MODELLING THE DYNAMICS OF PRODUCTION ADJUSTMENT TO SHORT-TERM MARKET SHOCKS

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Abstract

Models of agricultural economics typically operate at an annual basis or in a static equilibrium framework where inputs, outputs and their prices may change considerably. Production dynamics, however, imply that models relying on spatial and temporal aggregation do not capture the effects of biological constraints in the short run.

This paper examines short and long-term impacts of demand and production cost shocks in the pig sector. The analysis is carried out with a dynamic programming model which takes into account changes in export and domestic demand and market clearing price. It optimizes the supply of piglets on a monthly basis. Econometric techniques are used to estimate demand functions.

Short-term negative market shocks can already have significant income effects to agricultural producers. We simulated effects of pig meat export bans of different degrees due to livestock epidemics. Full closure of export markets for six months cost pig sector €21 million.

Key words: pig, demand, dynamic programming, export, livestock epidemics, price, supply

1. Introduction

European livestock production has faced several short-term market shocks over the past two years as well as over the past decade(s). Market shock is, by definition, an unexpected event which significantly differs from what can be reasonably expected given the information available (e.g. Black, 1997). Market shocks can have very significant income effects to agricultural producers locally and nationally, and there are numerous examples on recent market shocks in Europe. Let us mention a few recent examples.. In the UK, short-term foot and mouth disease epidemic and consequential export bans related to it caused considerable losses to local producers in Autumn 2007, although much larger shock was experienced in 2001. Import bans imposed by food buyers in the Middle East in 2005 caused losses to agricultural producers and dairy industry in Denmark. News about the spread of Avian influenza in the World and news about its potential threat to human health staggered consumer demand for poultry products in 2006 especially in Southern Europe, thus causing a slump in meat prices. Soaring grain prices in fall 2007 increased feed costs on pig farms across Europe whereas meat prices stagnated. In this paper we consider two specific types of shocks, namely those affecting input prices of pig sector and those affecting demand for pig meat.

Supply of goods is often very inelastic in the short run, but becomes more elastic when the time span is expanded (e.g. Tomek and Robinson, 2003). Kujala (2006), for instance, estimated the elasticity of supply of pig meat with respect to net revenues (i.e. pig meat price+support) at 0.14. The demand for food is also generally inelastic (e.g. Laurila, 1994). Due to biological constraints, the supply of pig meat is almost predetermined in the short run (6-9 months). Producers can thus hardly avoid negative shocks in the short run as they have virtually no option but to accept income loss (unless the shock can be transmitted to produce or input prices). It is also challenging for producers to benefit from positive shocks in the short run, because even if producer prices rise quickly, it is costly to adjust production instantaneously. In the long run producers can adjust production levels and thus minimise income losses caused by negative changes in markets. However the duration of a market shock is often unknown. Adjustment costs and uncertainty about the duration of the market shock implies that it is difficult for a farmer to fully adjust to a market shock. If the market shock is temporary by nature (for example, a small scale animal disease epidemic), then it may not be rational to fully adjust to the market shock due to high adjustment costs. For example, it is difficult to conjecture the duration of the record high cereals prices or the duration of the export ban due to animal disease epidemic. Driving down and up the animal stock due to a temporary market shock may be more expensive for a farmer than the market shock itself.

Highly contagious animal disease epidemics provide a useful example on an emerging market shock. Epidemics have the potential to cause strong market shocks which reduce demand for animal products and affect producer prices in the infected country (e.g. Mangen and Burrell, 2003, Schoenbaum and Disney, 2003, Pritchett *et al*., 2005). Export restrictions imposed by importing country are particularly important in this context, because even if domestic demand was unaffected, an outbreak of foot and mouth disease, classical swine fever, avian influenza or another animal disease specifically listed by World Organization for Animal Health typically closes down export markets for an exporting country. Sudden drop in the export demand results in excess supply if exports exceed imports, and thus pushes down relevant livestock producer prices. Studies therefore often take into account the effects of these diseases on trade (e.g. Rich *et al.* 2005).

Export and import of livestock products has gained more importance in the EU over the past decade. Statistics show that export:production ratio on one hand, and import:consumption ratio on the other hand has increased in most OECD-countries over the past decade (OECD, 2007). Thus, European livestock producers may have become more vulnerable to market distortions. In 2006, Finnish pig meat exports accounted for 23% of domestic production, imports to Finland represented 10% of consumption, and domestic supply was 16% higher than consumption (Niemi and Ahlstedt, 2007).

Models of agricultural economics typically operate at an annual basis or in a static equilibrium framework where inputs and outputs as well as their prices may change considerably. In such frameworks, after all adjustments have taken place, short-term market shocks imply only marginal economic impacts. This is because the supply and demand is assumed to be in equilibrium after all adjustments during the entire year. However, production may face considerable adjustment costs in the short run and hence it may take several months before any significant changes take place in the animal stock or in feeding decisions. Hence, production of the entire year cannot be reasonably assumed to take place at the equilibrium values of output and use of inputs. Dynamics of production imply that considerable losses may accumulate in few months, but these effects are not captured in models relying on spatial and temporal aggregation.

This paper models the dynamics of pig meat production on a monthly level thus taking into account predeterminancy of supply. It examines short and long run impacts of unexpectedly shifting demand and soaring production costs in the pig sector. The goal of this is to study how pig production can adjust to market shocks and how large income effects these shocks have. Cases examined in this paper include the closure of export markets for Finnish pig meat, an increase in production costs and implications of more flexible demand for pig meat. It is important for agricultural producers to recognize opportunities to minimise income losses due to negative shocks. The analysis is carried out with a dynamic programming model which takes into account changes in export and domestic demand and market clearing price. It optimises the supply of piglets on a monthly basis and by considering herd dynamics. Econometric techniques are used in estimating domestic and export demand functions.

2. Material and methods

2.1. Simulation model for pig sector

Simulation model for Finnish pig sector illustrates how representative pig producers make decisions on how many pigs it is profitable to produce. Further details of the model are given by Niemi *et al*. (2006). It simulates pig markets on a monthly basis by optimizing the number of piglets which are redirected to reproduction and by simulating the number of sows which are re-inseminated or removed from the stock. The optimal piglet allocation maximises productive value of pig sector over a period of about 20 years. These imply that profits are maximised and supply of pig meat is controlled by taking into account biological constraints of production (Figure 1) and empirically validated demand functions. Demand for pig meat in the model is stratified into three market regimes which are domestic demand for Finnish pig meat, export demand for Finnish pig meat and demand for pig meat imported into Finland (Figure 2). Finnish pig meat and imported pig meat are considered as imperfect substitutes in the demand system. Imports and exports of live animals are ignored, because they are negligible in Finland.

The value of pig sector is obtained when production costs are subtracted from income of selling the pigs for slaughter plus slaughter subsidy. The model takes into account that Finnish meat markets respond to changes in supply and the EU market situation. This implies that when either the volume of pig meat supplied by Finnish producers increases or market prices in the EU are reduced, pig meat prices in Finland also tend to decrease. If prices are reduced significantly, producers reduce production until prices recover to the level which is satisfactory from the profitability's point of view. On the other hand, if pig meat prices in Finland are high, producers may have incentives to increase production.

The model operates with rational expectations. The sector takes into account that reducing the level of supply raises domestic prices and import of pig meat, but decreases exports. Domestic producers compete with imported products, which are imperfect substitutes for Finnish pig meat. The model further assumes that the pig sector in Finland operates in a monopolistic manner, and the pig sector minimises market shock losses as a single agent who competes with imports at the domestic markets and faces a given, largely inelastic export demand. Despite the fact that the assumption about monopoly in domestic production exaggerates market power of the industry, it is noted that after recent corporate acquisitions two largest slaughter pig purchase companies buy almost 86% of slaughter pigs in Finland (Finnish Competition Authority, 2007, and Figure 3). In their largely distinct operating regions, these companies also coordinate majority of piglet trade in Finland and they have the opportunity to coordinate the level of meat supply. The model will be extended to cover competitive markets in the near future.

Due to biological constraints, it is costly or infeasible for pig producers to accommodate supply in the very short run even if market conditions changed rapidly. For instance, it takes 6-18 months to significantly increase supply, because piglets born from an insemination decision taken today are ready for slaughter approximately 10 months from now. If gilts need to be produced, it increases the delay by further 8-9 months (Figure 1). Decreasing production very quickly may also be costly because premature disposal of sows leaves some of their production potential unused. Thus, pig meat supply is almost predetermined in the short run.

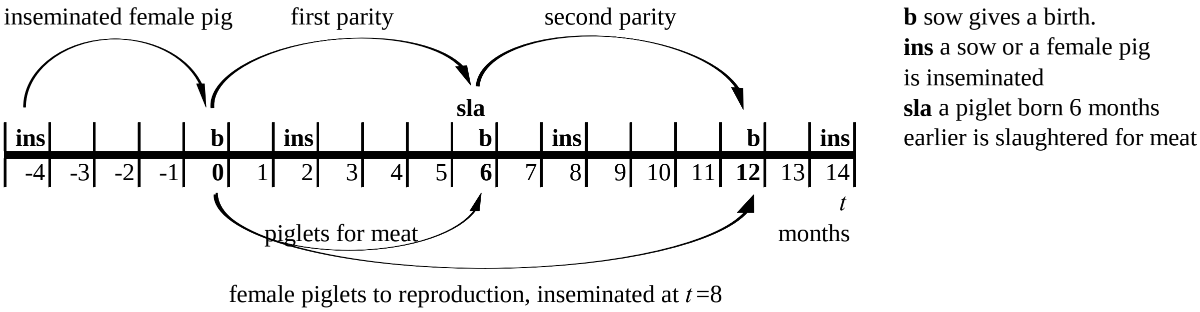


Figure 1. Biological lags and constraints taken into account in the model.

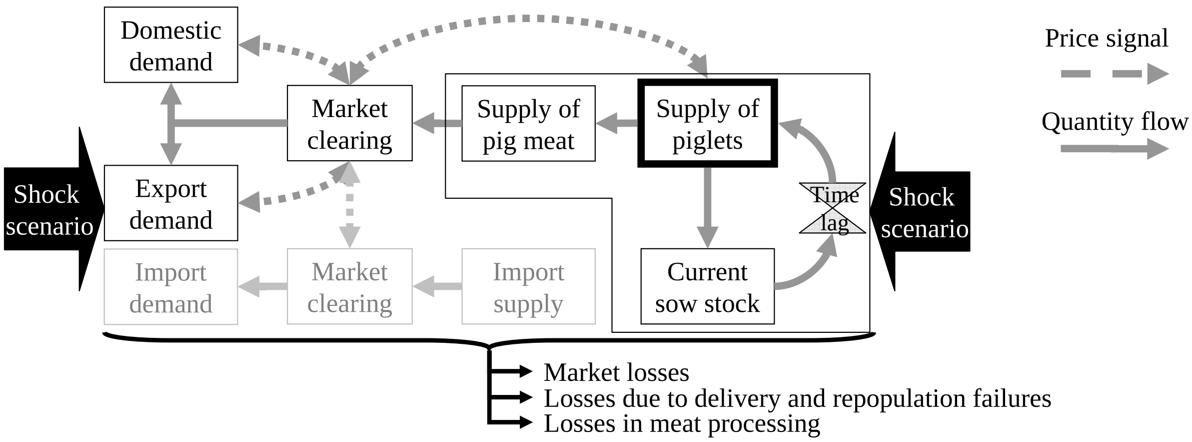
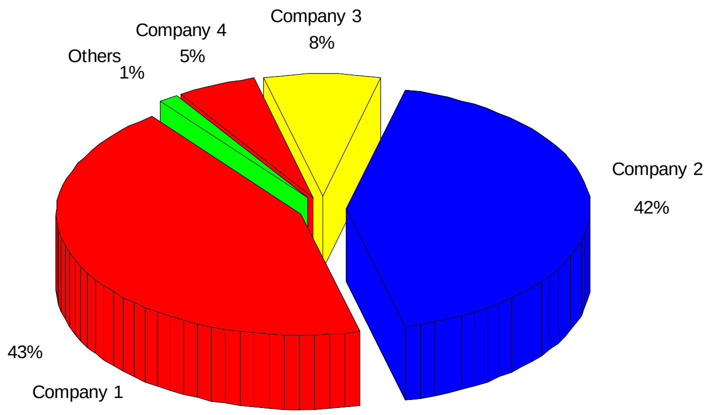


Figure 2. Linkages between export, import and domestic demand, supply of piglets for fattening or reproduction and pigs for slaughter, and the impact of market shock in the model.



Source: Calculations based on statistics and information obtained from company websites on 11 December 2007.

Figure 3. The degree of market concentration in the slaughter pig purchase sector (excluding meat processing), indicated by market shares of slaughter pig buyers or buyer corporation groups.

The structural-form optimization problem was solved numerically with dynamic programming (Bellman, 1957). Objective function of representative producer can be characterized with the Bellmann equation of the form:

$$(1) \qquad V_t(\mathbf{x}_t) = \max_{\mathbf{u}_t}\left\{R_t(\mathbf{x}_t, \mathbf{u}_t) + \beta E(V_{t+1}(\mathbf{x}_{t+1}))\right\},\ t = 1,..,T$$

s.t.

$\mathbf{x}_{t+1} = g(\mathbf{x}_t, \mathbf{u}_t)$	(transition equations for herd dynamics),
$V_{T+1}(\mathbf{x}_{T+1})$ is given	(value at the end of planning horizon),
$\mathbf{x}_0$ is given	(initial state of nature),
$R(\mathbf{x}_t, \mathbf{u}_t) = P_t(\mathbf{x}_t, \mathbf{u}_t)\mathrm{Q}(\mathbf{x}_t, \mathbf{u}_t) - \mathrm{C}(\mathbf{x}_t, \mathbf{u}_t)$	(instantaneous returns),

where V_t is value function for the pig sector at time t; $\mathbf{x}_t$ is the state variable characterising the number of sows in the stock at a given time period and in a given production stage class (e.g. recently farrowed lactating sows, sows about ready for insemination, sows pregnant for the first, second, third or fourth month) of the production cycle; t denotes monthly time index; $\mathbf{u}_t$ is the control variable characterizing proportion of piglets at each age group allocated to reproduction; $R_t(\mathbf{x}_t, \mathbf{u}_t)$ is instantaneous return to sector based on current state of nature and production decisions; $P_t(\mathbf{x}_t, \mathbf{u}_t)$ is inverse demand function which is used to determine producer price of pig meat at time t; $\mathrm{Q}(\mathbf{x}_t, \mathbf{u}_t)$ denotes supply of pig meat at time t as a function of the state variable and control variable; $\mathrm{C}(\mathbf{x}_t, \mathbf{u}_t)$ denotes aggregate production cost of fattening pigs and piglets; β is discount factor; $V_{t+1}(\mathbf{x}_{t+1})$ the value function in the subsequent period; $g(.)$ is transition equation characterizing how the number of pigs kept on farms evolves over time; $V_{T+1}(\mathbf{x}_{T+1})$ is the terminal value of pig sector at the end of planning horizon t=1,…,T; and $\mathbf{x}_0$ denotes initial value of the state variable.

The product of price and quantity, $P_t(\mathbf{x}_t, \mathbf{u}_t)\mathrm{Q}(\mathbf{x}_t, \mathbf{u}_t)$, denotes market income from selling pigs to slaughter. The model assumes market clearing such that meat produced is sold at price which clears domestic markets. Imports did not enter the optimization problem as decision variables, but they were taken into account when estimating demand equations, and the changes in imports are implicitly taken into account in the production decisions in the model.

2.2. Data and estimation method

Three demand equations were specified linear and estimated with three-stage least squares procedure by LeSage (2001). The method takes into account error term correlation between demand equations and allows endogenous explanatory variables. The data used in demand equations included time-series data on quantities of domestic supply, import and export as explained variables from April 1995 to September 2003, data on deflated pig meat and its substitute prices in Finland, pig meat prices in major import source and export destinations, and a number of exogenous demand shifters such as livestock epidemics in the EU. Exogenous and lagged endogenous variables were used as instruments for meat prices in Finland, which were allowed to be endogenous. Elasticity estimate of domestic demand for pig meat with respect to pig meat price in Finland was -0.58 (standard error 0.14). Corresponding elasticity for export demand was -3.54 (standard error 0.56). For further details, see Niemi *et al*. (2006) and Niemi *et al*. (2007).

The dynamic programming problem was solved numerically with a recursive and discrete grid seach-type algorithm (e.g. Judd 1997) programmed in Matlab 7.1 (Mathworks inc., MA, USA). Production costs used in the optimization were based on model calculations for gross margin in 2003 (ProAgria, 2003). The model was calibrated in order to replicate markets in 1997-2003 as well as possible. Calibration was performed by imposing an extra cost to capital that is kept idle. Thereafter, parameters of the model were deviated from their baseline values one at a time and the outcome was compared to outcome obtained from the baseline simulations. Results presented in Chapter 3 below are based on such comparisons. For instance, a price change or an income loss due to a market shock is the difference in price or income simulated by deviated-parameter model and non-deviated parameter model. As a starting point we had a market in which pig meat producer price was €1.38/kg and pig meat was produced at the cost level of 2003.

2.3. Scenarios

Scenarios analysed in this paper include both persistent and short-term shocks (Table 1). Shocks affecting export demand for Finnish pig meat are assumed to fade away over time whereas other shocks are assumed to have permanent effect on pig markets. Shocks are implemented by scaling either up or down relevant parameter in the production cost function or demand function. As an example of an export demand shock, we consider the closure of export markets for Finnish pig meat for either 6 or 8 months. The shock closes down export markets either fully or leaves half of export markets open, thus scaling down export demand by 50%. Such export shocks can be caused by, for instance, sporadic foot and mouth disease or classical swine fever outbreak[1]. A small reduction in the supply due to the disease is taken into account, but due to sporadic case, it has only a marginal impact on results. When calculating the impacts of the export scenarios we also include minor income losses to meat processing and government expenditures. We examine how changes in selected model parameters affect consequences of an export shock.

As examples of domestic market shocks we examine consequences of 1) an increase in feed costs, 2) increase in all variable production costs, and 3) the cost of keeping capacity idle.

An increase in production costs is not transmitted to producer prices unless supply of pig meat decreases.

Finally, we examine how a less flexible domestic demand affects results. Since own-price elasticity of demand is negative, an increase in parameter implies that it approaches zero and thus, domestic demand for pig meat at a given price increases (ceteris paribus).

Table 1: Description of major the type of shocks examined in this paper, their impact on model parameters and duration of the shock.

Description of a market shock	Magnitude of change	Duration of the shock
Feed prices increase	+10 %, ca. +8 c/kg meat	permanent
All variable costs increase	+10 %, ca. +16 c/kg meat	permanent
The cost of idle production capacity increases	+10 %	permanent
Price parameter of domestic demand increases	elasticity -0,58 => -0,52	permanent
Closure of export markets 1[1)]	Export demand falls 50 %	6 months
Closure of export markets 2[1)]	Export demand falls 100 %	6 months
Closure of export markets 3[1)]	Export demand falls 50 %	8 months

1) Characterises possible decrease in export demand for Finnish pig meat after a highly contagious animal disease has been introduced into Finland, but limited to a sporadic case. These shocks include small decrease in supply.

3. Results

We calculated effects of pig meat export bans of different degree due to animal disease epidemics. Temporary export demand shock implied tumbling meat prices while the shock was effective. Despite the small adjustments in animal stock, full closure of export markets caused already in six months income losses of almost €21 million per event. When compared to permanent shocks, the advantage was temporary nature of these losses. Losses due to an export shock increased when shock duration increased, but were significantly smaller if export markets were only half-closed. Increasing shock duration from 6 to 8 months when export markets were half-closed increased losses less than increasing the degree of market closure from 50 % to 100 % (Figure 4). Losses decreased when demand for pig meat became more elastic or when production costs decreased. In contrast to this, a 10% decrease in export demand would have had hardly any impact on pig meat production. Lost value

[1] According to Raulo and Lyytikäinen (2005), sporadic outbreak is the most likely outcome for a classical swine fever outbreak.

added due to the shock and disease expenditures to the government were jointly less than €2 million per shock.

Permanent demand and input price shocks could have a significant impact on pig producer incomes (Figure 4). In contrast to temporary export demand shock, a permanent 10 %:n decrease in own-price elasticity of domestic demand increased pig meat production by 2 % in the year after introducing the shock, producer prices instantaneously by 5 % and annual income of pig sector on average by €19 million.

A 10 % increase in feed price decreased incomes of pig farms by €15 million per year. A 10 % increase in all variable costs of pig production decreased income of pig sector by €37 million per year. Permanent increase in production costs also reduced meat supply. Reduction due to 10% increase in feed prices was quite modest whereas a stronger increase in production costs had more prominent impact on production. Once supply of pig meat reduced, producer prices rose in the year after the shock (Figures 4 and 5). Hence the downward adjustment of the animal stock provided some pay-off since slightly higher prices after the shock, due to the relatively rigid supply in the short run, provided some compensation for producers for the losses experienced during the negative shock.

In addition to results reported in Figures 4 and 5 we simulated the effect of an export demand shock at alternative production cost and elasticity of demand parameters. When production costs of pig meat were 10% higher than in the baseline model, losses due to export demand shock were about 30 % higher than reported in Figure 4 for 50% closure for a period of 6 months. A prolonged duration of the export shock appeared to reduce supply for pig meat in the year after the shock. An increase in input prices reduced meat supply and increased meat prices thus resulting in a higher income loss due tumbling meat prices after introduction of an export demand shock. Relative change in meat prices was of the same magnitude regardless of the input price level. Input prices had stronger impact on losses in the event of full closure of export markets than in the event of 50 % market closure.

A 10% increase (decrease) in the absolute value of Finnish meat price parameter in demand equations, i.e. less elastic demand, decreased (increased) the losses due to the 50% export closure (for 6 months) by approximately 40% (Fig. 3). Thus, domestic demand responded more elastically to excess demand and a smaller price decrease was then required to clear markets than reported in Figure 4. More elastic demand for pig meat reduced losses due to export bans particularly when there was a lot of excess supply (i.e. when the export markets were fully closed). Reduced losses due export shock were also affected by the fact that more sensitive demand for pig meat with respect to price changes resulted in smaller volume of supply regardless of the nature of the export shock.

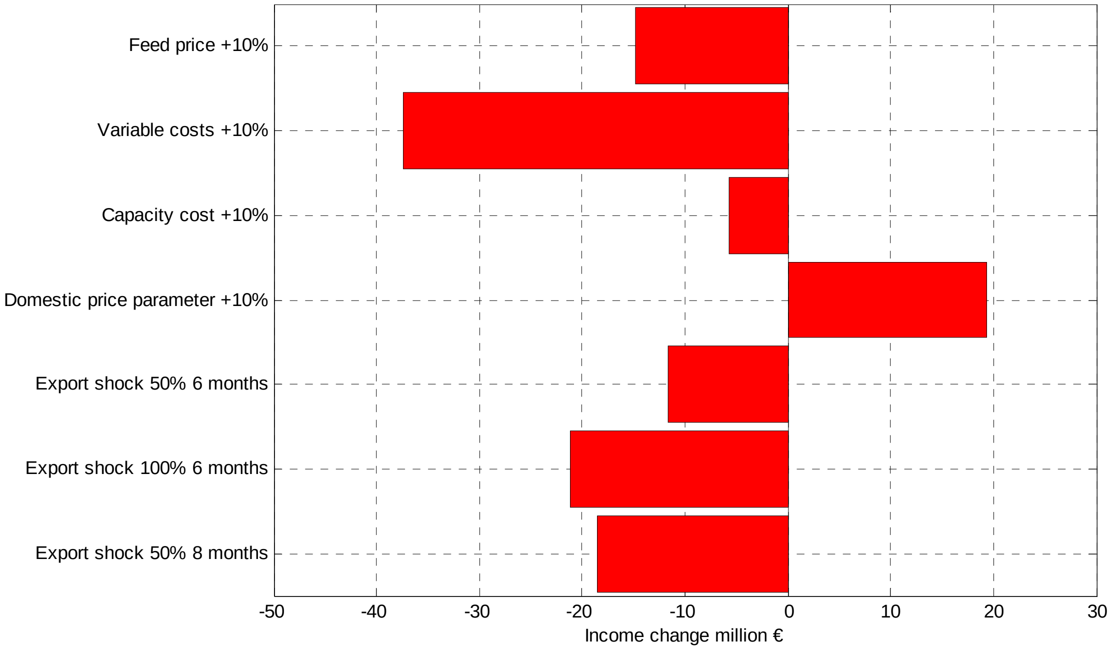


Figure 4. Simulated impacts of permanent market shocks and short-run export market shocks producer income (€ million per event).

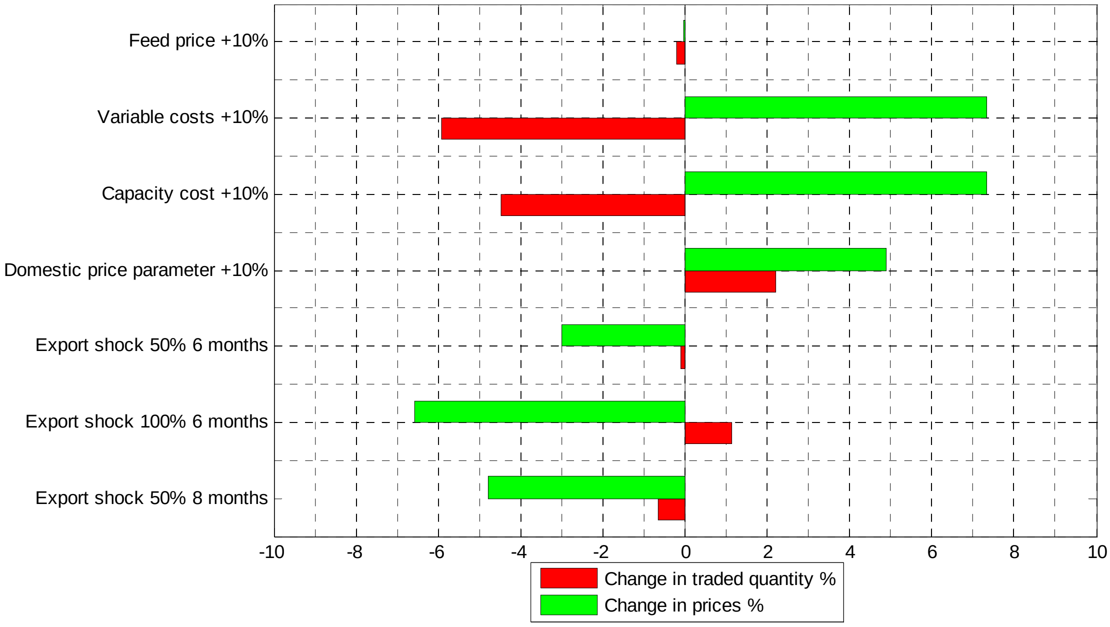


Figure 5. Simulated impacts of permanent market shocks and short-run export market shocks on producer income (€ million per event).

4. Discussion

4.1. Income effects

This paper has examined implications of short-term export demand shock and permanent input price and domestic demand shocks. Results suggest that market shocks which are large in terms of their impact on input prices or domestic or export demand can cause considerable income losses to agricultural producers. Shocks which reduce demand also reduce producer prices of pig meat to a large extent. Results are in line with previous studies such as Mangen and Burrell (2003), Schoenbaum and Disney (2003) or Niemi *et al*. (2006). There are two main reasons for the simulated income losses. Firstly, production is (almost) predetermined in the short run and therefore producers have virtually no option but to accept instantaneous losses. Secondly, when negative market shock is permanent or long-lasting, it decreases profitability of production which decreases producer income also after they have had enough time to adjust production levels according to what is optimal in the new market situation (i.e. income is monotonic in prices or model parameters).

Losses simulated for various demand shocks suggest that policy options which reduce demand for livestock products, even temporarily, should be applied only after careful consideration. Agricultural producers may have little incentives to implement these policies since they are likely to cause significant income losses which are hard to be avoided by high adjustment costs. In the context of highly contagious animal diseases, one of these options is emergency vaccination. However, each policy option should be analysed in detail taking into account state-specific context.

An interesting result is that losses due to export demand shock decreased when demand for pig meat became more elastic or production costs decreased. These observations are linked to the fact that production costs and demand affect the producer prices and the level of meat supply, and thus they affect to quantity and value of production affected by the shock.

Market shocks raise a question about the degree of competition in the livestock markets. Literature provides evidence that stakeholders may use market power to gain from market shocks (for a theoretical introduction, see e.g. Mas-Colell *et al*. 1995). Hence the question: How valuable is competition and market flexibility? We show that more responsive demand may significantly decrease losses caused by market shocks. Hence market flexibility should be among the key issues in policy planning.

From the sector point of view, benefits from more elastic demand for pig meat depend on the nature of the shock and are somewhat conflicting, however. On one hand, more elastic demand for livestock products implies that if strong negative market shock occurs in export markets, markets can be cleared with a smaller price decrease than when demand is very stagnant. Elasticity can be increased for instance by making short-term delivery contracts or establishing good connections to several premium-price import destinations (which is useful if one or two destinations are closed). On the other hand, increased price elasticity of demand or market flexibility also implies that production becomes more vulnerable to any increase in production cost or reduction of import prices. In other words, more elastic demand implies that the level of supply depends more and more on efficiency of production.

This, in turn, implies that producers have difficulties in passing increased production costs to producer prices as it reduces traded amounts quite easily.

4.2. Impact on production and prices

It is important for a pig producer to know how to adjust production when market conditions change. Our simulations indicate that meat supply decreases when production costs rise, whereas stronger demand for pig meat increases meat supplies. Thus, strong increase in feed prices, such as the one seen in Autumn 2007, decreases meat supplies unless producers are able to transmit these costs in meat prices. Result is self-explanatory and in line with the economic theory.

Due to adjustment costs, even strong cost and demand shocks may not affect pig meat supply to a large extent, especially in a short-term. Due to dynamic interactions in the sector, pig production may recover and increase to a higher level after the shock, compared to the production level before the shock. This behaviour stems from the increasing product prices after the shock during which producers decrease production. In our simulations, the supply of pig meat is determined according to the number of pigs kept on farms at a given moment. Since pig producers did not have the option to accommodate the level of supply instantaneously in accordance with decreasing demand or rising prices (it is too costly), it implied that a short-term market shock had only a small instantaneous impact on production. However, long-lasting or voluminous negative shocks reduced the supply of pig meat. Using the lag structure of our model, supply of pig meat may also increase when demand for pig meat recovers in the year after the shock.

Despite inelastic supply, other studies suggest that there are few options to adjust production levels in accordance also in the short run. For instance, pig producers can sell pigs to slaughter earlier than they would have sent in the absence of the shock. Thus, less meat is produced per sow but production capacity is left unused. Pig producers can also consider restricted feeding as a short-term solution to gain value-added from producing leaner carcasses waiting for higher prices (cf. Niemi, 2006). Farms can also consider the option to cease unprofitable production (cf. Dixit and Pindyck, 1994). This option may have value especially on fattening farms.

The model could be extended to take into account consequences of market shocks to different stakeholders such as consumers in addition to producers. Interesting future extensions for the analysis include also considering whether there are mode options to adjust production in the short run. A model with similar strong biological dynamics will be developed to cattle sector as well.

5. Conclusion

Models of agricultural economics typically operate at an annual basis or in a static equilibrium framework where inputs and outputs as well as their prices may change considerably. Production dynamics, however, imply that models relying on spatial and temporal aggregation do not capture the effects of biological constraints in the short run. It is therefore important to take into account short-term limitations when studying implications of market shocks such as soaring input prices or plunging producer prices or demand.

Short-term negative market shocks can already have significant income effects to agricultural producers without supply being significantly reduced. Short-term market shocks can affect production momentarily, but their effects seem to pass over time. In contrast to this, permanent shocks have long-term impact on supply as well.

6. Acknowledgements

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