animal in the country for Finland to be able to regain a disease-free status. In addition, the vaccinated area should be shown to be FMD-free by extensive surveillance of vaccinated animals. This vaccination policy would increase trade losses considerably. Assuming that other countries would accept products originating from vaccinated animals in their markets, and that third countries would follow OIE regulations, this would imply approximately €33 million in additional losses due to prolonged trade distortions. Moreover, consumers would be unable to gain further significant monthly benefits from falling food prices, as the markets would already be saturated.

In the worst-case scenario, the losses that are incurred after the day of the first detection of FMD in Finland exceeded €33 million in only 0.6% of iterations (Figure 45). On day 34 (day 38) after the introduction of FMD into Finland, only 0.3% (0.2%) of iterations in the worst-case scenario are expected to incur further losses worth €33 million or more. Hence, when the decision to vaccinate is taken along the lines of scenarios 2 and 3 above, and trading partners follow OIE regulations, the increased trade losses only are sufficient to rule out protective vaccination as a disease control measure. In addition to this, the direct cost of vaccination would be quite high, up to €16 million, because the number of vaccinated animals could be large.

If potential savings in direct costs only are taken into account, the median observation in the worst-case outbreak will incur €4.2 million in additional direct costs after the detection of the first case. In 95% of iterations, this potential for savings in directs costs falls below €13.4 million. On day 35 after the first infection, the respective values are €1.4 and €8.0 million. Because the direct cost of vaccination could easily be more than €10 million, protective vaccination in practice would not reduce losses caused by an FMD outbreak in Finland.

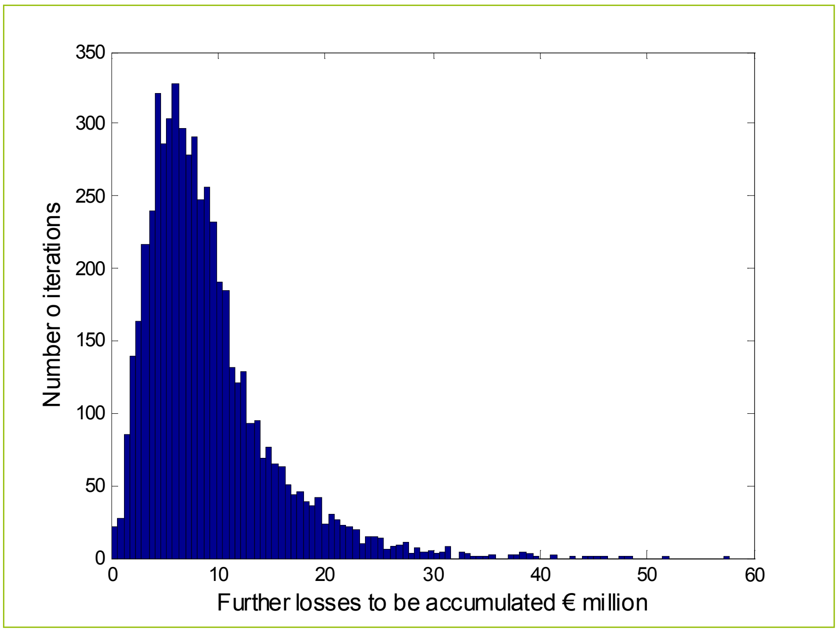

Figure 45. *Histogram of losses (€ million) that will be accumulated after the first detection in the worst-case outbreaks.*

Sensitivity analysis

Epidemiological simulations

Infectivity of contacts & duration of infective period

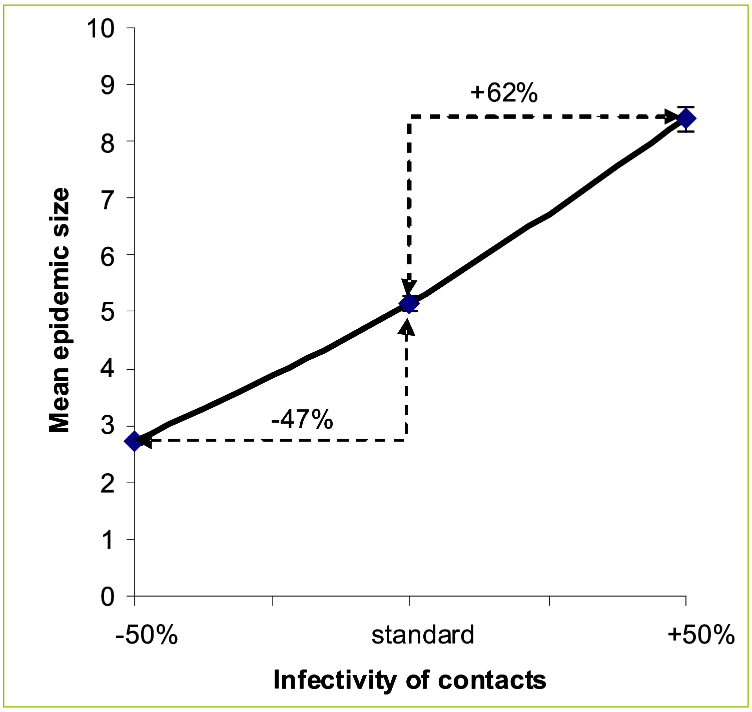

Figure 46. *The effects of infectivity on the mean epidemic size (number of farms).*

Standard indicates the result when the infectivity of contacts in Table 21 was applied, while for other points infectivity was either increased or reduced by 50%. Error bars indicate the 95% confidence interval of the mean. Each point represents the mean results from 10 000 iterations.

In this sensitivity analysis, the infectivity of contacts was manipulated. The mean epidemic size achieved by non-manipulated infectivity of contacts was compared with the mean epidemic size achieved when the infectivity of contacts was either reduced or increased by 50%.

If the infectivity of all contact types is reduced by 50%, this would lead to a similar reduction in the mean epidemic size. Conversely, if infectivity is increased by a similar magnitude, the increase in the mean epidemic size is even slightly higher (Figure 46). Because the outcome is defined by the infectivity of contacts, the number of unique contacts and the length of the infective period, similar relative changes in the number of unique contacts or length of infective period would lead to equal-sized changes in outcomes.

Importance of tracing and zones

This sensitivity analysis was performed by examining the relationship between different-sized epidemics at the time of first detection with the final size when different combinations of measures have been implemented after the first detection. There were two separate simulations, which both used the same iterations until the first detection, meaning that the results were same before performing the simulation of alternative combinations of official measures. Two alternative sets of administrative efforts were examined:

1. *Official measures as defined in EU legislation,* after first positive diagnosis: tracing of contacts, surveillance and protection zones are applied, restrictive measures are implemented on all farms in zones and traced by contacts. Culling of animals and initial cleaning of infected farms are performed after the positive diagnosis.
2. *Official measures as defined by EU legislation except that restrictive zones are not established and contact tracing is not carried out*

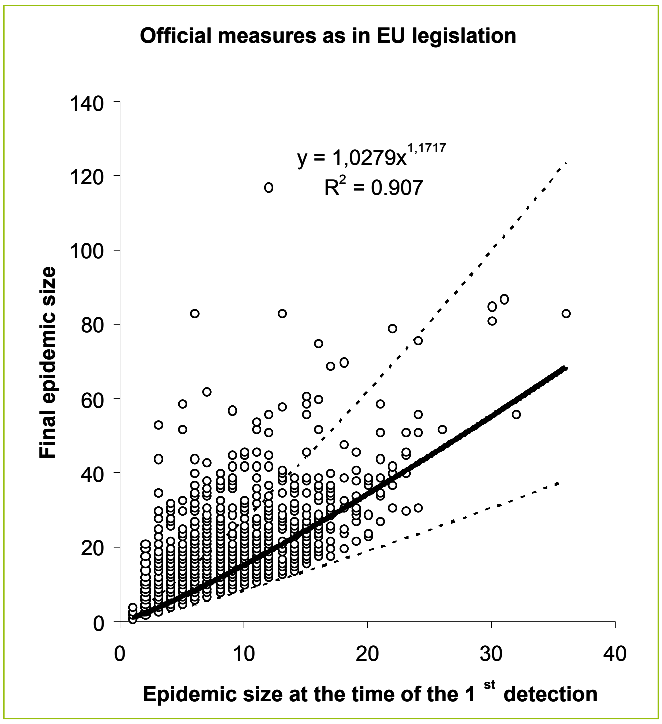

Figure 47. *The relationship between epidemic size at the time of first detection with the final epidemic size when normal EU measures are implemented.*

The points represent the iterations. The solidline indicates the least square fit of the power function, dotted lines indicate the 95% confidence interval of prediction. The power function (y = final epidemic size, X = Epidemic size at the time of first detection) and coefficient of determination (R^2) are given in the figure.

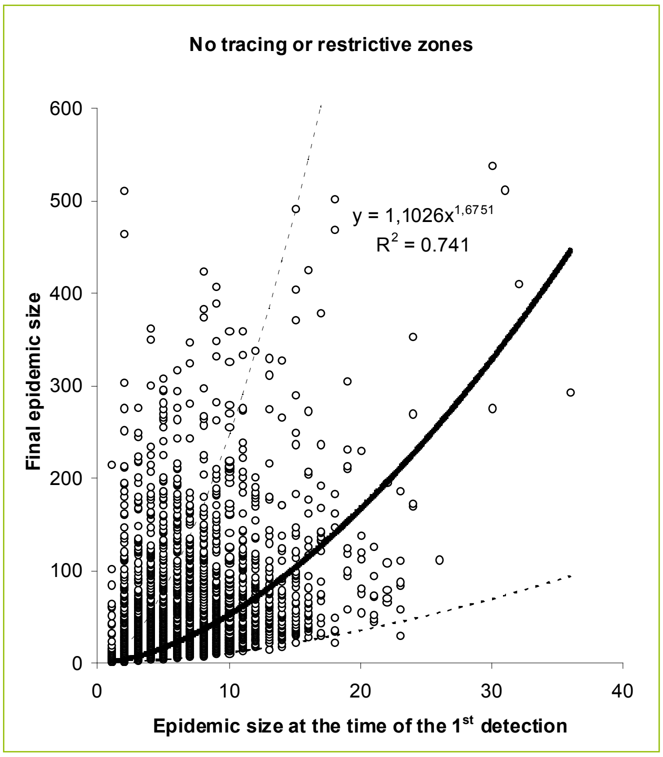

Figure 48. *The relationship between epidemic size at the time of first detection and the final epidemic size when the tracing of contacts and zones are not implemented.*

The solid line indicates the least square fit of the power-function, and dotted lines indicate the 95% confidence interval of the prediction. The power function (y = Final epidemic size, X = Epidemic size at the time of first detection) and coefficient of determination (R^2) are given in the figure. The scale is different from that in Figure 47.

Without tracing and restrictive zones, the final epidemic size is larger than when applying these measures, as can be seen in Figures 47 and 48. The relationship between the epidemic size at the time of first detection and at the end becomes less predictable when no tracing or zoning is applied in administration, as the coefficient of determination is smaller without the tracing and restrictive zones than when EU measures have been applied.

Adequacy of resources

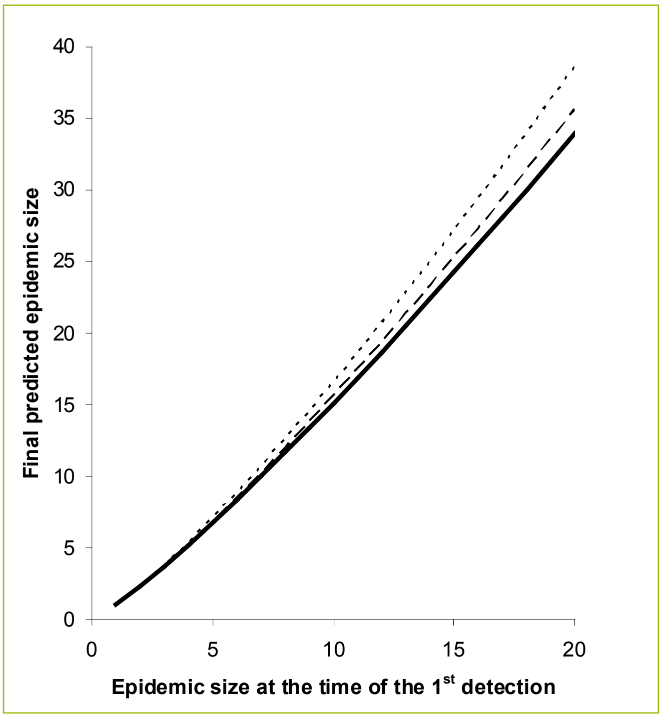

Figure 49. *The implication of a delay in culling for the mean epidemic size.*

Solid line = no additional delay, dashed line = 0–7-day delay after 10 positive diagnoses, dotted line = 0–7-day delay after 5 positive diagnoses. Simulations until first detection are the same in each set of 10 000 iterations. Lines indicate the least square fits for the data.

In this sensitivity analysis, the basic result is compared with the situation where the culling of animals of infected farms is delayed by 0–7 days. This delay may occur if administrative resources are exhausted or either diagnoses, culling or both are delayed. In addition, with the baseline option (without the delay), two alternative scenarios were simulated: culling was delayed until after either 5 or 10 farms had already been detected as FMD-positive. The mean epidemic sizes of the scenarios were then compared. Because the events before first detection are unaffected by the scenarios, each scenario was simulated by using the same simulated set until the first detection in the country.

It appeared that an additional 0–7-day delay in culling only slightly influenced the final epidemic size. The impact was greater if there were more infected farms at the time of first detection (Figure 49), or if the time lag appeared in early stage of the eradication campaign.

Economic simulations

Sensitivity analysis was performed with respect to selected economic variables. A 10% increase in direct costs increased the total loss by 0.2% (5th percentile) to 1.2% (95th percentile). The impact was this small because direct costs represented only a part of the total loss. If exports were not halted at all, the total loss would have been close to the estimated direct loss, although not exactly the same, as there would still have been market effects. In contrast to this, a 10% increase in the pig sector's market losses increased the total loss by approximately by 4%, and a 10% increase in the cattle sector's market losses increased the total loss by approximately by 5% (Table 47). This also shows that the pig sector contributed relatively more to the total loss when considering its size relative to the dairy sector's size. Moreover, if price elasticity estimates were increased, the losses were decreased, as more price-elastic demand would have reduced the effects of trade distortions.

Table 47. Societal losses (€ million) simulated for a typical scenario with and without a 10% change in direct costs, a 10% change in market losses and the existence of trade distortions

	<5%	Median	Mean	<95%
Basic simulations	-22.6	-24.2	-25.8	-34.3
Direct costs +10%	-22.6	-24.3	-26.0	-34.9
Pig sector market losses +10%	-23.6	-25.3	-26.9	-35.6
Cattle sector market losses +10%	-23.8	-25.5	-27.1	-35.9
No trade distortions	-0.2	-0.7	-1.6	-6.1

8 Discussion

Predicted epidemic size is small

The potential for FMD spread in Finland is low. The results indicated that more than one-third of the outbreaks in Finland would be sporadic FMD outbreaks that would not cause further spread. These sporadic outbreaks would on average last 3.5 weeks until the farm was disinfected and the restrictive measures were lifted. The most typical outcome occurred in more than 60% of the iterations and resulted in an outbreak that would include an average of 5 infected farms and have a duration of approximately 5 weeks. Even in the worst case, the outbreak lasted only 10 weeks (77+ days) and included 29 infected farms (Table 34). No escalated outbreak that would be out of control was achieved in 100 000 iterations.

Compared to the FMD epidemics occurring worldwide during 1992-2003, which included up to 100 infected premises (median <20), and especially the large epidemics in the UK in 2001, even the simulated worst-case scenario in Finland seemed to be rather reasonable in size (McLaws & Ribble 2007). The reasons for the large 2001 epidemic in the UK, which lasted for about 225 days and included more than 2000 infected farms, is partly described as being contributed to by late detection, a high livestock density, frequent animal movements and insufficient control measures (McLaws & Ribble 2007). The livestock density, number of farms and animals and the animal movements in Finland differ considerably from the circumstances in the UK. The livestock density is smaller and animal markets are not used for animal trading, both of which reduce the possibility of disease transmission in Finland. Sheep production in Finland is 1/300 of that in the UK. All these factors together resulted in the epidemics appearing to be more easily controlled in our simulations than in the UK outbreak in 2001.

Official measures are effective

Our results indicated that the mandatory EU policy would be able to prevent and slow-down the spread of FMD in all cases. Official measures of EU legislation seemed to be effective. Even without tracing and zoning, an FMD outbreak would eventually die out, given that infected farms are put under restrictive measures, animals are culled and farms are cleaned according to the EU directive. Sensitivity analysis fortified this view: the largest epidemics would remain under control even if part of the EU measures were not carried out as planned. Sensitivity analysis also indicated that even if our registries or basic assumptions of valid key parameters were to deviate from the ones applied in the simulations, these deviations would not negatively affect the above conclusions. Finnish farm density is low compared to several other European countries, farm sizes are clearly smaller, animal transfers between farms are controlled by large meat houses and there are no animal markets, which all contributed to a low ability of FMD to spread in the simulations. An important factor may also be that in addition to the generally low farm density, farms are clustered in small groups that are separated by forests and lakes. The results are also partially due to the model choice, which will be discussed later.

The endpoint in the epidemiological simulation was the initial cleansing and disinfection of the last infected farm in the country. The tracing of contact farms and other administrative work, as well as effects on the trade of cattle and pig products, will last much longer.

Trade effects determine economic losses

While epidemiological simulations are focused on the course of an outbreak, economic analysis mainly focuses on the consequences. Economic results emphasize the role of consequential losses, as major economic impacts were due to trade distortions rather than the culling and disinfection of infected farms. Consequential losses to uninfected farms under restrictions also play an important role, because the number of these farms can be large. This is particularly true when protective vaccination is being examined. However, the number of infected farms should not be ignored, because several factors such as outbreak duration and the number of uninfected farms under restrictive measures are strongly correlated with the number of infected farms.

One of the factors underlining the importance of consequential effects is that these effects can impact on a *large* number of economic agents. Even a small loss (benefit) per individual agent can contribute a substantial amount of losses (gains). For instance, in protective vaccination, the direct costs of vaccination can exceed €16 million, even if the cost per individual animal is less than €10. On the other hand, in the event of effects on consumers, an impact of less than €20 per consumer can contribute over €100 million in aggregate gains to Finnish consumers. The aspect of a potentially small change affecting large volumes is also relevant in the event of trade distortions that affect the entire Finnish production.

A further factor that deserves attention is the role of time. Outbreak duration is particularly important when aiming at reducing losses due to trade distortions and business interruption losses to farms under restrictive measures. Hence, even if rapid eradication of FMD was not important in reducing the number of infected farms, it would be important in reducing trade losses and consequential losses to individual farms. The results regarding the role of trade distortions are in line with previous studies (e.g. Schoenbaum & Disney 2003), whereas the importance of outbreak duration has traditionally been given less attention.

One situation that could increase the duration of an outbreak is the case where resources available to combat the disease are insufficient. Even if the lack of resources did not increase the number of infected farms, time-related costs would already increase the costs by almost €1.5 million per additional week. However, epidemiological simulations (Figure 49) indicate that an additional delay of 0 to 7 days in diagnosis would slightly influence the final epidemic size. In the worst-case scenario, a delay of one week in diagnosis could increase losses by approximately €3 million.

Our results suggest that an FMD outbreak would typically result in losses that are below €35 million. However, consumers could benefit and producers loose almost €100 million. For instance, the magnitude of our simulated losses in the dairy sector is similar to the impacts of the global dairy market crisis in 2008, which reduced the producer price of milk by over 20%. Because an outbreak occurs unexpectedly, it increases the need to acquire additional funding for the livestock industry. The situation is likely to be most severe in farms that have recently invested and in farms that have a low profitability and cannot tolerate unexpected reductions in their revenues. Such economic problems in the industry can last for several years and reduce investments in the industry in the years following an outbreak. Similar problems have been observed after a contagious animal disease outbreak, for instance in the Netherlands (Saatkamp & Bruijnen 2009) and the UK (Franks et al. 2002). Hence, one of the most important issues for public policy and individual stakeholders is to be prepared for financial problems following an outbreak. Preventive measures could include reduction of the risk of disease introduction and providing farms with funding alternatives in an epidemic situation.

Spatial differences in epidemic size and their consequences

There were no clear differences in the number of infected farms between PVO districts. In addition, it seemed to be possible that the worst-case scenario could start in any Finnish PVO district. However, there appeared to be large differences in how many non-infected farms would undergo administrative restrictions. Obviously, the most densely populated parts of the country would produce the largest number of uninfected farms within protection and surveillance zones. In less densely populated parts there tended to be slightly more traced, uninfected contact farms outside the zones, which is natural, as there were fewer zones, fewer farms in the zones and the contact structure between farms was sparser. Consequently, tracing is relatively more important in sparsely populated areas, while protection and surveillance zones are more important in densely populated areas.

The administrative effort per infected farm tended to decrease as the epidemic size increased. This is a consequence of several issues. Contacts tend to be correlated, as different infected farms partly share the same contact farms. In addition, the restriction zones of different infected farms may overlap and farms may be located in more than one restriction zone. This is especially true in the most densely populated parts of the country. Sharing of the same contact farms reduces the administrative costs per infected farm, but causes the highest administrative costs per infected farm in a sporadic case.

The production sector of the primary infected farm partly defined which types of farms would subsequently become infected. An epidemic outbreak in the cattle sector would probably remain within the cattle sector. However, if the epidemic outbreak started within the pig sector, it might spread to the cattle sector, but most of the infected farms would typically be pig farms. The consequences for uninfected farms were also dependent on the production type of primary infected farm. In an outbreak starting in the cattle sector, most of the uninfected farms involved were cattle farms. In an outbreak starting in the pig sector, however, a higher proportion of uninfected cattle farms would be placed in restriction zones than vice versa. These dependencies will influence the economic consequences and administrative efforts of an outbreak, as tracing and culling, for instance, require different resources in the pig and cattle sectors.

There was variation in whether an outbreak would remain in the same PVO district where it started or spread to another district. Naturally, the probability of remaining within one PVO district decreases with increasing epidemic size in all PVO districts, except Turku. Outbreaks would most probably remain within Turku and Vaasa districts, which have the highest farm densities. One factor explaining the results could be that supplemental animals can more often be delivered and received from local resources in these regions, while in the parts of the country with a sparse animal population available local resources can be limited. In addition, both regions have large slaughterhouses, and it seems apparent that those parts of the country lacking a large slaughterhouse are connected with the districts that have them. In the most animal-sparse parts of the country, the probability of an outbreak remaining in the initial PVO district seemed to be low, which offers further support for this hypothesis.

Within PVO districts there appears to be large variation in the ability of the disease to further spread. It is possible for a worst-case outbreak to start from some farms in any PVO district. Knowing the PVO district adds only a little in predicting the probability of a worst-case scenario. On the contrary, knowledge of whether a farm is located in a municipality where worst-case scenario is more probable than usual had much greater predictive power. Therefore, for instance, the PVO district of Oulu, which generally has a low farm density, can produce large epidemics in some southern parts of the district, where the farm density is as high as in Vaasa district.

Veterinary resources during an outbreak

One issue in contingency planning is how many farms a veterinarian can inspect without posing the risk of spreading the disease. The least risky option would be that a veterinarian inspects only one farm. An upper limit to avoid the possible spread of disease is that when a veterinarian has inspected a farm with FMD, he or she does not continue to another farm for inspection until an adequate time has passed from the inspection of the farm with clinical signs of FMD. We estimated how many farms one veterinarian can in a worst-case scenario inspect before he would on average transmit the disease (Table 48). Inspections of protection zones are more likely to identify a new FMD case than inspections in surveillance zones or on contact farms. It is more probable to find an infected farm in one inspection in a protection zone than in a surveillance zone or among traced contact farms. One reason is that the disease can spread by airborne and neighbourhood spread within a protection zone. Another reason is that there might be more contacts among farms located close to each other. Typically, one veterinarian can inspect six farms before a new FMD case is observed (Table 48). Inspection of one protection zone may require more than one veterinarian, because the mean number of farms within a protection zone in Finland is eight. Inspections in surveillance zones and on traced contact farms are much less likely to result in a veterinarian detecting a new FMD case and not being able to continue inspections.

Table 48. Median number of infected farms that could be detected by contact tracing and zone inspections. Expected efficiency and the expected number of farms that could be inspected before one FMD-infected farm would be found in a worst-case scenario.

Operation	Expected number of infected farms	Expected number of uninfected farms	Upper limit of expected efficiency	Median number of farms inspected before a FMD case is found*
Inspection of protection zones	12	150	<10%	6
Inspection of surveillance zones	9	600-700	1.5%	45
Inspection of traced contact farms outside the zones	9	400	2%	34

*Estimated by a negative binomial distribution (r = 1, P = upper limit of expected efficiency)

Although the probability of finding a new FMD case during inspections on contact farms and farms in zones seems to be low, an outbreak would be much larger without these efforts. The inspections reduce the potential of spread especially in the worst-case scenario. With these measures, an outbreak involving 18 infected farms at the time of first detection would produce an average of 30 infected farms. Without these measures, the expected value would be 140 infected farms, i.e. 4.66-fold. Epidemiologically, these measures limit the maximum size of an epidemic outbreak in Finland.

Prioritizing of inspections of farms during an outbreak

It could be reasonable to prioritize the order of inspection of farms after the detection of the primary infected farm. Prioritization should take into account the potential spread by a contact farm in order to prevent the further spread of disease as much as possible.

Farms inside the protection zone within a 3 km radius around an infected farm are considered potently affected by neighbourhood and airborne spread and comprise 39.2% of infected farms in the worst-case scenario. These farms are, however, under restrictive measures and could only spread the disease further by airborne and neighbourhood spread within the protection zone and nearby farms in surveillance zones. Pig farms should be prioritized over cattle farms, because they are more potent virus emitters.

Other farms that have been in direct or indirect contact with the primary infected farm within 21 days prior to the detection will also potentially be infected. Those contact farms that are outside the restrictive zones represent a large risk for further spread because their contacts are not under surveillance. Contact farms could be further prioritised according to the type of contact they have with the infected farm, and the operations of the contact farm. The largest risk of disease transmission is firstly among farms that have received animals, secondly among farms that have had contact with the primary infected farm through animal transportation, and thirdly via milk tankers and AI technicians. These contact types and their contribution to the probability of a worst-case scenario are summarized in Appendix 1 and can also be used to prioritize the relative risk of contact farms receiving or delivering the disease. The contact farms may be further prioritised due to the risk of transmitting infection further. The most likely high risk farms are those that have received animals during the early phase of the infective period, as they have most probably been able to spread the disease further. One possible rule could be that those contact farms that are located in an area with several farms nearby should be inspected first, and that inspections should also concentrate on those farms that can be expected to bestrongly connected with other farms (such as dairy farms, sow farms and farms rearing weaned calves and piglets).

The lowest efficiency would be for inspections of farms in the surveillance zone, because these farms are already under restrictive measures. Farms that are situated in the outskirts of the surveillance zone should be prioritized over those farms in inner parts of the surveillance zone in order to avoid the spread of the disease outside the established surveillance zone.

Farm size can be used as a proxy or first indicator of a farm with strong connectivity. However, our previous studies have indicated that it is not a good predictor of risk (Lyytikäinen & Kallio 2008), as even a low potency spreader can spread the disease efficiently if it is connected with potentially high spreaders. A better estimate could be achieved by performing an epidemiological inquiry on an infected farm. Part of the inquiry would define the risky contacts to and from the farm. In our prediction models of worst-case scenarios, the size of the primary infected farm was no longer a statistically significant predictor if its weighted contact number was known. This means that when the number of contacts is known, the size of the farm provides no additional information in the prediction of the final size of an outbreak. For the contact farm, similar estimates can be rapidly estimated, for instance by utilizing registry data on animal transportation, milk tanker routes and routes of the AI technician. This would provide a better estimate of the relative risk, as contact farms may contribute to the further spread of FMD. This would require the development of tools to rapidly extract relevant information from the registries and combine it to enable real-time risk classification.

Feasibility of vaccination

The results do not support emergency vaccination policies in Finland given that the criteria in Table 17 are applied. Emergency vaccination in a sporadic or typical outbreak was not considered as rational option to eradicate FMD in Finland due to the small size and short duration of the simulated epidemic. Vaccination would not prevent the further spread in a sporadic or typical outbreak. Similar conclusions can be drawn when recent European FMD epidemics are examined and compared with the production conditions in Finland.

A vaccination policy in a worst-case scenario required further elicitation to assess whether in that special case it would generally be a feasible option during a FMD outbreak. As a general conclusion, vaccination would have only a small effect on the spread of the disease and therefore is not a rational policy to be applied in Finland, even in worst-case outbreaks.

A suppressive vaccination campaign was generally not a rational policy to prevent the spread of FMD in Finland, either. Because a worst-case scenario is difficult to predict, even from simulation results, such a case is also unlikely to be correctly detected in the actual policy choice situation. Based on our results, suppressive vaccination would probably be an excessive measure, as a mild outbreak would die out due to the eradication measures. More animals would be culled than without the suppressive vaccination. Protective vaccination could be less damaging for the animal stock than suppressive vaccination. However, the benefits of protective vaccination did not justify the effort, as the vaccination campaign itself is costly, it is unlikely to reduce the number of infections, and most of all, vaccination could severely distort the Finnish export of beef, pig meat and dairy products.

Vaccination strategies for FMD have been assessed on several occasions using simulation models. For instance, during the UK epidemic in 2001, the conclusions according to every model were that the time for successful vaccination had already passed (Kao 2002). Similarly, in the Netherlands, a study by Velthuis and Mourits (2007) revealed little validity in applying emergency vaccination as the sole additional eradication measure at farm densities that are far above the highest farm densities in Finland. Boender et al. (2010) have estimated that the minimum EU measures are adequate up to densities of 5.9 to 6.0 farms per km^2, which is four times higher than the highest farm density in a 3 km radius kernel in Finland. Vaccination strategies have also been investigated in a number of other countries, and several of them have failed to show a clear benefit from a suppressive emergency vaccination campaign during an FMD outbreak, if the criteria set in this study are applied. Keeling and Rohani (2008) examined what would be the lowest limit for a vaccination campaign in the UK by comparing it with the number of culled animals achieved by a contiguous culling strategy. They predicted that if epidemic outbreak remained at 200 farms with culled animals, there would be more damage than benefits from applying a vaccination strategy. Similar results have also been obtained in other studies. Ward et al. (2009) investigated FMD control policies using the AuSpread model (Garner & Beckett 2005) in Texas and showed very little impact on controlling the outbreak by vacci-nation or surveillance actions. A limited reduction in the epidemic size by ring vaccination was also estimated in the Republic of Korea, where ring vaccination in a radius of up to 3 km around infected premises typically produced 309 de-populated farms and reduced the number of infected farms from 15 to 14 (Yoon et al. 2006).

Emergency vaccination is not an economically viable option

Our results suggest that emergency vaccination is not an economically viable option to control an FMD outbreak in Finland. In principle, protective or suppressive vaccination could be able to reduce the total costs of an outbreak if it was particularly large and long-lasting under a no-vaccination policy, but not with vaccination policy. However, given the time delay required to reach the full protective effect of vaccination and the minuscule probability of a pareto-optimal outcome, the value of the option to vaccinate is small. Suppressive vaccination is generally not able to reduce the costs.

A number of factors reduce the profitability of emergency vaccination in Finland. Probably the most important factor is that the simulated outbreaks were quite small and short-lived, even without emergency vaccination. Another important factor is that there is a time delay between the decision to vaccinate and the time when a maximal protective effect is expected to be reached. Protective vaccination is ruled out by reduced access to export markets, because according to OIE regulations, trade distortions are prolonged by three months after protective vaccination has been applied. Moreover, vaccinating a large number of animals in a protective vaccination campaign incurs substantial costs. Suppressive vaccination can substantially increase the number of culled animals and thus increase the direct costs of vaccination. Moreover, information about the true cost of risk is uncertain and signals about the risk can be mixed. Hence, decision makers are poorly informed about the true state of affairs when the decision to vaccinate is to be made. The level of confidence that experts were requiring from a positive vaccination decision to take place could not be reached. The simulations show that the accuracy of prediction of epidemic costs increases approximately two weeks after the first detection. However, the value of information about the number of detected farms starts decreasing soon after this point.

A rapid vaccination decision is problematic

The rapid initiation of a vaccination campaign is crucial for its success, and it is demonstrated in scenarios 1, 2 and 3 (see section on vaccination scenarios). In these scenarios, the earlier vaccination campaign resulted in a better outcome than the later one. Similar observations have earlier been noted by Schoenbaum and Disney (2003). A rapid decision would require the ability to identify the worst outbreaks early in the epidemic. This is naturally a difficult task, because available information lags behind reality and decisions must be made with only partial information.

It would be very convenient to find a way to be able to predict the size of an epidemic directly at the time of detection of the first infection. In order to do so, the possibility to predict the size of an emerging epidemic was tested on the basis of the characteristics of a primary infected farm. This only gave an indication of the possible outcome, and the highest predicted probabilities were approximately 10 times higher than the general probability of worst-case scenarios (5.5%). A more reliable prediction was achieved if the incidence of new infected, detected farms could be used. The problem is that at the time the incidence is known, it is too late to make a decision to vaccinate.

Validity of risk assessment

Potential biases of data sources

In some cases, such as dairy logistics and the identification of dairy farms, different data sources were combined in order to improve the quality and coverage of the database. Similarly, information regarding the number of animals was combined from two separate sources: one was the information collected in connection with EU subsidy applications and the other was the monthly notifications of the number of animals. This type of combination improves the reliability of data (Wallgren & Wallgren 2007), but also increases the effort required in data handling.

One problem with the registries is that they are often planned for some specific use, and thus classifications, definitions and information are solely planned for a specific task. This can be seen in incompatible specifications, which makes it difficult to combine information from several sources and in some cases may lead to the loss of information. Registries should be planned in such a manner that they are easy to combine and the information in separate registries should be compatible.

One example of the importance of definitions concerns the number of farms in the country. The farm number in our model is higher than that in the official statistics. This is because the official statistics are comprise of farms that have applied for subsidies and informed the number of animals on the farm on 1 May 2006. In addition, there may be farms that ceased to operate before or started operating after that date, and which are not therefore included in the official statistics, even though they still operated in 2006.

The identification of farms is one problem confronted in risk assessment. Official registries apply farm identification numbers, but part of the information is divided among the production units of the farm, which have separate EU identification numbers. In contrast to official registries, other operators (such as meat companies and dairies) do not use the same identification codes but instead use their own customer databases and coding, which makes it difficult to combine information reliably and rapidly.

The reliability of questionnaires is also sometimes questioned. In our comparisons, the results from questionnaires corresponded well with the registry data. The response rates were high for both the pig and cattle farm questionnaires, and the veterinary questionnaire was consistent with the frequency estimates of both farmer-related questionnaires (Sahlström et al. 2009).

Sensitivity of the results to assumptions

The biosecurity aspect has not been considered as a separate factor in the simulation. By using transmission probabilities adopted from the outbreaks in the Netherlands and the UK, it is simultaneously assumed that the overall level of biosecurity in Finland is equal to that these countries. If the Finnish biosecurity level is higher than it was in the UK and the Netherlands during the 2001 outbreak, it would reduce the size of the epidemic and the probability of a worst-case outbreak. In that case, vaccination would be even less justified. Boklund (2008) estimated that Danish SPF-free farms are 25% less susceptible to diseases than other farms resulting from direct animal contacts and people visiting the farm. These contact types comprise only part of the infection pressure of FMD, and the upper limit of the biosecurity effect on the infectivity of a farm up to the SPF level is therefore probably less than 25% in those iterations where some of the involved farms would have a better than usual biosecurity level. The Finnish pig farm sector has a class in which a higher biosecurity level is required. In 2006, less than 10% of Finnish pig farms belonged to this class.

On the contrary, in the cattle sector there is no clear definition of a higher biosecurity class in the country, although the level varies between farms. Together, these facts lead to the conclusion that the extra biosecurity level was not practically relevant to the model in evaluating emergency vaccination strategies or estimating the final epidemic size in the country.

Sensitivity analysis indicated that should there be severe biases in key parameters, the out-of-control spread of FMD would still not occur in simulations. In addition, we showed that the EU minimum requirements were able to reduce the expected size of the worst-case scenario from 140 to 30 infected farms. The time lag, which would delay the culling of animals and initial cleaning of infected farms, had little influence on the outcome, but it was apparent that the earlier the delay occurs, the more it would influence the final epidemic size.

We applied point values to define the time required after the introduction of FMD virus for a farm to become suspected. By using a point-wise approach in our simulation, the first infected farm was always the first farm on which FMD was suspected and diagnosed. This is a simplification, as the events leading to suspicion are uncertain. In an earlier CSF risk assessment (Raulo & Lyytikäinen 2005), we applied a distribution in defining the time to become suspected, and the FMD model is also capable of performing simulations in this way. However, sensitivity analysis indicated that if the average time to detection was altered by 50%, the corresponding spread would be either an approximately 50% increase or decrease depending on the direction of change in time to suspicion. Such random variation (+/- 50%) in the suspicion time of the farms would increase the variation in the outcomes, but would not alter the average outcome of simulation.

We assumed that tracing was always 100% effective. In some earlier FMD studies, slightly lower values (85–95%) have been applied (Ward et al. 2009). In our case, sensitivity analysis in which tracing and zoning was not applied resulted in a 4.66-fold epidemic outbreak in the worst-case scenario. Because tracing was potentially important in shortening the infective period on approximately 30% of infected farms in the worst-case scenario, the expected effect of a lower tracing efficiency would be 1/60 of a 4.66-fold increase (5% not traced, 30% traced farms not in zones), which corresponds to a 7% increase in the epidemic size in the worst-case scenario. The magnitude of this size can be considered insignificant.

In this study we did not apply all possible detection routes. For instance, inspections in slaughterhouses could in theory shorten the detection time in some instances. This would require that transporter of animals has already ignored or left unnoticed the clinical signs of the animals, or that the clinical signs appear during transportation. If the disease were already in the country, this would be quite a leakage in the system. On the other hand, the inclusion of this detection route would have to shorten the detection time more than the administrative routes that have been included (tracing /zoning) to be an effective component and to influence the expectation of the final epidemic size in a practically significant manner. This is not likely to be the case, as for instance in the risk assessment of classical swine fever these routes appeared generally insignificant, although the initial time to suspicion was far longer (Raulo & Lyytikäinen 2005).

The importance of exclusions

Sheep and goats, as well as reindeer and moose, were excluded from this risk assessment for different reasons: The populations of sheep (116 000) and goats (6600) are small in Finland compared to the production of pigs and cattle, as seen in Table 1. The mixing of sheep or goats with other production animals in Finland is also minor (see section "sheep and goats" above). This is also supported by the fact that 40% of the sheep in Finland are situated either in the northern parts (Rovaniemi PVO district), where the cattle and pig population is small, or in the Åland archipelago, which was not included in this risk assessment. The production of sheep meat is also often organised separately from other production animals; it is, for example, more common that sheep and goats are slaughtered in separate slaughterhouses than cattle and pigs. The transmission of FMD from sheep is not as likely as from pigs (e.g. Alexandersen & Donaldson 2002; Velthuis & Mourits 2007). At the time of the collection of data (2006), there were no existing registries of sheep and goats in Finland.

Although sheep are not an important production sector in today's Finland, the situation in the future may be different. A large amount of lamb meat is imported into the country every year, and the domestic demand for lamb meat has steadily increased. Lamb may also provide a means for long-distance jumps in disease spread, and it is therefore important to verify how common long-distance movements of this kind are, and how this can impact on the general risk of the cattle and pig production sectors.

There is a fairly large population of reindeer in Finland. This is, however, situated in only the northern part of Finland, in Rovaniemi PVO district, isolated from the areas having the main production animal population. This means that there are not natural frequent contacts between reindeer and cattle or pigs. Moose, on the other hand, are distributed all over the country, but the epidemiological information is scarce. According to serosurveillance by Elbers et al. (2003) after the FMD outbreak in the Netherlands in 2001, there was no evidence that FMD had been transmitted to roe deer or wild boar. Because of the way cattle and pigs are currently housed, contact with deer and wild boar is minimised. After the UK outbreak in 2001, 484 samples examined from deer (wild and farmed) were all negative. Elbers et al. (2003) concluded that it is very unlikely that deer or wild boar could infect cattle. The real epidemiological role of reindeer, moose and deer is difficult to assess, but their likelihood of transmitting disease to cattle and pigs is considered negligible in this risk assessment.

The applied model – was it suitable for the assessment?

Applied model was of a type previously referred to as a micromodel (Schley 2007). A micromodel attempts to mimic as many events and operations at the farm level as possible using Finnish information sources. Regarding the epidemiological parameters for FMD, we relied on European research efforts.

Because we applied registry information, the model is a spatio-temporal network model. This limits the spread, as contacts have a limited capacity to spread disease, and further spread also always requires further contacts that are positioned in the time and space of a network in a way that permits further escalation of the disease. A network may limit the magnitude of the worst-case scenario and should thus provide more realistic worst-case estimates than if this is not taken in account. Recent results from network models in other studies are consistent with this view (see for instance Keeling 2005; Kao et al. 2006; Kiss et al. 2006; Smieszek et al. 2009; Natale et al. 2009).

Another similar phenomenon that follows naturally from applying registries in simulation is that if there are repeated events, this is taken into account in simulation. This can be seen both in mean and worst-case outcomes. Differences are larger in worst-case scenarios (Lyytikäinen et al. 2008, 2009). In animal production, repeated contacts can be assumed to be quite common. For instance, a dairy tanker drives the same route to farms every second day for approximately 6 months. Close-by farms may form a production network where animals are only transported between some limited set of farms. For instance, nearly 20% of pig production was concentrated in different types of operational networks in Finland in 2009. There may also be other reasons for repeated contacts, such as geographic locations, logistics and operational reasons related to meat companies or persons visiting farms. The importance of repeated contacts to the outcome is greater if contacts are infrequent and the infectivity of a contact is low (Smieszek et al. 2009).

One reason for limiting worst-case scenarios by applying registries is that production is to a large degree separated. For instance, some farms only keep animals for slaughter and never deliver them to other farms. Such farms operate as sinks and slower the spread of disease. Similar operations are possible if a farm is just in starting phase and is collecting animals from several farms but is not yet actually in full-scale production. One benefit of applying registry data is that these operational characteristics are also modelled as they appear in real life. Another reason that is apparent when the contacts are repeated is that the number of susceptible farms will dry up more rapidly than when repeated contacts are not taken in account.

The model is prepared to reflect the real world and how, for example, official control is expected to work. However, in a real life situation, several unforeseen events could occur simultaneously and result in catastrophic situations that are considered to occur with low probability. In contrast to a real epidemic outbreak, simulation models can consider all the possible realisations that might be a consequence of one particular outbreak. In contrast to this, a real epidemic outbreak is only one realisation of all the possible outcomes.

There are several other spread models that utilize contacts and transmission probabilities as the basis for quantifying the spread of an outbreak by simulating state transitions from susceptible to infected and then removed. Such models include InterSpread and its varieties (Sanson 1993; Sanson et al. 1994; Morris et al. 2001; Stevenson 2003), NAADSM (Harvey et al. 2007) and AUspread (Garner & Beckett 2005). While these models take contacts into account, they also include airborne pathways for spread and are therefore flexible for various prediction purposes. These models resemble each other in several ways, but the details of parameterisation, assumptions, programming implementation and capabilities of the models vary. The first attempts to compare models have been made, and have provided some general conclusions and results (Dubé et al. 2007). Despite differences in the absolute outcomes, a recent comparison demonstrated that the policy results of these models are similar (Sanson et al. 2010).

In another modelling approach (e.g. Keeling et al. 2001), spread is simulated with fewer parameters and the spread around the infected farm is described by a spatial kernel in which probability declines with increasing distance. This type of model has also succeeded well in post-prediction of the UK outbreak in 2001. Because kernels have built-in spatial autocorrelation, this type model may work similarly well in predicting an observed epidemic and the potential of spread in similar conditions to those in an observed epidemic outbreak. However, the transition of kernels to another production environment might not be as successful. Kernel type models do not have an interpretation that the spread is driven in some particular way. Rather, they are empirical fits to existing data on an outbreak.

One type of model applied in the prediction of FMD spread is aerosol models that try to predict the spread of the disease solely by the atmospheric route. This approach has been variably successful. In the UK outbreak of 1967/68, the aerosol model worked well, while in 2001 this type of model showed poorer predictive power, as only 9 out of 160 first-infected premises were estimated to become infected by airborne transmission (Kitching et al. 2005). This type of model may also only work in some situations due to spatial autocorrelation of the connection patterns between farms (as in the kernel model). These models are generally less useful for those countries without data on an actual outbreak, and should not be used in designing general control strategies.

FMD has also been modelled with mass action-based models, which essentially treat the population of susceptible farms as more or less randomly mixed. This type of model has also been successfully used predicting the final size of an FMD outbreak (Keeling 2005). Nevertheless, models make unrealistic assumptions of a homogeneous population and random contact structure, which has been criticized in several studies (Kostova 2004; Chowell et al. 2006; Velthuis & Mourits 2007; Dickey et al. 2008). This type of assumption ignores spatio-temporal correlations between operations within the simulated regions and is not therefore suitable to estimate situations where the variance of outcomes may have some value. Because vaccination efficiency is strongly dependent on the timing of the campaign, spatial characteristics of the vaccinated area and the scale of expected outcomes, this type of model is not very suitable in studying the efficiency or feasibility of a vaccination campaign, although these difficulties can be partially solved with more complicated parameterisation.

Validity of economic results

Our results support the choice of risk management measures to combat contagious animal diseases in Finland. Besides epidemiological information, it is important to have information on the economic impacts of FMD outbreak and the risk management measures. This is particularly important in the event of highly contagious animal diseases such as FMD, because an outbreak can affect the entire industry, even if only one farm is infected. Besides choosing preventive measures, our results can be used to design the funding mechanism for animal disease damage.

Economic results are sensitive to price elasticity estimates for livestock products. It is therefore important to estimate these parameters carefully and to conduct sensitivity analysis that reveals how sensitive the results are to the possible parameter bias. In our case, these parameters were estimated from statistical data by using three-stage least squares, which produced valid estimates for this type of estimation problem. Moreover, efforts should be devoted to calibrating the model with actual data. In our case, the sector models were calibrated to produce figures based on 2006 data. The results regarding milk processing are sensitive to which products are the most profitable to produce when exports markets become partially closed. These products can vary according to the season and global market situation. Therefore, our result regarding increased production of creams during an export closure may be sensitive to the market situation, relative prices between different dairy products, and elasticity estimates. Moreover, the livestock and food processing sector may have other adjustment methods available besides those examined in this study. For example, feeding of animals could be at least slightly changed in a way that reduces production and production costs. However, we considered feed use changes to be of minor importance due to animal physiology and risks to animal welfare. High yielding dairy cows, for example, require a sufficient protein and energy intake, especially in the early phase of the lactation period. We also considered the empirical basis of less intensive feeding to be too weak to make generalisations on production effects and cost savings, and did not assume the possibility of significantly reducing animal feeding. Instead, feeding that fulfills the standard feeding recommendations was generally assumed.

Regarding the direct cost of a FMD outbreak, it is important to have information on the costs and resource requirements of different tasks to control FMD. No such data were available from Finland. We therefore calculated these costs mainly based on data from the UK outbreak in 2001. These estimates are sensitive to the large variation between farms in their characteristics, and differences between Finland and the UK in farm structure, such as unit size and spatial density, production costs and the price level of inputs and outputs, as well as in organization, available resources and the cost structure of veterinary services.

As disease risk management measures involve considerable uncertainty, future research should focus on elaborating the role of information in decision making. In particular, economic research should examine how uncertainty and imperfect information impacts on the choice of control policy. This could include, for instance, the examination of various risk management measures by means of real options theory, which takes into account the accumulation of information over time, and expected utility theory. Moreover, studies that would help to design and implement risk-based preventive measures and surveillance in an economically efficient manner would provide invaluable information to support risk management. An example of this is the risk classification of livestock farms.

How applicable are the results today?

This risk assessment is based on the production structures and operations of 2006. Since then, there have been changes in the Finnish animal production sector. The number of farms has decreased in both the pig and cattle sectors. An especially clear decline has been apparent among dairy farms (-18%) and pig farms (-12–22%) between 2006 and 2008. Simultaneously, the size of the farms has grown 10% in the pig sector and 11% in the cattle sector. The number of sheep in Finland grew by 5%

between 2006 and 2008, but the number of farms dropped in the same time period by 8% (TIKE 2010).

Because the number of farms has decreased, it can be expected that the farm density has also declined. The epidemiological importance of this depends on how this decline has occurred. Have the farms disappeared from areas where farms are close to each other or from more remote areas of the country? Because farm size is increasing and because the number of small operators is declining more rapidly than large operators, the contact network may have become sparser and the potential for FMD spread may have declined. On the other hand, individual farms may have become more effective in spreading the disease. To verify these hypotheses, contact structures should be compared between the years. Moreover, the potential consequences arising from a single infected farm have increased due to the larger number of animals that would be involved in culling. If farm disappearance has occurred equally in every part of the country and area, it would also reduce the number of uninfected farms involved in an outbreak, and thus probably at least part of the administrative work would be less nowadays than in 2006. Because the potential for spread among farms has probably declined, vaccination is still not feasible as a general policy in Finland.

Among the abattoirs, two large slaughterhouses no longer slaughter pigs and at least one no longer slaughters cattle. Similarly, the number of dairies has declined since 2006. It can be expected that the number of contacts has not been affected by these changes. However, the spatial dynamics of FMD spread could have been altered by lengthened transportation distances and changes in logistics.

Further research

In the future, it would be important to include sheep and goats in epidemiological studies. These are currently small, but growing populations. It would be important to study their role in the Finnish animal production system, and to be able to avoid possible misjudgements when choosing the patterns of development for the increasing sheep production sector in Finland. Since 2009, there has been a compulsory data registry of sheep and goats in Finland.

There is a need for more research on the effect of biosecurity factors. If biosecurity measures are effective, they should also be taken into account in simulated predictions of epidemic sizes. These factors would reduce the difference between large and small-sized farms in their ability to acquire infection, and would modify the distribution of risk of acquiring disease, because biosecurity routines are more often applied in large farms than in smaller ones. Biosecurity is also important if certain preventive measures are going to be targeted at farms that possess the highest ability to either spread a disease or to be exposed to a disease, as measures may modify the underlying risk caused by the contact network of the farm.

Risk classification by proactive simulations may enable faster reaction if a worst-case outbreak of FMD is initiated in the country, and may help in selecting epidemiologically and economically reasonable risk management policies. The usefulness of risk classification should, however, be further studied. One option may be achieved by assessing the correlation of risk classes with the incidence of other diseases that are nowadays present in the country. If such correlations exist, risk classification can be used in the planning of risk-based surveillance and monitoring of other diseases in Finland.

Registry based models are unfortunately always looking into past and are not really suitable for the future predictions or to study the effect of re-organisation of contact networks or to define risk-classes of future farms. It is possible to develop network-model also for predictions but it would require methodological work. First step toward predictions is to understand which factors define key connection rules between farms and how these rules may change or remain unchanged in future animal production structures.

The development of registries to enable real-time applications is an important general goal that should be further empathised. In particular, official registries and different data sources containing logistic information should become more compatible. An easy way to improve this would be to support individual companies to renew their database so that these databases contain the same identification coding as in official registries. By increasing compatibility, the general traceability of contacts would improve and less effort would be required in true epidemic outbreaks of any disease.

More research is also needed to support the pre-outbreak financing of contagious animal disease damage. Finance issues require information such as how individual economic agents respond to risk, the scale of losses an outbreak can cause, and what are the benefits of investing in biosecurity practices that reduce the probability of disease introduction into Finland and the consequences of an introduction. An important issue for economic research is also how production decisions in primary production, the storage capacity and food processing could be adjusted to reduce economic losses. Moreover, further research is needed to examine the value of products originating from disease-free or non-vaccinated animals. This value could be examined in the domestic consumer market and in export markets. Such research could provide supplementary information on the market premium that is available to Finnish producers when they are able to maintain a disease-free status in the country in the long term.

9 Conclusions

According to this risk assessment, the maximum size of an outbreak would be relatively small and it would eventually be stopped by applying normal EU eradication measures. There would generally be no need to use emergency vaccination in Finland in the case of an outbreak of FMD. It would be more useful to ensure that the basic eradication procedures are operating smoothly, rapidly and efficiently. Applying a suppressive vaccination policy would lead to the unnecessary culling of a larger number of animals than would be necessary if the policy were not applied. A protective vaccination policy would not be economically beneficial in Finland, even if some outbreaks on farms could be prevented.

Despite the relatively small size of outbreaks, the agricultural and food sector could suffer relatively large economic damage as a result. This is due to business disruptions and disruptions in the foreign trade of milk and meat products. In contrast, consumers may be able to benefit from a possible occasional fall in food prices. Moreover, economic losses would increase with an increase in the number of infected farms and/or outbreak duration. In particular, direct costs paid by taxpayers would increase proportionately more rapidly that the number of infected farms. Regarding the vaccination policy, very little in costs could potentially be saved after the day when a vaccination campaign is started. Suppressive vaccination increases the costs of an outbreak because it boosts the number of culled animals, whereas protective vaccination increases epidemic costs by prolonging trade disruptions. Hence, emergency vaccination is concluded to generally not be an economically rational policy to combat FMD in Finland.

Spatial differences at the PVO district level in the expected epidemic size are small, as a worst-case outbreak could start in any PVO district. By contrast, the administrative consequences of an outbreak would deviate considerably. In the most densely populated parts of the country, a much higher number of uninfected farms would come under restrictive measures than in the more sparsely populated regions. The spread of FMD would mostly remain within the production sector in which the outbreak had started, more clearly so if the outbreak started in the cattle rather than the pig sector. The results of this assessment could be applied in contingency planning.

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91/495/EEC COUNCIL DIRECTIVE 91/495/EEC of 27 November 1990 concerning public health and animal health problems affecting the production and placing on the market of rabbit meat and farmed game meat.

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94/65/EC COUNCIL DIRECTIVE 94/65/EC of 14 December 1994 laying down the requirements for the production and placing on the market of minced meat and meat preparations.

EC 1760/2000 Regulation (EC) No 1760/2000 of the European Parliament and of the Council of 17 July 2000 establishing a system for the identification and registration of bovine animals and regarding the labelling of beef and beef products and repealing Council Regulation (EC) No 820/97.

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12 Appendix

Appendix 1 Scaling of the contact parameter used in the predictive function of the worst-case scenario

The index variable (contacts) was formed by weighting estimated contacts within 30 days by coefficients of logistic regression, describing the relationship of different contact types with the worst-case scenario. Coefficients were estimated by logistic regression and then scaled against the estimated coefficient of direct animal contacts (0.044).

index = N_{out} + (0.015/0.044)N_{pig} + (0.028/0.044)N_{cattle} + (0.006/0.044)$N_{slaughter}$ + (0.035/0.044)N_{milk} + (0.001/0.044)N_{AI}, where

N_{out} = Number of unique farms where animals have been delivered to the farm within 30 days
N_{pig} = Number of unique farms that are connected with the farm by a vehicle transporting pigs within 30 days
N_{cattle} = Number of unique farms that are connected with the farm by a vehicle transporting cattle within 30 days
$N_{slaughter}$ = Number of unique farms that are connected with the farm by a vehicle transporting animals to slaughter during a 30-day period
N_{AI} = Number of unique farms that are connected with the farm by an AI technician during a 30-day period
N_{milk} = Number of unique farms that are connected with the farm by a milk tanker during a 30-day period

Because the index variable was highly skewed, it was then square-root transformed and further standardised within each farm type (sow farm, finisher farm dairy farm, beef cattle farm, suckler farm and other cattle farm) by subtracting the farm type-specific mean and dividing by farm type-specific standard deviation (Table 1a).

Table 1a. Applied standard deviations and means of the square root of the index variable for Finnish farm types

Farm type	Mean	Standard deviation	Mean at original scale
Sow farm	4.154	1.811	17.1
Finisher farm	2.966	1.357	8.8
Dairy farm	5.361	1.901	28.7
Beef cattle farm	2.541	1.846	6.5
Suckler farm	1.725	1.578	3.0
Other cattle farm	1.137	1.051	1.3

Appendix 2 Application of covariance-variance matrices in the initial phase of an iteration

Covariance-variance matrices were applied when a predictive function was used to estimate the properties of the simulated farms. Covariance-variance matrices were simulated simultaneously with the predictive function. By including the covariance-variance matrix as a preliminary step, each farm during the same iteration was simulated by one possible parameter solution of the predictive function, and thus the uncertainty related to the parameters and their correlations was included in the calculations. Variance-covariance matrices were sampled applying the norm_rnd function of the Econometrics Toolbox (Le Sage 2002).

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