Market implications of FMD epidemics in the Finnish pig sector: Does market structure matter?

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Abstract— **This paper examines the role of market coordination and market distortions caused by a hypothetical FMD outbreak in the Finnish pig sector. By using stochastic dynamic programming, it simulates the consequences of two outbreak scenarios (large vs. small) under two distinct market regimes (competitive market vs. monopoly in the domestic supply). Simulated losses depend on the magnitude of outbreak and expected duration of possible turndown of meat exports, whereas market regime has a limited impact.**

Keywords— **Foreign trade, livestock epidemics, dynamic programming.**

I. INTRODUCTION

Highly contagious diseases such as classical swine fever, foot-and-mouth disease (FMD) or high-pathogenic avian influenza can have devastating impact on food production and economy of rural areas in the infected country e.g. [5], [8], [9]. These diseases need to be notified to the World Organization for Animal Health (OIE), they can spread rapidly, threat animal welfare and health, and distort international trade.

FMD outbreak typically removes animals from the market, closes down export markets and possibly reduces domestic demand for animal products. If trade restrictions take place, producers in export-oriented countries can be hit especially badly. There can also be considerable uncertainty and variation in outcomes.

The importance of market structure is well recognized. It is considered harmful to society if a company has too dominant market position. Retailing is, nevertheless, quite concentrated in many countries and meat processing can also be well coordinated. For instance, two companies buy about 85% and four companies almost 99% of pigs fattened in Finland.

Regarding livestock epidemics, producers can have the opportunity to reduce losses through coordinated actions, for instance, when exports are halted or disease removes a lot of animals from the market. During the 2001 FMD epidemic in the United Kingdom, the gap between farm gate and consumer prices of beef increased [10]. The study argues that producer prices can fall and marketing margins of retailing and processing can increase during an epidemic due to changes in hygiene costs and meat demand even if market power was not misused. As exploiting market power can increase this margin, it is important that markets function properly.

The goal of this paper is to simulate consequences of hypothetical FMD outbreak in the Finnish pig meat market. The analysis is carried out with a stochastic dynamic programming model for the Finnish pig sector. The model takes into account implications of herd dynamics, biological time lags and adjustment costs, which incur when pigs are unexpectedly lost or exports halted. The market system focuses only on pig sector, which is segregated from beef and milk sectors.

We analyze two scenarios under two distinct market regimes. Outbreaks differ in magnitude, but they both prevent the exporting of pig products temporarily. The magnitude of outbreak is exogenous and its duration is unknown in advance. The objective function maximises either producer profits only (regime: "monopoly" in the domestic supply, but producers compete with import demand) *or* the sum of producer profits and consumer surplus (regime: "competitive market"). Calibrated meat quantities are assumed to be the same under both regimes. In other words, producer's opportunity costs differer between regimes. We thus examine whether it matters if analyst makes faulty assumptions about the market structure, i.e. "what if the market actually is a monopoly, but there is a difference in the opportunity cost?"

II. A DYNAMIC PROGRAMMING MODEL

A. Value functions

The model simulates the impact of FMD outbreak to producers (incl. primary production and slaughtering) and consumers (incl. meat processing, retailing and final consumers in Finland) as a group on a monthly basis. Demand and supply models with an epidemiological scenario jointly characterise pig markets (Figure 1). The model characterises derived demand for pig meat with four equations:

1. Domestic demand for Finnish pig meat,
2. The quantity of Finnish pig meat exported to the EU,
3. The quantity of Finnish pig meat exported to non-EU countries, and
4. The quantity of pig meat imported into Finland.

Demand equations implicitly include the storing of meat. Imports and exports of live pigs are considered negligible. Demand equations are specified using logarithmic transformations of variables. The most interesting variable explaining meat quantities is elasticity estimate, which establishes the link between meat price P_t^{i} and meat quantity D_t^{i}.

The model takes into account the utility-maximising behaviour of producers and consumers. Our specification implies that production is coordinated, i.e. supply emanating from previous production decisions is known and agents as a group can minimise losses due to epidemic. Short-run supply adjustments constitute a partial optimisation problem conditioned by the number of pigs currently kept at farms and adjustment options such as slaughter weight and storing. In the long run, producers can control supply also by adjusting the sow stock.

Domestic supply monopoly pricing (Equation 1) includes area below inverse demand curve only up to the market value of pig meat, whereas competitive domestic supply behaviour (Equation 2) includes all area. Objective function for the monopoly case is:

$$
\begin{aligned}
V_t\,(\mathbf{x_t}) = \max_{\{\mathbf{u_t}\}}\{ & S_t\left(\mathbf{x_t},\mathbf{u_t}\right)P_t^{\mathrm{prod}}(\mathbf{x_t},\mathbf{u_t}) + \\
& -C_t\,(\mathbf{x_t},\mathbf{u_t}) + \beta\,E(V_{t+1}(\mathbf{x_{t+1}}))\} \text{ for } t = 0,..,T
\end{aligned}
\tag{1}
$$

s.t. $\mathbf{x_{t+1}} = g(\mathbf{x_t},\mathbf{u_t})$, and $\mathbf{x_t}$ and $V_T\,(\mathbf{x_T})$ are given,

where $V_t\,(\mathbf{x_t})$ is the maximised value of pig production sector in Finland; t is time index (months); $\mathbf{x_t}$ is the state vector, which contains information on the number of sows farrowing in Finland, the number of pigs in Finland, and the share of export markets closed at period t; $\mathbf{u_t}$ is the control vector which contains the numbers of piglets allocated to reproduction and slaughter, and slaughter weight; $S_t\left(\mathbf{x_t},\mathbf{u_t}\right)$ is pig meat supply; $P_t^{\mathrm{prod}}(\mathbf{x_t},\mathbf{u_t})$ is producer price of pig meat; $C_t\,(\mathbf{x_t},\mathbf{u_t})$ is production cost incurred at period t; β is the discount factor; $E(\bullet)$ is expectations operator; T is the terminal period; and $g(\mathbf{x_t},\mathbf{u_t})$ is the transition equation, which characterises animal stock dynamics and stochastic jump process for the continuation of export distortions. Dynamics imply that an insemination shows up as pigs sold to slaughter 10 months later.

The objective for the competitive market pricing is:

$$
\begin{aligned}
W_t\,(\mathbf{x_t}) = \max_{\{\mathbf{u_t}\}}\{ & \int_{\mathrm{q}}^{D_t^{\mathrm{dom}}} P_t^{\mathrm{dom}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{dom}})dQ_t^{\mathrm{dom}} + \\
& \int_{\mathrm{q}}^{D_t^{\mathrm{imp}}} P_t^{\mathrm{imp}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{imp}})dQ_t^{\mathrm{imp}} - P_t^{\mathrm{imp}}Q_t^{\mathrm{imp}} + \\
& P_t^{\mathrm{EU}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{EU}})Q_t^{\mathrm{EU}} + P_t^{\mathrm{row}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{row}})Q_t^{\mathrm{row}} + \\
& -C_t^{*}(\mathbf{x_t},\mathbf{u_t}) + \beta\,E(W_{t+1}(\mathbf{x_{t+1}}))\} \text{ for } t = 0,...,T
\end{aligned}
\tag{2}
$$

s.t. $\mathbf{x}_{t+1} = g(\mathbf{x_t},\mathbf{u_t})$, and $\mathbf{x}_t$ and $W_T\,(\mathbf{x_T})$ are given,

where $W_t\,(\mathbf{x_t})$ is the value of Finnish pig market; $P_t^{\mathrm{dom}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{dom}})$ and $P_t^{\mathrm{imp}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{imp}})$ are inverse demand functions for domestic and import demand, respectively, used to integrate area below the demand curve from q to D_t^{dom} or D_t^{imp}; $P_t^{\mathrm{EU}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{EU}})$ and $P_t^{\mathrm{row}}(\mathbf{x_t},\mathbf{u_t},Q_t^{\mathrm{row}})$ are export prices at EU and non-EU markets as functions of export distortion, meat storing and quantity Q_t^{EU} or Q_t^{row} exported to EU or non-EU market; and $C_t^{*}(\mathbf{x_t},\mathbf{u_t})$ is production cost.

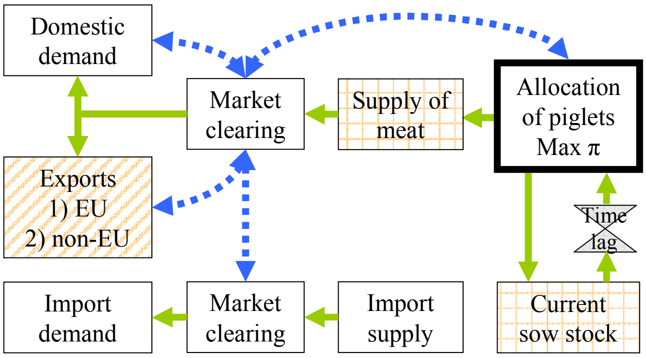

Fig. 1 Price signals (broken line), good flows (solid line) and the segmentation of markets in the simulated market, where epidemic scenario directly affects supply and sow stock, and export scenario directly affects exports.

Aggregate demand for Finnish pig meat is conditioned to meet the supply of Finnish pig meat at the same period. Prices adjust along the demand curves, except when exports are halted and export demand shifts due to FMD. Furthermore, after subtracting transaction costs and constant margins, Finnish pig meat has the same price at domestic and export markets. Simulated price system also takes into account contractual frictions which may induce stable meat prices in the very short-run.

B. Data and outbreak scenarios

Monthly data regarding Finnish pig meat markets were obtained from the statistics of Information Centre of Ministry of Agriculture and Forestry and Statistics Finland, except data about imports and exports of pig meat, which were retrieved from the Eurostat website.

Instantaneous returns at each period are income from selling meat to slaughter minus the production cost of a batch of piglets with existing sows and gilts, the cost of producing gilts from piglets, the cost of fattening pigs to slaughter, and slaughter costs. There are adjustment costs which make it costly for a producer to keep production capacity idle, expand sow stock or adjust slaughter weights. Slaughter weights vary only limitedly. Production costs in pig fattening were simulated using production functions [6] and other data on the costs of primary production [7].

Epidemiological scenarios used in the analysis were based on a separate epidemiological simulation study [4]. The scenarios were selected from set of 900 000 simulated epidemics, which were started from each Finnish pig farm in its turn. These simulations suggest that epidemics originating from ‘high-risk farms’ can be very different in size than disease outbreaks originating from ‘medium-risk farms’ (Table 1).

Table 1 Epidemic scenarios for median and high-risk farms.

Characteristic	Median-risk	High-risk
Number of infected farms	4	20
Number of removed sows	270	3539
Number of removed fattening pigs	1629	14372
Farms in restriction zones	62	380
Sows in restriction zones	3536	28213
Fattening pigs in restriction zones	23557	125711
Expected duration of export shock	4	5

C. Estimation method

Four demand equations were first estimated with three-stage least squares procedure [3]. Structural-form optimization problems were then solved numerically with dynamic programming [1]. Price, demand and production levels were calibrated to average monthly markets in 2006 by adjusting opportunity cost of capital and constants in equations. At calibrated quantities, the difference in capacity costs between two market regimes was 3.49 eurocents per kg. Finally, the effects of disease shocks were obtained by comparing simulated scenarios.

III. RESULTS

In the econometric estimation, statistically best performance was obtained for specification in which price elasticity of demand with respect to Finnish pig meat price was -0.14 for domestic demand, 0.87 for import demand, and -0.51 for export demand to non-EU and -0.97 for export demand to EU destinations.

Table 2 illustrates income losses for simulated scenarios. Results show that consumers generally gain and producer loose welfare due to the export shock and disease outbreak. When export shock duration increases, temporary storing capacity is quickly used up and excess meat supply in domestic markets increases. Producers can therefore suffer quite a lot in both disease scenarios. Losses in the median-farm scenario for instance are about 8% of market value of annual meat production.

Simulated prices fall due to excess supply during the export demand shock. The cost of an export shock increases with its duration. Benefits to producers from reducing slaughter weights are slightly higher in monopoly than competitive market regime. However, the benefits to producers from lower slaughter weights are small as few other costs can be decreased in the short run and quite large decrease in production would be required to recover prices during the outbreak. Thus, slaughter weights decrease very little.

Production adjustment takes primarily place through adjusting animal stock. Since culling sows prematurely is considered costly and irreversible decision, producers reduce insemination rates when an outbreak occurs. The reduction in insemination is the stronger the longer export restrictions are expected to last (the duration is stochastic). Outbreak size has smaller impact on the number of inseminated pigs than the duration of export restrictions has.

Overall, the impact of an outbreak on production quantity 10 months after introducing the market shock is generally less than 1%. Differences in market adjustment between domestic supply monopoly and competitive domestic monopoly cases, during the export shock, are quite small, although competitive domestic supply faces stronger domestic and import competition than domestic monopoly. However, monopoly regime provides incentives to adjust production more strongly than competitive domestic supply particularly in the high-risk farm scenario and when export shock ends sooner than expected.

Market regime has smaller impact on the producer welfare than that of consumers. Producers seem to suffer slightly higher losses in our simulations under monopoly regime than under competitive market regime. This result is due to different opportunity costs assumed in the monopoly case than in competitive market case. However, the result suggests that market regime may have larger impacts on consumer welfare than on producer welfare in the case of FMD outbreak.

Consumers can benefit when prices fall. The benefits to consumers are larger under competitive market regime than monopoly regime. Small impact on consumers is linked to short-term market frictions. It is also due to the estimation results, which induce that price changes decrease import supply quite elastically, whereas domestic supply is very inelastic. Thus, when an outbreak occurs, vast amount of excess meat enters domestic markets, meat prices fall and the utility gained from (more elastic) import demand decreases. Consumers therefore gain relatively little from disease outbreak despite increasing the consumption of domestic pig meat because utility from import consumption simultaneously decreases.

Table 2. Economic impacts (€ million per outbreak to consumers*, producers*, public funds and total loss) under monopoly and competitive market regimes and for epidemics starting from a median-risk or a high-risk farm.

Scenario	Consumer	Producer	Public funds	Total
Median-farm				
Competitive	5,5	-21,7	-0,6	-16,8
Monopoly	2,3	-22,2	-0,6	-20,5
High-risk farm				
Competitive	3,6	-24,4	-6,5	-27,3
Monopoly	-0,5	-25,1	-6,5	-32,0

*Producers include pig producers and slaughterhouses, but not meat processing. Producers are compensated for the value of lost animals. Consumers include final consumer, meat processing and retailing.

IV. CONCLUSIONS

Results raise two major conclusions. Firstly, market power can increase the adjustment of production, but market power can have only a limited impact on producer's disease losses due to import competition, especially if import demand is relatively elastic. However, welfare gain to consumers from the export closure and low prices may be lower in the case of domestic monopoly than in the case of competitive markets. Effects to consumers largely depend on the direct impact of disease on supply and producer incentives to decrease production during and after an outbreak. Secondly, high-risk farms require more attention from the risk management point of view than median-risk farms.

An agent who has monopoly power can exploit his status in order to minimize the market losses by responding more strongly to the number of lost animals, and possibly increase exports more strongly after the export closure than an agent in competitive markets. Monopoly can also reduce supply more aggressively than competitive markets would do.

The net effect of switching from one market regime to another however depends on price elasticity of domestic and import demand which influence how meat prices and production costs change between regimes. For this reason our results are conditional on estimated model parameters. When comparing producer losses between monopoly and competitive market regimes, trade-offs between reduced production costs and the ability to control market prices in favour of producers are important. As there is uncertainty about demand elasticity estimates, results cannot be widely generalised in a group of net-exporting countries. Results, however, support the view that domestic monopolies can cause some harm to society in the event of animal disease outbreak.

These results did show producers benefiting from an increased size of an epidemic [5]. Epidemics simulated here were reasonably "small" and exports were considered to be fully halted. Furthermore, the larger epidemic in Table 1 was expected to cause longer export shock than the smaller epidemic. Moral hazard problems are possible in the absence of export distortions or when their extended duration is not connected to epidemic size. In such cases producers as a group can be better off in large epidemics of diseases such as FMD for which it is possible to receive compensation for the value of lost animals. This may not hold for diseases which costs are paid by the industry.

The starting point for the larger epidemic in Table 1 is a high-risk farm, which operates and is connected to other farms in a way which increases the total number of infected farms. Society suffers larger losses when disease is introduced into a high-risk farm than into a median-risk farm. Probability of a farm to get a disease can be reduced by bio-security measures, which investment should be put more emphasis in high-risk farms than in median-risk farms. Result is consistent with an earlier study [2]. As producer losses seem less connected with epidemic size, prevention of the first infection is important to them. Noteworthy is also that public expenditures increase more steeply than the number of infected farm. This highlights the importance of preventive measures.

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