Chapter 27

Market effects of vaccination and non-vaccination strategies to control HPAI epidemics in the Netherlands

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Abstract

A vertically-linked dynamic partial equilibrium model of the Dutch layer sector is developed which is designed to incorporate supply and demand shocks, trade bans and marketing restrictions associated with HPAI outbreaks. Shocks are based on the output of an epidemiological simulation model of HPAI epidemics in the Dutch commercial poultry sector under different control strategies, including vaccination and non-vaccination. A scenario-based design is used to explore the effect of different types of shocks on the market for poultry and poultry products and on the welfare of market participants. The aggregate effect on the welfare of producers disguises very differentiated effects across stakeholder groups, where some stakeholders gain and some lose as a result of HPAI epidemics. Market effects are very different depending on whether epidemics occur in densely or sparsely populated poultry areas. Assuming demand effects do not differ, vaccination and non-vaccination strategies differ according to their epidemiological effectiveness. The distribution of affected farms across the different levels in the production chain has an important effect on the prices of live poultry and eggs. The analysis points to a number of important determinants of the market effects of HPAI epidemics. These include the expected size, length and location of epidemics, the structure of the poultry industry, the nature of intra- and inter-EU trade and the size of any market for lower quality or processed markets.

1. Introduction

The economic impact of avian influenza (AI) outbreaks differs according to whether outbreaks occur in commercial poultry flocks or backyard flocks and according to the size and structure of the poultry production in affected areas. The economic effects of AI epidemics in commercial poultry flocks can include shocks to the supply, demand and international trade in poultry and poultry products. These shocks affect the prices and quantities sold and therefore the welfare of producers in the poultry production chain and consumers. Much of the economic impact of contagious animal diseases is associated with the control measures implemented and not with mortality or morbidity caused by the disease itself. For member states of the European Union (EU), the AI Directive outlines the minimum measures to be implemented in the event of a highly pathogenic (HPAI) or low pathogenic avian influenza (LPAI) outbreak. These measures include the culling of poultry on infected farms, movement restrictions within the protection and surveillance zones and marketing restrictions for poultry and poultry products originating from affected areas. Particularly in densely populated poultry areas (DPPAs) more stringent measures are often needed, such as pre-emptive culling, vaccination and restocking restrictions. Such measures can create different supply shocks. The 2003 H7N7 HPAI epidemic in the Netherlands lead to the culling of 30 million poultry from both commercial and backyard poultry flocks (Stegeman *et al.*, 2004). The 1999-2000 H7N1 HPAI epidemic in Italy resulted in the culling of 16 million poultry (Marangon *et al.*, 2005), while LPAI epidemics in 2000-2001 and 2002-2003 led to the culling of 1.7 and 7.7 million poultry respectively (Busani *et al.*, 2007). These figures reflect the supply shocks associated with culling of affected and at-risk farms only. Accompanying control measures such as restocking bans, movement restrictions and vaccination (LPAI epidemics in Italy) create additional and different supply shocks.

Demand shocks may also be relevant for contagious animal disease epidemics, particularly if diseases are perceived as risks for human health. Reports of H5N1 outbreaks throughout Europe in 2005 and 2006 led to large temporary demand shocks in Italy, France, and Greece but much smaller demand shocks in the UK, the Netherlands and Germany (Flach, 2006). These large demand shocks have not been seen with more recent outbreaks of H5N1 in wild poultry and backyard flocks in Europe. Results from a Eurobarometer survey in March-april 2006 showed very large differences between declared consumption changes between EU member states, consistent with declines in actual consumption (Anonymous, 2006a). Of Dutch respondents only 9 per cent declared that they had reduced consumption, compared to 20 per cent of German respondents. Differences in risk perception about BSE (Bovine Spongiform Encephalopathy) was also found by (Kalogeras *et al.*, 2008), with German consumers reacting much more strongly than Dutch or American consumers.

A comparative study on the effects of HPAI and BSE outbreaks in Japan, showed that BSE had a larger and more persistent demand shock than HPAI, with recovery in demand beginning one month after the outbreak of HPAI and full recovery occurring 8 months after the outbreak (Ishida *et al.*, 2006). This can be explained by differences between the two types of health risks (for countries where HPAI is epizootic, the HPAI health risk is relatively short lived while BSE is much more long term and uncertain). Similar differential effects were found for BSE and a milk contamination incident, where the milk contamination incident was also a short-lived and isolated incident similar to the HPAI outbreak in Japan (Mazzocchi, 2006). Empirical evidence for how repeated food scares may affect demand is mixed: the effects of the 1996 BSE crisis in France were estimated to persist for 3 years, while the effects associated with a second BSE crisis in 2000 lasted just 4 weeks (Allais and Nichle, 2007). An opposite effect was found in Italy, with the second BSE crisis associated with a much more persistent effect on preferences (Mazzocchi *et al.*, 2006).

Beach et al. (2008) explored the effect of news media coverage of HPAI H5N1 events on Italian purchases of fresh and frozen poultry meat. Newspaper articles were either related specifically to Italy (Italy-specific) or about HPAI in general. Newspaper articles (both specific and general) had a statistically significant effect on both fresh and frozen poultry, resulting in approximately 20 per cent decline in consumption of fresh poultry, with the peak demand shock occurring in the second week following the newspaper articles. Cornelis and Fischer (2007) found differences between Dutch households in the consumption pattern of poultry in relation to different market shocks. For some household subtypes, the 2003 HPAI epidemic was associated with a structural break but the HPAI did not lead to permanent demand shifts. For other household types, no structural break was found. The demand response to the 2003 HPAI outbreak in the Netherlands appears to have been rather limited, however this epidemic occurred before the wave of H5N1outbreaks worldwide and associated media attention.

Demand shocks may differ according to the control strategy implemented. The potential reaction of consumers and large supermarket chains to products from vaccinated animals is a major issue within the Dutch intensive livestock sector. There is little empirical evidence regarding the perceptions of consumers for vaccinated products (see for e.g. Scudamore, 2007). A questionnaire amongst Dutch consumers of pork meat suggests that vaccinated meat is perceived as having both positive (such as more animal friendly and better for the environment) and negative attributes (taste and quality) in comparison to conventional meat (Bergevoet *et al.*, 2007). Results from the Eurobarometer survey showed that over 50 per cent of respondents did not believe that vaccinated poultry meat carries no risk for human health

(Anonymous, 2006a). Again there were major differences between EU member states, with 29 per cent of Dutch respondents not believing in the safety of vaccinated poultry meat compared to 59 per cent of German respondents. There remains large uncertainty about the potential demand shocks associated with a vaccination policy. Voluntary restriction of products from vaccinated poultry to either the domestic or processed markets may be a potential policy tool to alleviate any potential demand shocks in response to vaccination.
Epidemics of both HPAI and LPAI lead to the implementation of trade bans by trading partners. Trade bans are unpredictable in terms of product coverage, degree of regionalisation and the length of the trade ban. Long trade bans can lead to a loss of export markets. This effect is evident in the market shares of world trade in unprepared poultry meat, which have changed significantly in response to worldwide outbreaks of HPAI H5N1 (Nicita, 2008).
A number of studies exploring the market effects of contagious animal disease epidemics exist. Supply shocks are either assumed or derived directly from an epidemiological simulation model. For HPAI, studies to date use supply shocks based on the assumed size, length and location of potential epidemics (e.g. Brown *et al.*, 2007) or by assuming the size of the supply shock directly (e.g. Paarlberg *et al.*, 2007). Examples of combined epidemiological and economic modelling where supply shocks are linked directly to output from epidemiological models exist for other contagious animal diseases, including Berentsen (1992), Paarlberg et al. (2008), and Rich and Winter-Nelson (2007) for FMD and Mangen and Burrell (2003)for CSF. The current study extends the previous literature in terms of the level of disaggregation within the sector which is modelled and the extensive use of epidemiological input to model supply and demand shocks. Although supply shocks are based on output from an epidemiological model, the shocks in the economic model of Rich and Winter-Nelson (2007) are based only on the average number of animals culled and the average length of the outbreak, while Mangen and Burrell (2003) used weekly epidemiological output regarding the number of animals culled and the number of pig places under restocking restrictions. In this paper, the following simulated epidemiological outputs are explicitly used as weekly shocks in the economic model: the number of poultry (per type) culled, the number of poultry in a movement restriction zone, the number of empty poultry places, the number of poultry vaccinated, the weeks in which the epidemic begins and ends and the weeks in which vaccination begins and ends.
The aim of this chapter is to explore how different demand and supply shocks associated with HPAI epidemics could affect the market for live poultry and poultry products and thereby the welfare of market participants in the Dutch layer sector. A dynamic, vertically-linked partial equilibrium model of the Dutch layer sector is developed. The model is designed to incorporate supply shocks, domestic and export demand shocks, trade bans and restrictions on the marketing of specific types of poultry and poultry products. These shocks are derived from simulated HPAI epidemics in the Dutch commercial poultry sector. A scenario-based design is developed to explore the potential effects of different shocks. Each scenario is a combination of several different variables: the control strategy, representative epidemic size, farm density in the area of virus introduction, the channelling or marketing restriction policy followed, size of basic and vaccination demand shocks, size of export demand shocks and the size of the trade ban.

2. Material and methods

2.1. Integrated model structure

Three models are used in an integrated manner to explore the market effects of HPAI epidemics in the Netherlands, as shown in Figure 1. Epidemiological outputs for a given control strategy and index farm are generated by the simulation model InterSpread Plus parameterised for HPAI epidemics in the Netherlands. The epidemiological model is described in chapter 26. The output of the epidemiological model is then used as an input for a conversion model programmed in SPSS, which analyses the output and calculates the direct costs and consequential losses for affected farms. This was described in chapter 27. In addition, the conversion model generates weekly shock parameters for the partial equilibrium model DutchLAY. The shock parameters generated are discussed more fully in section 2.3.

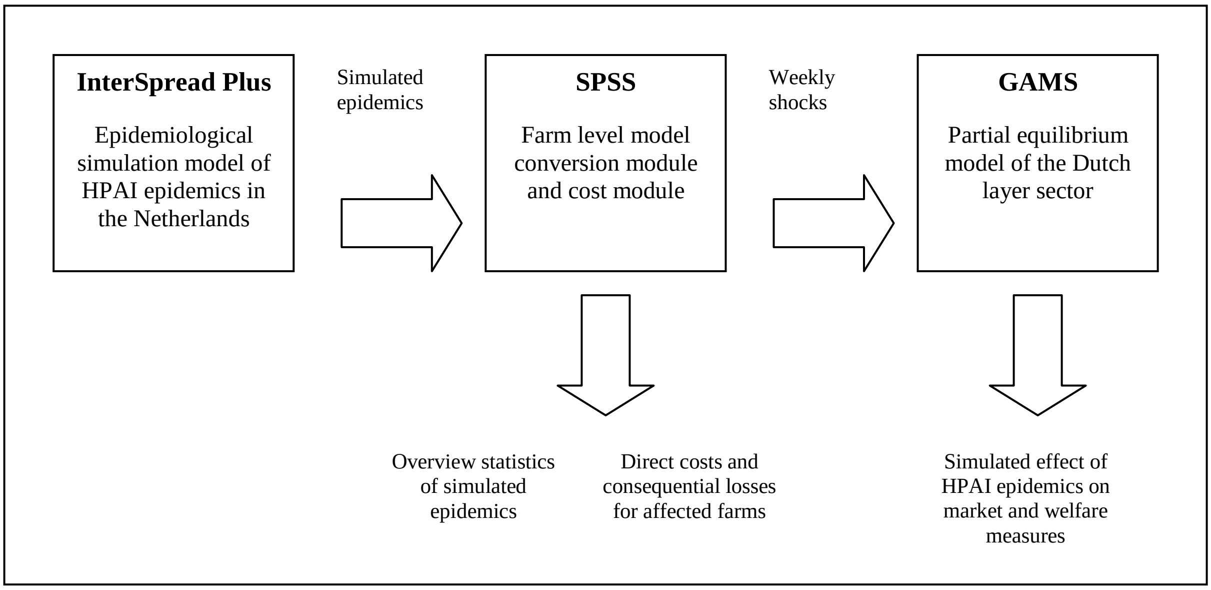

Figure 1. Integrated modelling approach to simulate the economic effects of HPAI epidemics in the Netherlands.

2.2. Partial equilibrium model

A dynamic vertically-linked partial equilibrium model of the poultry sector in the Netherlands was developed. The model is currently restricted to the layer sector but will be extended to include the broiler sector in future research. The baseline is a constant weekly situation based on the year 2006; trend variables are not included. All results are presented as changes from the baseline situation, assuming that exogenous trend variables will be the same in both the with and without situations.

2.2.1 The Dutch layer sector

The Netherlands is the largest exporter of table eggs in the world, with annual exports in 2007 of 5.7 billion eggs (around 63 per cent of production), of which 91 percent were exported to EU member states. Germany is the major trading partner, accounting for 75 per cent of all table egg exports in 2007. Approximately 2.75 billion eggs are supplied to the egg product industry which are processed into 140 thousand tonnes of egg products of which 90 per cent are exported. Germany is also the major trading partner for egg products. Egg products are intermediate products for the food industry. A proportion of all eggs is generally lower quality and supplied to the egg product industry. However, the proportion of eggs supplied to this industry is much higher in the Netherlands than the technical proportion of low quality eggs.. The Netherlands also imports and exports hatching eggs and day old chicks for the layer sector, however international trade in hatching eggs and day old chicks is more important for the broiler sector. In 2006, approximately 31 per cent of exports in day old chicks and hatching eggs were to EU member states.

In contrast to many other countries, the Dutch layer sector is a highly disaggregated chain with varying degrees of cooperation and integration between chain members (see chapter 3 for an overview of the layer production chain). In particular, contracts are in place between breeding farms, hatcheries and rearing farms. The breeding sector consists of breeding organisations with hatcheries, breeding and rearing farms with grandparent and parent layer stock. Hatching eggs produced by breeding farms are set in hatcheries, where the hatching process takes three weeks. Hatcheries supply day old chicks to rearing farms where the pullets are reared until an age of 17 weeks and then transported to laying farms. The production cycle on layer farms lasts for approximately 58 weeks (Anonymous, 2006b). Layer farms generally supply eggs to packing stations, although a small proportion of layer farms supply eggs directly to the egg products industry.

2.2.2 Model structure

The partial equilibrium model has a time period of one week and solves for the equilibrium prices and quantities of products for five levels in the layer sector: a simplified breeding sector, hatcheries, rearing farms, layer farms and packing stations. Five intermediate live products are included in the model: parent hens (*PL*), hatching eggs (*HL*), day old chicks (*DL*), reared pullets (*RL*) and layer hens (*LL*). Two final products are modelled, table (*EL*) and industrial (*IL*) purpose eggs. Final consumer demand is modelled for *EL*, and intermediate demand for *IL* by the egg products industry.

Dynamics are modelled using a stock variable (*ST*) at each level of the live production chain, with the levels vertically linked through output supply (*QS*) and input demand (*QD*) functions. Export (*QX*)and imports (*QM*) are included for day old chicks and for table eggs, reflecting the situation in the sector[1]. Exports and imports are modelled explicitly (instead of a net export approach) for two reasons. Firstly, the nature of imports and exports is generally different. Imports are often associated with long term contracts between companies in neighbouring countries or represent business activities of companies which operate in both countries. Secondly, this approach facilitates the implementation of trade bans and export demand shocks in the model.

The stock variables (and implicitly also output supply) are modelled as a function of lagged dependent variables, introducing a partial adjustment mechanism into the model dynamics. This represents physical production lags at the individual farm level and gradual adjustment at the aggregate level, since the possibilities to change behaviour are dependent on the stage in the production cycle and are fairly limited except near the beginning and end of a production cycle. The coefficient for the lagged dependent variable defines the speed of stock adjustment following a shock. This coefficient is based mainly on physical characteristics of the production process including the length of the production cycle and average mortality rates. The length and nature of shocks associated with HPAI epidemics also play a role in the formation of price expectations. Although epidemics of HPAI in the Netherlands can be expected to be short, the trade and demand shocks and delay until full capacity is reached suggest that price effects may continue much longer. It is unclear how price expectations are formed as a result of such large short term market shocks. For the Dutch pig sector, Mangen and Burrell (2003) assumed that short run supply is not responsive to actual or expected prices as a result of a CSF epidemic, stating that uncertainty about market effects, compensation, and difficulty in obtaining expansion permits are reasons supporting an

[1] Hatcheries usually export and import both hatching eggs and day old chicks. In this model, all trade is converted into day old chick equivalents.

inelastic short run supply. Paarlberg *et al.* (2008) allowed price expectations to be set by the modeller but do not further elaborate on how this is achieved and Rich and Winter-Nelson (2007) used a partial adjustment structure and current prices. Given the shorter production cycles in the poultry industry, it is expected that this industry is more price-responsive than the pig industry. Price expectation formation in such situations is an issue deserving further investigation. In the framework of this paper, price expectations are naïve but some form of partial adjustment structure is introduced via the formulation of the stock and supply variables and via lagged prices.

The structure of the model is presented in Figure 2. The stock (*ST*) variables and flow variables modelled (*QD* and *QS*) for each sector participant (left hand side) are shown. All flow variables are modelled using constant elasticity functions, following Paarlberg *et al.* (2008) and Rich and Winter-Nelson (2007).

The simplified breeding sector uses feed and reared parent hens to produce hatching eggs throughout the production cycle, and spent parent hens for slaughter at the end of the production cycle. Hatcheries use hatching eggs to produce day old chickens at the end of the production cycle. At this level, imports and exports of day old chicks take place. Rearing farms use day old chicks and feed to produce reared pullets ready for laying (reared layers) at the end of the production cycle. Layer farms use reared layers and feed to produce eggs for consumption throughout the production cycle, and spent hens for slaughter at the end of the cycle. Within the model, packing stations are assumed to sort eggs and allocate the total supply to either table eggs or industrial eggs so as to maximise revenue. At this level, import and export of eggs also takes place. Demand for table eggs is modelled for retail/final consumers while intermediate demand for industrial eggs is modelled for the egg product industry.

A few prices are exogenous to the model: the price of reared parent hens, spent layer and parent hens, feed, and the price of alternative products in the final demand function for eggs. The price of reared parent hens is the input price for the simplified breeding sector modelled here. The layer breeding sector is dominated by a few breeding organisations that operate internationally (see chapter 3) with extremely stringent hygiene standards. These companies ensure a relatively stable and elastic supply since supply of reared parent hens is also possible via exports and imports of day old chicks and hatching eggs. Given the complexity involved in modelling this part of the sector in detail, the price of reared parent hens was kept exogenous and a relatively elastic supply of reared parent hens was assumed. The price for spent layer and parent hens is also modelled exogenously. These are very low value residual products whose price shows large fluctuations even during normal market situations.

The price of feed is modelled exogenously. In production terms, feed for layers is approximately 16 per cent of total feed produced in the Netherlands in 2006 (Baltussen and Bolhuis, 2008). The cattle and pig sectors have much larger shares in the feed production. Modelling the feed price endogenously would require an extension of the model to other livestock sectors in the Netherlands.

Lastly the prices of competitive (substitutes and complements) products for eggs in the final demand function for table eggs were modelled exogenously. Evidence from the literature suggests that competitive products play little role in the demand for table eggs. Which products are competitive is also not clear and is likely to be country dependent; products in the literature include meat (pork, chicken, turkey, beef), flour and sugar and breakfast cereals, see for example (Brown and Schrader, 1990; Oczkowski and Murphy, 1999).

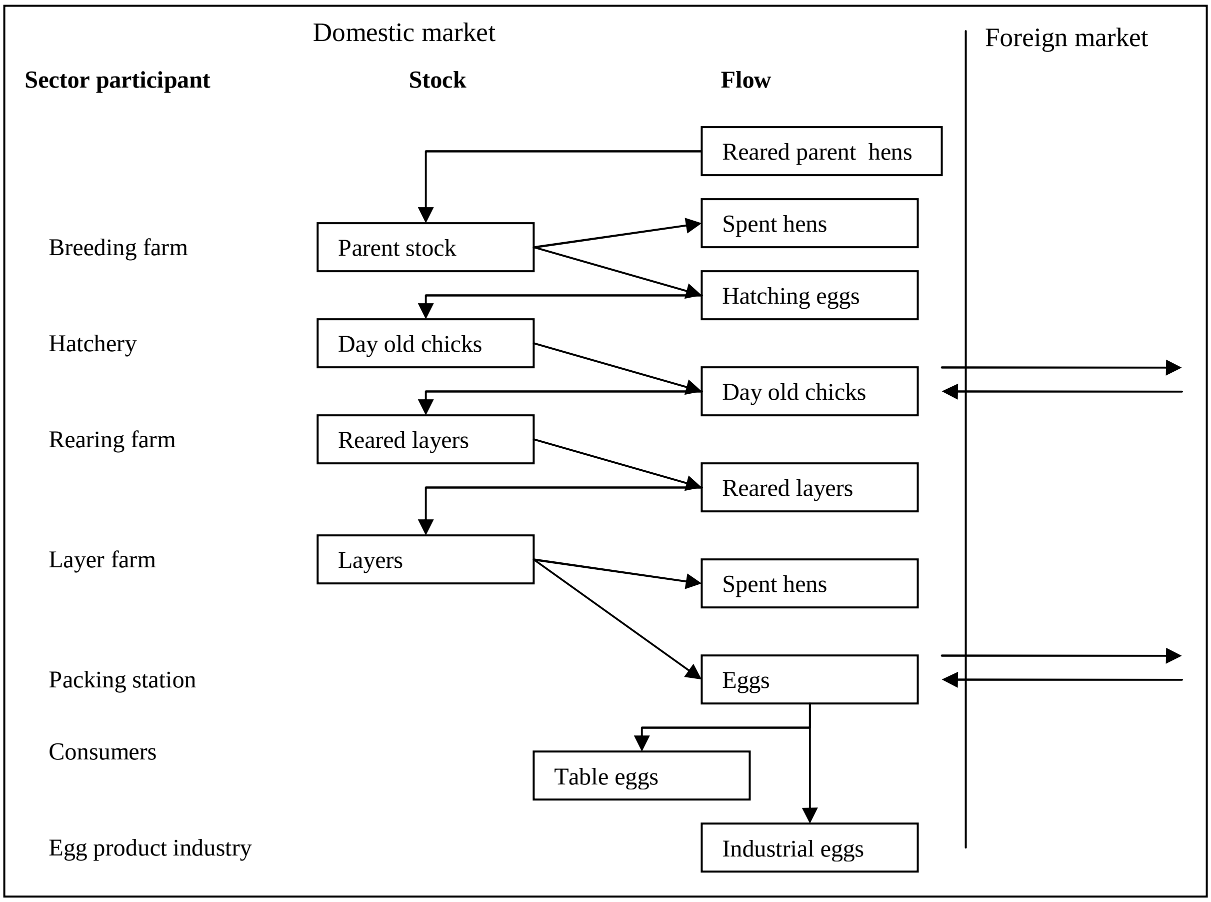

Figure 2. Structure of the partial equilibrium model DutchLAY

The model equations for the partial equilibrium model are presented in Table 1. The four levels in the live poultry production chain are modelled using a similar structure. Equation (1) provides the equation for the stock variables. Current stock (ST_t) depends on the proportion of surviving stock from the previous period, (ST_{t-1}) (where α is a weekly mortality coefficient and *cull* represents the percentage of poultry culled weekly to control the HPAI epidemic), the quantity demanded (QD_t) of the live input and the quantity supplied (*QSt*)of the live output. The stock variables therefore have a partial adjustment structure. Equation (2) represents the supply of live outputs. The supply function consists of an inelastic portion determined purely by lagged stocks, similar to Mangen and Burrell (2003) and a price responsive portion representing the small amount of flexibility that producers have in terms of the timing of output delivery at the end of the production cycle. The coefficient δ represents the proportion of supply which is inelastic and determined purely by the level of lagged stock. The calculation and values of this parameter are given in the appendix. The price responsive proportion of output supply is a function of current and lagged input and output prices. The supply of non-live outputs is given in equation (3); supply of hatching eggs and table eggs is determined only by the current stock. The demand for live inputs is given in equation (4). Demand for live inputs is fully determined by current and lagged prices of inputs and outputs. The equation defining imports and exports are given in equations (5) and (6). Imports and exports are modelled as a function of the domestic and foreign price. The parameter *xdem* in equation (6) is an export demand shock parameter discussed more fully in section 2.3. Equation (7) gives the specification for the adjustment of foreign prices. Foreign prices are specified as a function of the lagged foreign price (with coefficient γ) and lagged imports and exports.

Table 1. Behavioural equations in the partial equilibrium model.

No.	Behavioural equation	Relevant products
(1)	$ST_{i,t} = (1-[\alpha_i + cull_{i,t}])ST_{i,t-1,} + QD_j - QS_k,$	$i \in \{PL, DL, RL, LL\}$ $k \in \{MPL, DL, RL, MLL\}$ $j \in \{PL, HL, DL, RL\}$
(2)	$QS_{k,t} = \delta \frac{1}{cyc_i} ST_{i,t-1,} + QS_k(P_{j,t}, P_{j,t-1}, P_{k,t}, P_{k,t-1}, P_{FL,t}),$	$k \in \{MPL, DL, RL, MLL\}$
(3)	$QS_{n,t} = \phi_i ST_{i,t},$	$n \in \{HL, EL\}$
(4)	$QD_{j,t} \le QD_j(P_{j,t}, P_{j,t-1}, P_{k,t}, P_{k,t-1}, P_{FL,t}),$	$j \in \{PL, HL, DL, RL\}$
(5)	$QM_{l,t} = QM_l(P_{l,t}, P^*_{l,t}),$	$l \in \{DL, EL\}$
(6)	$QX_{l,t} \le xdem_{l,t} \cdot QX_l(P_{l,t}, P^*_{l,t}),$	$l \in \{DL, EL\}$
(7)	$P^*_{l,t} = \gamma_l P^*_{l,t-1} + P^*_l(QX_{l,t-1}, QM_{l,t-1}),$	$l \in \{DL, EL\}$
(8)	$P_{EL,t} \ge MAR \cdot P_{IL,t}$; $P_{EL,t} \ge \cdot \left(1+\frac{1}{\varepsilon_{IL}}\right) \Big/ \left(1+\frac{1}{\varepsilon_{EL}}\right) P_{IL,t}$	
(9)	$QD_{EL,t} = ddem_{EL,t} \cdot QD_{EL}(P_{EL,t}, P_{alt,t})$	
(10)	$QD_{IL,t} = QD_{IL}(P_{IL,t})$	
(11)	$QS_{IL,t} = QS_{EL,t} + QM_{EL,t} - QX_{EL,t} - QD_{EL,t}$	
	Equilibrium equations	
(12)	$QS_{HL,t} = QD_{HL,t} + SLA_{HL,t}$	
(13)	$QD_{DL,t} = QS_{DL,t} + QM_{DL,t} - QX_{DL,t} - SLA_{DL,t}$	
(14)	$QS_{RL,t} = QD_{RL,t} + SLA_{RL,t}$	
(15)	$QS_{IL,t} = QD_{IL,t}$	
	Shock variables	
(16)	$QD_{j,t} \le empty_{j,t} \cdot QD_{j,t=base}$	$j \in \{PL, HL, DL, RL\}$
(17)	$QX_{l,t} \le dom_{l,t} \cdot QS_{k,t} + QM_{l,t}$	$l, k \in \{DL, EL\}$
(18)	$QX_{l,t} \le pro_{l,t} \cdot QS_{k,t} + QM_{l,t} - QD_{j,t}$	$j, k, l = EL$
(19)	$QX_{l,t} \le ban_{l,t} \cdot QX_{l,t=base}$	$l \in \{DL, EL\}$

If *i=PL* then *j=PL*, *k=MPL*, *n=HL*; If *i=DL* then *j=HL*, *k=DL*; If *i=RL* then *j=DL*, *k=RL*; If *i=LL* then *j=RL*, *k=MLL*, *n=EL*.
Where *ST* = stock, *QS* = quantity supplied, *QD* = quantity demanded, *QM* = quantity imported, *QX* = quantity exported, *P* = domestic price, *P** = foreign price, *SLA* = slack variable.
Where *PL* = parent layers, *HL* = hatching eggs, *DL* = day old chicks, *RL* = reared layers, *LL* = layers, *EL* = table eggs, *IL* = industrial eggs.
Where *i*=the vector of stock variables, *k* = the vector of live output variables, *j* = the vector of live inputs, *n* = the vector of egg-type outputs, *l* = the vector of internationally traded products, and *t*= the vector of time periods.
Where ε_{EL} = own price elasticity of demand for table eggs, ε_{EL} = own price elasticity of demand for industrial eggs, δ = the proportion of the supply which is inelastic in the short run, α = weekly (nomal) mortality rate, φ= number of eggs laid per hen per week, *cyc* = length of the production cycle in days, γ = the coefficient of lagged foreign price in the foreign price equation.
Where cull, *xdem*, *ddem*, *empty*, *dom*, *pro*, and *ban* are all shock parameters associated with HPAI outbreaks. These are explained in section 2.3.

The market for industrial eggs is modelled as a large domestic market with highly elastic demand. Industrial eggs provide a secondary 'lower value' market where large quantities of eggs can be supplied at a relatively constant price. No distinction between trade in table and industrial eggs is made in the national trade statistics. Therefore it is assumed that all trade is in table eggs and that the packing industry allocates eggs as either table eggs or industrial eggs in order to maximise revenue. Although the Netherlands is a large exporter of egg products, this is not included in the model. The decision problem for packing stations is modelled as choosing the level of eggs supplied to the table egg market so as to maximise total revenue, where the prices of table eggs and industrial eggs are a decreasing function of the quantity of eggs sold on these markets. Manipulation of the first order condition for this problem (see appendix) leads to the price relationship in equation (8) in Table 1, where ε_{EL} and ε_{IL} refer to the own-price demand elasticity in the table eggs and industrial eggs markets respectively. Given the constant elasticity functions used, this leads to a constant price margin between table eggs and industrial eggs. The demand function for table eggs is given in equation (9) as a function of own price and the prices of alternative products. No In the current version, elasticities for prices of alternative products are zero. Empirical applications often find either very weak or no evidence for substitutes and complements in the demand for table eggs (see for e.g. Oczkowski and Murphy, 1999). The parameter *ddem* in equation (9) represents a domestic demand shock in response to a HPAI epidemic and is discussed more fully in section 2.3. The demand function for industrial eggs is given in equation (10). No output prices or prices for substitute inputs are modelled for this sector. The supply of industrial eggs is modelled as a residual as shown in equation (11).

Market equilibrium conditions are presented in equations (12-15) in Table 1.In the market equilibrium conditions a slack variable is included for products in the live poultry chain. Large epidemics of HPAI often result in temporary disequilibrium in the market, where products are either stored or destroyed. A slack variable is included to allow for temporary disequilibrium in supply and demand in the case of large shocks and to ensure that prices do not become negative. Minimum prices are included in the model and reflect the value of products in low value alternative uses (e.g. hatching eggs allocated as industrial eggs, or reared layers as spent hens). If a shock is large enough to ensure that a minimum price is reached, the slack variable is activated. Slack variables are included in the objective function with a large weight to ensure that they are only activated if shocks are so extreme that normal equilibrium in the market cannot be achieved. A slack variable is not modelled in the egg market since the market for industrial eggs already plays this role.

Equations (16-19) in Table 1 present additional constraints which are implemented to model the different shocks associated with HPAI epidemics. These are discussed in section 2.3.

Surplus measures are calculated for consumers, producers as a whole and for individual subsectors including breeding farms, hatcheries, rearing farms, layer farms, packing stations and the egg product industry. The equations for each surplus measure are presented in equations (20-27) in Table 2. Producer surplus is calculated as revenues minus variable costs (since not all variable costs are measured in this framework, this is a proxy for true producer surplus but remains relevant in terms of changes from the baseline). Consumer surplus is calculated following (Varian, 1990). Since changes in consumer surplus arise in this situation from both shifts along and shifts of the demand curve, the impact on consumer surplus is measured as the difference between the total consumer surplus for each scenario and the baseline (see equation 26). Due to the constant elasticity specification, a maximum price was needed in order to calculate a finite consumer surplus measure, this was set at 1 million euro. Weekly feed input per stock unit, v, was calculated using technical information in (Anonymous, 2006b). Revenues for layer farms were calculated assuming that packing stations pay the price of table eggs minus a discount, μ, and therefore that packing stations absorb the risks associated with the allocation of eggs as table eggs or industrial eggs. The discount, μ, is assumed to be half a cent per egg. Prices and quantities of outputs for the egg products industry were not available in the model, therefore a constant margin, ρ, of 20 per cent was assumed. A net present value measure of each surplus (given in equation 27 for consumer surplus) is calculated using an annual discount rate of 4 per cent converted to a weekly rate and a three year time horizon.

Table 2. Calculated surplus measures for each subsector of the Dutch layer sector.

No.	Surplus equation
(20)	$PS_{PAR,t} = P_{MPL,t} \cdot QS_{MPL,t} + P_{HL,t} \cdot QS_{HL,t} - P_{PL,t} \cdot QD_{PL,t} - P_{FL,t} \cdot \nu_{PL} \cdot ST_{PL,t}$
(21)	$PS_{HAT,t} = P_{DL,t} \cdot QD_{DL,t} + P^{*}_{DL,t}\left(QX_{EL,t} - QM_{EL,t}\right) - P_{HL,t} \cdot QD_{HL,t}$
(22)	$PS_{REAR,t} = P_{RL,t} \cdot QS_{RL,t} - P_{DL,t} \cdot QD_{DL,t} - P_{FL,t} \cdot \nu_{RL} \cdot ST_{RL,t}$
(23)	$PS_{LAY,t} = P_{MLL,t} \cdot QS_{MLL,t} + (1-\mu)P_{EL,t} \cdot QS_{EL,t} - P_{RL,t} \cdot QD_{RL,t} - P_{FL,t} \cdot \nu_{LL} \cdot ST_{LL,t}$
(24)	$PS_{PACK,t} = P_{EL,t} \cdot QD_{EL,t} + P^{*}{}_{EL,t} \cdot \left(QX_{EL,t} - QM_{EL,t}\right) + P_{IL,t} \cdot QS_{IL,t} - (1-\mu)P_{EL,t} \cdot QS_{EL,t}$
(25)	$PS_{IND,t} = \rho \cdot \left(P_{IL,t} \cdot QD_{IL,t}\right)$
(26)	$CS_t = \frac{A}{\varepsilon_{EL}+1} \cdot \left(P_{EL,\max}{}^{\varepsilon_{EL}+1} - P_{EL,t}{}^{\varepsilon_{EL}+1}\right)$
(27)	$NPV(CS_t) = \sum_t \frac{CS_t}{(1+r)^t}$ where $0.04 = (1+r)^{52} - 1$

Where *PS* = producer surplus, *CS* = consumer surplus, *ST* = stock, *QS* = quantity supplied, *QD* = quantity demanded, *QM* = quantity imported, *QX* = quantity exported, *P* = domestic price, *P** = foreign price.
Where *PL* = parent layers, *HL* = hatching eggs, *DL* = day old chicks, *RL* = reared layers, *LL* = layers, *EL* = table eggs, *IL* = industrial eggs.
Where ρ = constant margin for egg product industry, ν = weekly feed input per stock unit, μ = discount factor for table eggs in terms of price paid to layer farms, ε_{EL} = own price elasticity of demand for table eggs, ε_{EL} = own price elasticity of demand for industrial eggs.

2.2.3 Data

A base week data set was constructed from various sources including annual and monthly statistics of the Dutch Product board for Poultry, Poultry meat and Eggs (PVE), the Central Bureau for Statistics and standardised technical information (Anonymous, 2006b). Data were adjusted to ensure a consistent data set. The constructed base week data set is presented in Table A1 in the appendix. Elasticities were taken from literature where available and were otherwise plausible estimates which resulted in reasonable simulation results. The level of disaggregation and time period used in this model make it difficult to use elasticity estimates in the literature. The final demand elasticity for table eggs was -2.5; this is much more elastic than estimates in the literature; however it is similar to the elasticity for poultry meat estimated by Beach *et al.* (2008) using weekly data. Elasticities for shorter time periods (e.g. weekly) are usually much more elastic than longer time periods.

2.1. Modelling shocks associated with the control of HPAI epidemics

The model incorporates supply and demand shocks, trade bans and additional constraints reflecting potential channelling of poultry and products with a particular status, e.g. poultry and products originating from an affected area or vaccinated poultry and products. These shocks enter the model either as parameters in the behavioural equations presented in Table 1 or as additional constraints. Outputs from the conversion module in SPSS used to create shocks are the weekly percentage of different poultry types which are culled, located inside a movement restriction zone (MRZ), empty and under restocking restrictions or vaccinated. In addition, the SPSS module provides the week in which the epidemic is first detected, the week in which all control measures are lifted (end of the epidemic), and if relevant, the week in which vaccination begins and the last week in which vaccinated poultry are still in the market.

2.3.1 Supply shocks

Two types of supply shocks are modelled; the percentage of poultry which are culled per week as part of the HPAI control strategy and an additional constraint on the demand for live inputs to represent restrictions on restocking for farms located inside a MRZ. These shocks enter the model at each level in the live poultry supply chain. The culled poultry variable enters the stock equations as an additional mortality parameter (the *culled* parameter in equation 1) while the restocking restriction enters the model as a constraint on the demand for live inputs (see equation 16). The *empty* parameter represents the number of poultry places at each time period located inside a MRZ for which restocking is forbidden. This formulation assumes that the sector is at full capacity in the base period. The parameters *culled* and *empty* are calculated directly from the output of the SPSS conversion module.

2.3.2 Demand shocks

Demand shocks are constructed based on the four parameters concerning the timing of the beginning and end of simulated epidemics and the vaccination programme (if relevant). Demand shocks enter the model as a parameter *ddem* in the demand function for table eggs (final consumers) and as a parameter *xdem* in the export demand functions for table eggs and day old chicks. For table eggs, the model allows for two types of demand shifts, the first relates to the response of consumers to a HPAI epidemic (basic demand shock) and is considered to be independent of the control strategy, while the second is a specific response to vaccinated products (vaccination demand shock). The parameter *ddem* is assumed to be equal to the maximum of either demand shock at any period in time. No export demand shock is modelled for day old chicks in this chapter, therefore the parameter *xdem* for day old chicks always has a value of 1. The parameter *xdem* for table eggs is set relative to the domestic demand response; export partners have either no export demand shock, the same as Dutch consumers, or the response is lower or higher than Dutch consumers.

Following Beach *et al.* (2008), the basic demand shock assumes that demand drops sharply in the first two weeks following notification of an epidemic, to reach its lowest level two weeks after epidemic notification. For the duration of the epidemic demand recovers slowly, after the authorities notify the end of the epidemic demand recovers quickly. This pattern is governed by four parameters which are set for each scenario: the maximum demand shift, the shift in the first week, the speed of recovery during the epidemic and lastly the speed of recovery after the epidemic. The vaccinated demand shock represents a constant shift in demand during the period for which vaccinated products exist in the market. In figure 2, both demand shock patterns are presented for one possible scenario, corresponding to a maximum basic demand shock of 20 per cent and a maximum vaccination demand shock of 25 per cent. In this scenario, The outbreak begins in week 5 and ends in week 25, while vaccination begins in week 6 and vaccinated products remain in the market until week 45. Different basic demand shock scenarios are created by varying the maximum demand shock parameter while holding other parameters constant. Basic demand shock scenarios differ therefore according to the size of the shock but not the temporal pattern of the shock.

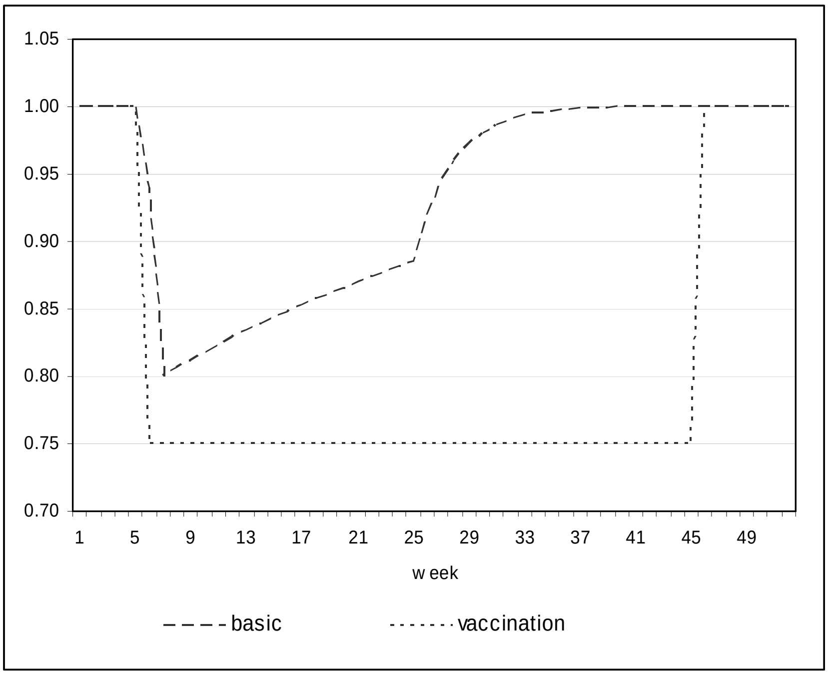

Figure 2. Values of the basic and vaccination demand shock parameters over time for a single scenario.

2.3.3 Trade bans

A trade ban is implemented in the model as a constraint on the volume of exports, where the constraint is defined as a percentage, *ban*, of the base period exports (see equation 19). It is assumed that for the first week of an epidemic a full export ban is implemented for the export of all poultry and poultry products. This one week export ban occurs regardless of the scenario, however the timing of the week in which the export ban occurs (the week that the first outbreak is notified) is scenario dependent. Thereafter, export bans are restricted to the percentage of exports to third (non-EU countries) countries (69 percent for day old layer chicks and 7 per cent for table eggs). EU member states are covered by EU regulations which state that all products outside of a restricted area may be continued to be traded among member states. Any demand response from EU trading partners occurs therefore via the parameter *xdem* in the export demand functions (equation 6).
The length of trade bans implemented by a trade partner is dependent on a number of factors including the degree of dependency of the importing country, political negotiations, and objective and subjective risk factors. Trade bans may last anywhere from a few months to several years and may become less restrictive over time. In this paper a simplified approach is taken to capture the effect of export bans on live poultry and poultry products. Third countries are assumed either to follow the EU regulations (i.e. trading partners are satisfied that the EU regulations are sufficient to ensure that no HPAI virus is imported) or to place an export ban on day old chicks and table eggs for the length of one year following the notified end of the epidemic. Scenarios differ according to the proportion of exports which fall in either option and consider therefore only the magnitude dimension of trade bans and not the length.

2.3.4 Channelling restrictions

Equations (17-18) provide additional constraints which model the effect of channelling restrictions on particular products. The parameter *dom* in equation (17) provides the percentage of the weekly supply of a product which is restricted to the domestic market, while the parameter *pro* in equation (18) is only relevant for table eggs and provides the percentage

of the weekly supply of eggs which is restricted to the processed market (industrial eggs). Using the equilibrium conditions which define the relationship between supply and exports; the supply restrictions are converted into equivalent constraints on exports.
During an epidemic, live poultry originating from a MRZ are restricted to the domestic market, while products originating from non-infected farms located inside a MRZ are assumed to be restricted to processed products (i.e. industrial eggs). It is also possible that additional restrictions will be put in place for vaccinated poultry and products. Vaccinated poultry are restricted to the vaccination area (and therefore the domestic market) under EU legislation, however no compulsory restrictions for products of vaccinated poultry exist. Potential voluntary restrictions include the restriction of all vaccinated products to the domestic market or to the processed product market. Additional channelling restrictions on vaccinated products are considered as a potential policy to reduce the severity of trade bans or export demand shocks in response to a vaccination policy. Restricting live poultry (day old chicks) to the domestic market implies that the domestic demand must be at least equal to the supply of day old chicks from vaccinated parent flocks, while restricting eggs from vaccinated layers to the domestic market implies that the sum of domestic demand for table eggs and demand for industrial eggs must be greater than or equal to the supply of vaccinated eggs. A channelling policy focused on channelling particular products to the processed market is more restrictive, in this case the number of vaccinated eggs must be smaller than or equal to the demand for industrial eggs.
Three channelling policies are considered in this paper. The first, CompONLY, concerns compulsory measures including the restriction of live poultry originating from an MRZ to the domestic market, the restriction of vaccinated poultry to the domestic market and the restriction of products from poultry originating from an MRZ to the processed market. The second, VacDOM, is the same as CompONLY with an additional restriction that products from vaccinated poultry are restricted to the domestic market. The third, VacPRO, is the same as CompONLY with the additional restriction that products from vaccinated poultry are restricted to the processed market.

2.4. Scenarios

An explorative scenario design is used to ensure that scenarios cover the range of potential shocks associated with simulated epidemics and that all potentially feasible combinations of different shocks can be generated.
Scenarios are generated from eight different variables: strategy, density, size, channelling policy, basic demand shock, vaccination demand shock, export demand shock and trade ban. The first three variables dictate which scenario is implemented in the epidemiological simulation model and which raw input is generated by the SPSS conversion model and used as the base for generating the shock variables. The last five variables are constructed in a first processing module in the DutchLAY model, based on the inputs from SPSS. For each scenario, the shocks *culled*, *empty*, *ban*, *domestic*, *processing*, *ddem* and *xdem* are constructed over time for the relevant products as outlined in section 2.3. The generation of input data in SPSS, the construction of the shock variables in GAMS and the running of the model for each scenario occurs automatically using a batch procedure. Scenarios are generated by specifying the combinations of the scenario variables in a tuple in GAMS.

Table 3. Description of variables used to generate scenarios.

Variable	Options	Description	Values
Strategy	EUmin BaseNL RV3+1km	The control strategy used in the epidemiological simulation model.	See chapter 27
Density	DPPA MPPA SPPA	Represents the farm density surrounding the index farm used in epidemiological simulations.	See chapter 27
Size	OutbreakSMA OutbreakMED OutbreakLAR	Represents the iteration for which output of the simulation model is used as input to shocks. Iterations are ranked according to number of infected farms.	5^{th} 50^{th} 95^{th}
Channelling policy	CompONLY VacDOM VacPRO	Represents the marketing restrictions on poultry and products either vaccinated or originating from the MRZ.	See section 2.3.4
Basic demand shock	BasicDemandNONE BasicDemand MED BasicDemandLAR	Size of the maximum basic shock parameter in the basic demand shock function.	0.00 0.20 0.40
Vaccination demand shock	VacDemandNONE VacDemandSMA VacDemandMED VacDemandLAR	Size of the maximum vaccination shock parameter in the vaccination shock function.	0.00 0.25 0.50 0.75
Export demand shock	ExpDemandNONE ExpDemandUNDER ExpDemandSAME ExpDemandOVER	Size of export shock relative to domestic demand shock.	0.00 0.50 1.00 1.50
Trade ban	FollowEUNONE FollowEU1THIRD FollowEU2THIRD	Proportion of third countries who follow the EU in terms of implementing trade bans.	0.00 0.33 0.66

3. Results

Results are presented as percentage changes from the baseline for a time horizon is three years. The simulated epidemic begins on day 1 of this time period, the week in which the outbreak of HPAI is notified is an output of the simulated epidemic. For the comparison of control strategies in section 3.1. results are presented in terms of the temporal pattern for stocks and prices and the net present value of welfare effects. For all other scenarios (sections 3.2-3.4), only the welfare effects are presented.

3.1. Comparison of control strategies in a DPPA and SPPA

In this section, a vaccination and non-vaccination strategy are compared for virus introduction in a DPPA and SPPA. The non-vaccination strategy is BaseNL (see chapter 27 for more detail), which includes pre-emptive culling in a radius of one kilometre around detected farms. The vaccination strategy RV3+1km is similar to BaseNL, but with the addition of ring vaccination in a ring of 1-3 kilometres around detected farms. The simulated epidemiological

effects, direct costs and consequential losses for affected farms for these two strategies were discussed in chapter 27.
The scenario variables channelling policy (CompONLY), basic demand shock (BasicDemandNONE), vaccination demand shock (VacDemandNONE), export demand shock (ExpDemandSAME) and trade ban (EUNONE) were kept constant for these simulations. This represents scenarios where only the compulsory channelling measures are applied, there are no demand shocks and export bans are at there maximum level (i.e. all third countries implement a trade ban lasting for one year after the epidemic). In Table 4 the main epidemiological characteristics of the epidemiological simulation results used for each scenario are presented. These are aggregated results only and do not reflect the distribution amongst different members in the sector.

Table 4. Epidemiological characteristics for the scenarios based on strategy, density and size

Strategy	Density	Size	Epidemic size[1]	Epidemic length[2]	Farms in MRZ
BaseNL	DPPA	MED	267	128	1339
RV3+1km	DPPA	MED	194	110	1023
BaseNL	DPPA	LAR	371	155	1514
RV3+1km	DPPA	LAR	316	113	1640
BaseNL	SPPA	MED	2	63	93
RV3+1km	SPPA	MED	2	63	93
BaseNL	SPPA	LAR	15	109	369
RV3+1km	SPPA	LAR	10	100	226

1. Number of infected farms
2. Length of epidemic in days

The location of the epidemic in terms of farm density is an important determinant for the resulting size of an epidemic. Epidemics in DPPAs are characterized by large numbers of infected and depopulated farms (in this example a medium sized epidemic in a DPPA results in 194 or 267 infected farms depending on the control strategy). Even with a stringent control strategy, large epidemics are expected in these areas. In contrast, epidemics in SPPAs are characterized by only a few infected farms (2 for a medium sized epidemic and 10-15 for a large sized epidemic). In terms of length, epidemics in a DPPA are longer, however large epidemics in a SPPA are almost as long as the medium-sized epidemic in a DPPA.
The dynamic effects of simulated HPAI epidemics on stocks and prices of live poultry and eggs are shown in Figures 3-5, for the strategies BaseNL (no vaccination) and RV1+3km (vaccination) for a medium-sized epidemic originating in a DPPA. Both simulated epidemics show similar patterns. During the epidemic, the stocks of all live poultry decline rapidly due to culling of infected and at-risk farms however the speed of decline and the minimum levels reached are different for stocks of layers, reared layers, day old chicks and parent hens. Once the epidemic (week 19 for the non-vaccination strategy shown in Figure 3a) is finished and all movement restrictions have been lifted then restocking begins. The speed of restocking is highest for parent stock and day old chicks; for day old chicks the quick recovery is facilitated by imports and for parent stock this reflects the assumption of a relatively elastic market. For parent stock and day old chicks, capacity returns to its pre-epidemic level about twenty weeks after the epidemic is finished but then declines again in response to lower prices for hatching eggs and day old chicks. Once the export ban is lifted prices increase sharply and then return to pre-epidemic levels and capacity increases to the pre-epidemic level.

The pattern of recovery for reared layer stock is different, with pre-epidemic levels being achieved approximately 30 weeks after restocking begins. At this stage, supply of reared layers has fully recovered but demand is still high since the layer stock remains below pre-epidemic capacity. A situation of higher prices for reared layers and relatively low prices for day old chicks ensures capacity is temporarily above its pre-epidemic level until the layer stock is fully recovered. The layer stock is the slowest to recover, with pre-epidemic capacity still not achieved after three years. These results are under the assumption that all farms are able to begin restocking as soon as the last movement restriction is lifted. A more gradual restocking would lead to lower prices but also a more gradual recovery of the stocks.

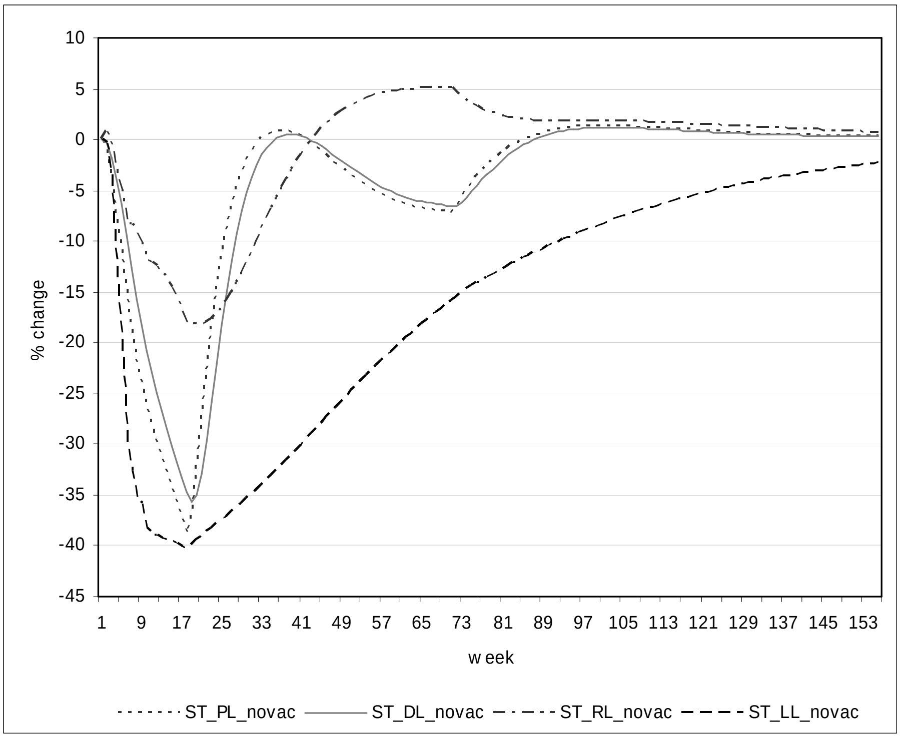

Figure 3a. Relative change in stocks of parent hens (*PL*), day old chicks (DL), reared layers (*RL*) and layers (*LL*) under the BaseNL (no vaccination) strategy for a medium sized epidemic originating in a DPPA.

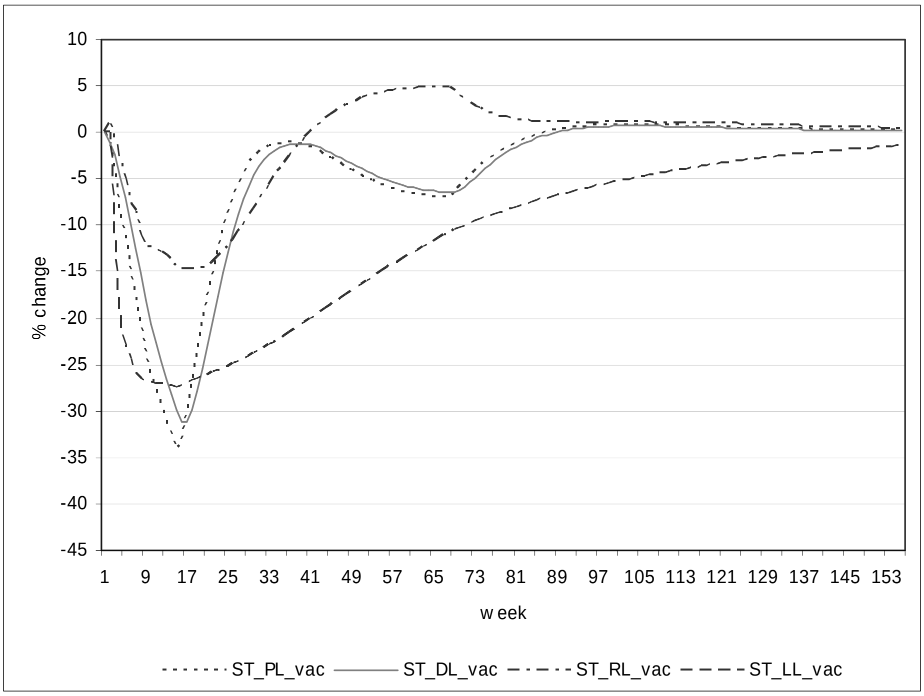

Figure 3b. Relative change in stocks of parent hens (*PL*), day old chicks (DL), reared layers (*RL*) and layers (*LL*) under the RV3+1km (vaccination) strategy for a medium sized epidemic originating in a DPPA.

The prices of live poultry (Figures 4a-b) show a similar pattern for both strategies with a collapse of prices during the epidemic, a sharp temporary peak once movement restrictions are lifted and restocking begins, and another much smaller peak once the export ban is lifted. The pattern is similar for hatching eggs and day old chicks but slightly different for reared layers. At the beginning of the epidemic the price of hatching eggs collapse due mainly to restocking restrictions for hatcheries located within the MRZ. This leads to a relative over supply, the price reaching its minimum level and the slack variable (e.g. eggs which are destroyed or supplied to the egg product industry) absorbing the over supply. This situation continues until the end of the epidemic, when restocking of hatcheries and limited supply of hatching eggs from the smaller parent stock causes a large peak in the price of hatching eggs. This price peak is smaller for day old chicks, since the rearing stock was less affected during the epidemic and imports are also available to meet the demand for day old chicks. Although the price of reared layers declines during the epidemic, it does not collapse (as was the case for hatching eggs and day old chicks), suggesting that although the drop in demand is larger than the decrease in supply, this mismatch is not so large that the market is in disequilibrium. Once the pre-epidemic capacity is reached for parent stock and day old chicks, the supply of hatching eggs and day old chicks is at pre-epidemic levels while the demand remains lowers due to the export ban on day old chicks. This leads to a situation of lower prices during the period of the export ban. The lifting of the export ban leads to a temporary positive price shock which gradually declines to pre-epidemic levels. In contrast, the price of reared layers remains above the pre-epidemic level; suggesting that the lower demand dominates the increased supply. The price of reared layers also shows some affect of the lifting of the export ban for day old chicks and table eggs, although this effect is dampened considerably.

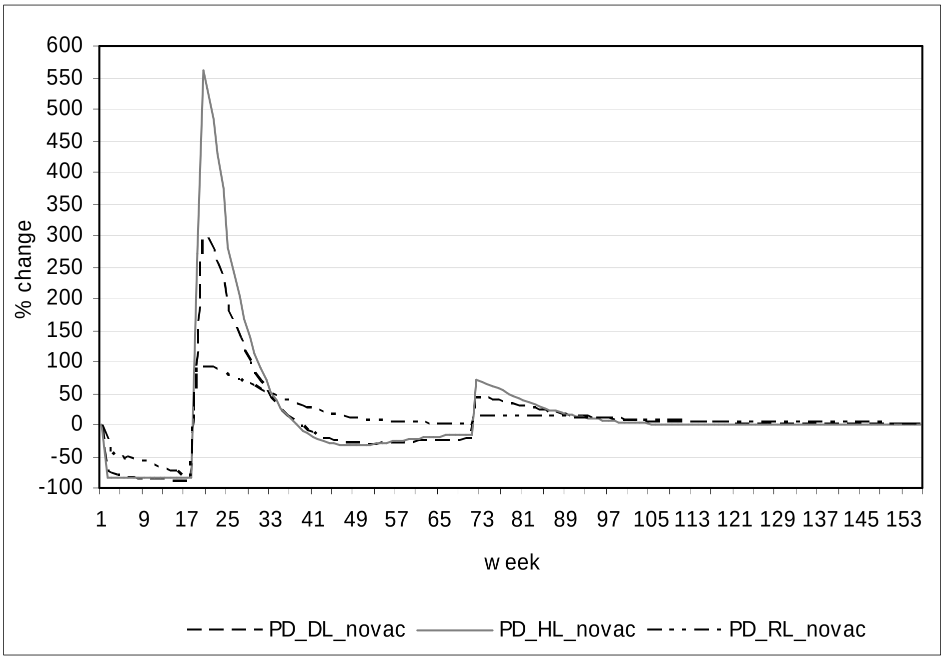

Figure 4a. Relative change in prices of hatching eggs (*HL*), day old chicks (*DL*) and reared layers (*RL*) under the BaseNL (no vaccination) strategy for a medium sized epidemic originating in a DPPA.

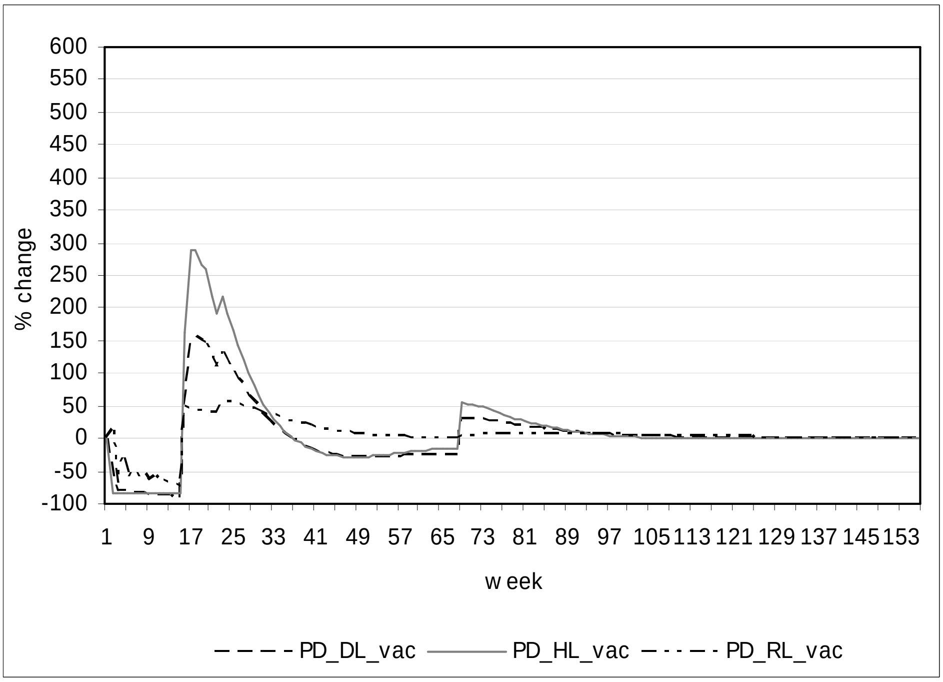

Figure 4b. Relative change in prices of hatching eggs (HL), day old chicks (DL) and reared layers (RL) under the RV3+1km (vaccination) strategy for a medium sized epidemic originating in a DPPA.

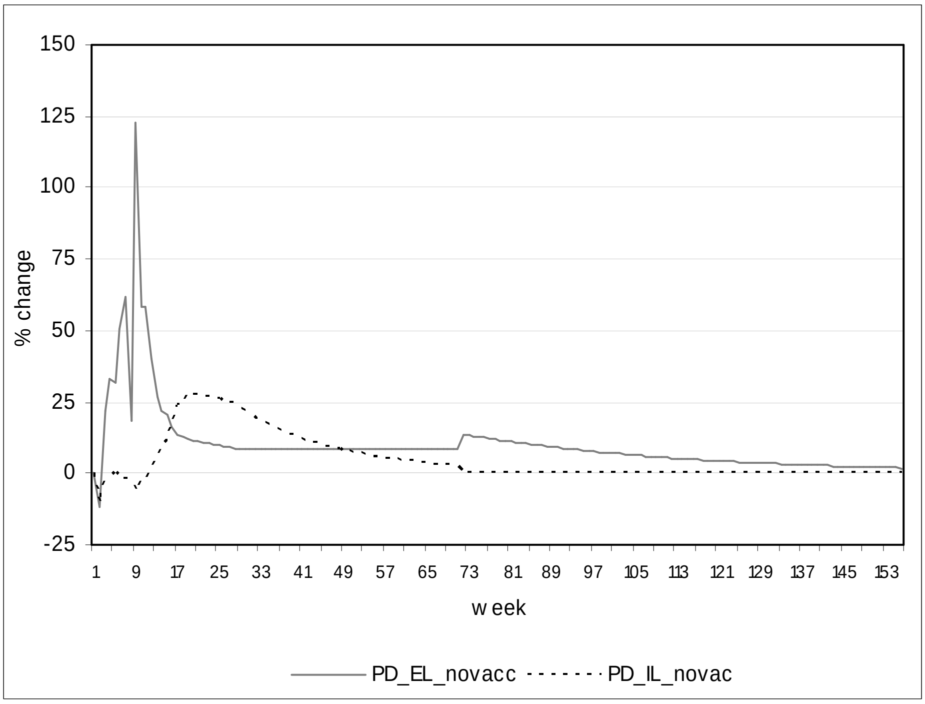

Figure 5a. Relative change in the price of table eggs (*EL*) and industrial eggs (*IL*) under the BaseNL (no vaccination) strategy for a medium sized epidemic originating in a DPPA.

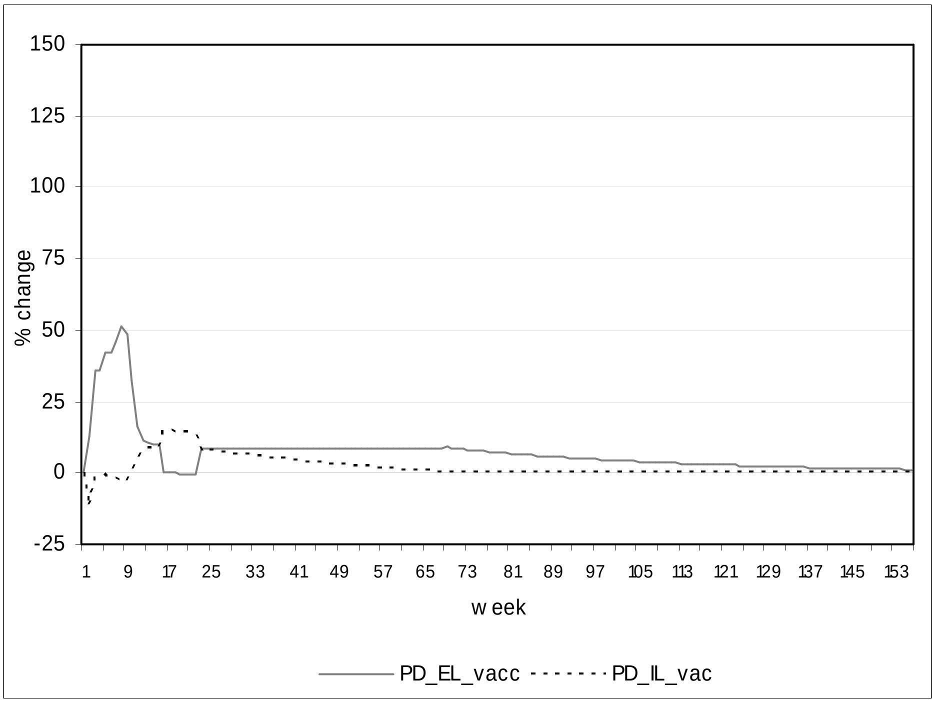

Figure 5b. Relative change in the price of table eggs (EL) and industrial eggs (IL) under the RV3+1km (vaccination) strategy for a medium sized epidemic originating in a DPPA.

For the no-vaccination strategy shown in Figure 5a, the price of table eggs initially drops in response to the short-lived total export ban. These eggs are temporarily supplied to the egg product industry leading to a decline in the price of industrial eggs. Once export to EU member states recovers, the price of eggs increases sharply as a result of the lower supply.

The no-vaccination strategy shows a large temporary drop around week 9 which is a result of the channelling restriction on eggs originating from the MRZ. As the price of table eggs begins to decrease, the quantity demanded increases and most of the available egg supply is directed to table eggs, leading to an increase in the price of industrial eggs. Until the export ban is lifted, the price of table eggs remains fairly constant at about 10 per cent above pre-epidemic levels, while the price of industrial eggs declines. This reflects a situation where the supply of table eggs is kept fairly constant and the increase in the supply of eggs is directed to the industrial market. For the non-vaccination strategy in Figure 5a, the lifting of the export ban leads to a temporary positive price shock which gradually returns to pre-epidemic levels. For almost the entire three year period, the simulated price of table eggs is above pre-epidemic levels.

The pattern for the development of stocks and the prices of live poultry is similar for the vaccination and non-vaccination strategies depicted. The decline in the layer stock is much larger under the BaseNL strategy. Both the epidemic patterns show a similar decline in the stocks of parent hens, day old chicks and reared layers, with the non-vaccination strategy showing slightly larger decreases. Once the epidemic is finished (week 17 under the vaccination strategy and week 19 for the non-vaccination strategy) restocking of empty farms begins. The demand from empty layer farms is much higher under the non-vaccination strategy, while the supply is similar under both strategies; this leads to a situation of much higher prices for hatching eggs, day old chicks and reared layers in the non-vaccination strategy, as seen in Figures 4a-b. In contrast, the pattern for the price of eggs is different under the two strategies; with the vaccination strategy showing a much smoother pattern over time. This suggests that the price of eggs is sensitive not only to the size and length of a epidemic but also to the distribution of affected farms across the layer production chain.

In Table 4, the welfare effects for different stakeholder groups are shown for combinations of strategy, density and representative epidemic size. The results in Table 4 show that the producers as an aggregate lose as a result of an epidemic, while consumers either gain or lose depending on the location of the epidemic. In the case of an epidemic in a SPPA, the supply shift caused by depopulation and restrictions on restocking is smaller than the demand shift from the export ban; resulting in a situation in which prices decrease. This decrease in prices leads to a gain for consumers in comparison to the no-epidemic situation. In the case of an epidemic in a DPPA, the supply shift appears to dominate the demand shifts; leading to an increase in prices. Although prices are generally higher in the DPPA scenarios, aggregate producer surplus is lower suggesting that the reduction in production dominates the benefits of higher prices. The welfare effects for the different stakeholder groups for epidemics in a DPPA indicate that for layer farms, parent farms and rearing farms the effect of higher prices dominates the loss due to decreased production; leading to an overall gain relative to the no-epidemic situation. Hatcheries, packing stations and the egg product industry lose relative to the no-epidemic situation. Hatcheries and packing stations are also directly effected by the export ban; particularly hatcheries who are more dependent on exports to third countries. The relative gains and losses for the different subsectors are reversed for epidemics in a SPPA, with the exception of hatcheries which lose regardless of the location of the epidemic.

Table 4. Percentage change in the net present value of consumer and producer surplus for sector participants for each scenario based on strategy and density.

No.	Strategy	Density	Size	CS	PS	HAT	IND	LAY	PACK	PAR	REAR
1	BaseNL	DPPA	MED	-13.92	-16.26	-54.72	-24.21	35.26	-103.78	55.85	8.72
2	RV3+1km	DPPA	MED	-10.87	-10.83	-49.64	-13.40	38.74	-87.56	34.78	7.49
3	BaseNL	DPPA	LAR	-16.84	-19.18	-60.95	-28.29	31.74	-122.74	45.23	21.70
4	RV3+1km	DPPA	LAR	-13.07	-16.27	-48.52	-23.97	25.85	-96.48	52.02	11.09
5	BaseNL	SPPA	MED	9.47	-6.60	-64.04	4.13	-45.54	49.04	-31.41	-10.91
6	RV3+1km	SPPA	MED	9.47	-6.60	-64.04	4.13	-45.54	49.04	-31.41	-10.91
7	BaseNL	SPPA	LAR	7.77	-7.10	-69.86	3.87	-32.88	35.64	-21.83	-13.70
8	RV3+1km	SPPA	LAR	9.28	-6.76	-64.59	3.16	-46.53	50.36	-38.04	-10.43

Where CS = consumer surplus, PS = aggregate producer surplus, HAT= producer surplus for hatcheries, IND = producer surplus for egg product industry, LAY = producer surplus for layer farms, PACK = producer surplus for packing stations, PAR = producer surplus for parent farms, REAR = producer surplus for rearing farms.

The control strategy chosen has an impact on the welfare of stakeholders since this affects the length and size of an epidemic and the distribution of affected farms across the layer production chain. Comparing scenarios 1 and 2 in Table 4 for a medium sized outbreak in a DPPA, suggests that consumers, aggregate producers, hatcheries, the egg product industry, layer farms and packing stations were all better off under the simulated vaccination strategy (which was shorter, smaller and more evenly distributed); while parent farms and rearing farms were better off under the non-vaccination strategy. The situation is similar for large outbreaks in a DPPA, except that layer farms were better off under the no-vaccination strategy and parent farms better off under the vaccination strategy. For medium sized epidemics in a SPPA, the chosen strategy had no affect on welfare of consumers and producers. For large sized epidemics, most stakeholders were better off under the vaccination strategy with the exception of the egg product industry, layer farms and parent farms. Clearly, the differential impacts of epidemics on the welfare of consumers and producers is not determined by the size and length of epidemics alone. Interpretation of the welfare effects becomes more complex for large epidemics.

3.2. Effect of trade bans

In Table 5, simulated results for producer and consumer surplus are presented for scenarios representing different trade bans. The scenario variables strategy (RV3+1km), channelling policy (CompONLY), basic demand shock (BasicDemandNONE), vaccination demand shock (VacDemandNONE), and export demand shock (ExpDemandSAME) were kept constant for these simulations. These scenarios represent situation where there is no demand shock (either domestic or export) and therefore the only demand shift is due to the export ban.

Table 5. Percentage change in the net present value of consumer and producer surplus for sector participants in each trade ban scenario.

No	Density	Size	% follow EU[1]	CS	PS	HAT	IND	LAY	PACK	PAR	REAR
9	SPPA	MED	0.66	4.49	-1.78	-23.48	1.62	-24.82	33.22	-18.13	-6.18
10	SPPA	MED	0.33	6.83	-3.58	-41.97	1.85	-35.23	44.17	-28.58	-8.35
6	SPPA	MED	0.00	9.47	-6.60	-64.04	4.13	-45.54	49.04	-31.41	-10.91
11	DPPA	MED	0.66	-8.91	-10.27	-46.17	-28.00	44.15	-54.57	22.64	-16.55
12	DPPA	MED	0.33	-9.13	-10.28	-44.69	-20.33	13.43	-62.41	33.28	14.97
2	DPPA	MED	0.00	-10.87	-10.83	-49.64	-13.40	38.74	-87.56	34.78	7.49
13	DPPA	LAR	0.66	-13.21	-15.95	-43.85	-33.19	-9.08	-88.58	29.85	44.89
14	DPPA	LAR	0.33	-13.29	-16.10	-43.78	-29.25	17.63	-101.52	40.01	26.80
4	DPPA	LAR	0.00	-13.07	-16.27	-48.52	-23.97	25.85	-96.48	52.02	11.09

Where CS = consumer surplus, PS = aggregate producer surplus, HAT= producer surplus for hatcheries, IND = producer surplus for egg product industry, LAY = producer surplus for layer farms, PACK = producer surplus for packing stations, PAR = producer surplus for parent farms, REAR = producer surplus for rearing farms.
1 Percentage of third country exports which follow the EU and do not implement an export ban.

For epidemics in a SPPA, lower trade bans change the magnitude of the gain/loss but do not change which stakeholders gain or lose from an epidemic in relation to the maximum trade ban scenario. For epidemics in a SPPA, a lower trade ban (e.g. more countries follow the EU and do not implement a trade ban, scenarios 9 and 10) is beneficial for producers as an aggregate but not for consumers. A lower trade ban is consistent with a smaller negative demand shift and therefore higher prices relative to larger export bans. In this situation, hatcheries, layer farms, parent farms and rearing farms all benefit from smaller trade bans, while the packing industry and the egg product industry are worse off. This is an expected result for the egg product industry, since this industry is required to pay higher prices for industrial eggs. For packing stations the effect is more complex. Under the current model assumptions, export bans also affect the foreign price. A smaller export ban is consistent with higher total supply in the foreign market and therefore lower foreign prices. Since packing stations export a large proportion of table eggs to the EU market, lower foreign prices represent lower revenue for this stakeholder and this affect appears to dominate the benefit of higher domestic prices.

The size of the trade ban has very little effect on consumer and (aggregate) producer surplus for epidemics (both medium and large) in a DPPA. For individual stakeholder groups, the effects of lower trade bans do not appear to be linear. This is particularly evident for layer farms, where for a medium sized epidemic, the gain is highest under the minimal trade ban scenario (scenario 11) and smallest under the 33 per cent trade ban scenario (scenario 12). A large outbreak results in a welfare loss for layer farms under the minimal trade ban scenario (scenario 13) and a gain for scenarios where the trade ban is higher. Although producers as a whole gain from lower trade bans, these effects are minimal for outbreaks in a DPPA and disguise complex and conflicting effects for the different producer groups. Given the proportion of exports to third countries is much higher for day old chicks, it could be expected that the effects of lower trade bans would be more obvious at the level of the hatchery or rearing farm. The results in Table 5 however, suggest that the impact is relatively small for hatcheries but much larger for rearing farms.

3.3. Effect of demand shocks

In Table 6, simulated results for producer and consumer surplus are presented for scenarios representing different demand shocks. The scenario variables density (DPPA), size (MED), channelling policy (CompONLY), basic demand shock (BasicDemandMED) and trade ban (FollowEUNONE) were kept constant for these simulations.

Table 6. Percentage change in net present value of consumer and producer surplus for sector participants in each demand shock scenario

No.	Basic	Vac	Export	CS	PS	HAT	IND	LAY	PACK	PAR	REAR
2	NONE	NONE	NONE	-10.87	-10.83	-49.64	-13.40	38.74	-87.56	34.78	7.49
15	MED	NONE	NONE	-12.40	-11.30	-49.65	-12.86	35.31	-85.55	34.33	7.29
16	MED	NONE	UNDER	-11.56	-11.41	-49.68	-13.33	25.57	-74.61	34.18	7.21
17	MED	NONE	SAME	-10.78	-11.71	-50.36	-13.61	17.21	-66.53	33.22	7.69
18	MED	NONE	OVER	-10.18	-12.16	-51.22	-13.25	10.80	-61.78	32.54	8.33
19	MED	SMA	NONE	-16.50	-12.61	-50.14	-10.41	32.73	-88.19	33.21	6.59
20	MED	SMA	UNDER	-14.05	-12.91	-58.59	-14.63	3.53	-56.84	20.49	11.34
21	MED	SMA	SAME	-12.60	-14.86	-59.76	-11.26	-7.10	-50.89	20.16	8.50
22	MED	SMA	OVER	-11.06	-17.37	-59.44	-7.25	-18.33	-48.13	19.52	6.53
23	MED	MED	NONE	-22.20	-14.72	-50.93	-7.23	23.78	-86.68	31.92	5.46
24	MED	MED	UNDER	-18.71	-16.97	-60.21	-7.82	-25.94	-37.50	19.68	6.57
25	MED	MED	SAME	-17.05	-22.54	-56.60	2.78	-34.90	-47.21	23.01	-1.32
26	MED	MED	OVER	-16.50	-31.49	-50.22	16.71	-39.01	-85.80	17.01	-1.93

Where CS = consumer surplus, PS = aggregate producer surplus, HAT= producer surplus for hatcheries, IND = producer surplus for egg product industry, LAY = producer surplus for layer farms, PACK = producer surplus for packing stations, PAR = producer surplus for parent farms, REAR = producer surplus for rearing farms.

Scenarios 15-18 represent situations where there is a maximum domestic demand shock of 20 per cent in response to the HPAI epidemic but no response to vaccination. As the export demand shock increases, the loss in consumer surplus decreases and the loss in aggregate producer surplus increases. As the export demand shock increases, layer farms suffer the most while packing stations gain the most. As expected, if the demand shock is attributable to domestic demand then consumers lose (comparing scenarios 2, 19 and 23) while if the demand shock is attributable to export demand then consumers gain in response to lower prices. Under the different demand shock scenarios, the distribution of stakeholders who win or lose as a result of a HPAI epidemic generally remains the same as for scenarios where no demand shock occurs. The exception is for larger demand shocks. For these scenarios

(scenarios 21-22,24-26) layer farms and sometimes also rearing farms lose as a result of the epidemic.

3.4. Potential impact of channelling policies for vaccinated products

Channelling policies represent a potential tool for alleviating the effects of foreign and domestic demand reactions to vaccinated products. These policies could have three potential effects: a positive effect on export demand (reduction in the export demand shock), a positive effect on the size of the trade ban (reduction in the number of countries which implement a trade ban) and potentially a negative effect on domestic demand (vaccination demand shock) since vaccinated products are now allocated to the domestic market. Scenarios A-K in Table 7 represent different combinations of these potential effects. For these simulations, the following scenario variables were kept constant: strategy (RV3+1km), density (DPPA), size (MED) and domestic demand shock (DomDemMED). The reference scenario for comparison purposes is where the channelling policy is CompONLY, the vaccination demand shock is small, no third countries follow the EU and where the export demand shock is the same as domestic demand; the change in surplus measures for this scenario (scenario 27) are presented in Table 8. Scenario A represents a situation where the chosen channelling policy has no effect on either domestic demand, export demand or the trade ban. Scenario B represents a potential situation where the channelling policy leads to a smaller export demand shock; while scenario C leads to a lower trade ban. Scenario D represents a situation where the channelling policy has no effect on trading partner behaviour but leads to an increase in the domestic demand shock in response to vaccination. In scenario E both export demand and the trade ban by third countries are positively influenced by the channelling policy; a similar situation is represented by scenario H but with channelling also leading to a larger domestic demand shock. Both scenarios F and G represent larger domestic demand shocks, accompanied by a reduction in the trade ban in scenario F and a reduction in the export demand shock in scenario G. Scenarios I and J represent situations where the reduction in the export demand shock is relatively large; in scenario J this is accompanied by an increase in the domestic demand shock. Scenario K illustrates the effects of different channelling policies if there are no effects on demand and where the comparison scenario is scenario 2 (no demand shocks).

Table 7. Specification of different scenarios for exploring the effects of channelling policies.

Scenario	ExpDem	FollowEU	Vac. Dem	ExpDem	FollowEU	Vac. Dem
A	0	0	0	SAME	0.00	SMA
B	+	0	0	UNDER	0.00	SMA
C	0	+	0	SAME	0.33	SMA
D	0	0	-	SAME	0.00	MED
E	+	+	0	UNDER	0.33	SMA
F	0	+	-	SAME	0.33	MED
G	+	0	-	UNDER	0.00	MED
H	+	+	-	UNDER	0.33	MED
I	++	0	0	NONE	0.00	SMA
J	++	0	-	NONE	0.00	MED
K	0	0	0	NONE	0.00	NONE

The results for scenarios A-J presented in Table 8 show the effect of two different channelling strategies for vaccinated eggs in terms of their difference from the CompONLY policy (scenario 27). If the channelling policy has no effect on demand; then both producers and consumers gain marginally under the VacDOM policy while there is no difference under the VacPRO policy. This suggests that for medium sized outbreaks in a DPPA, the domestic and processed markets are large enough to absorb the vaccinated eggs without too many disruptions. Scenarios B, C, E and I all represent situations where the channelling policy has a positive effect on export demand and/or the size of the trade ban. For these scenarios, aggregate producers are better off than compared to the situation where vaccinated eggs are not restricted. Consumers however are worse off under these scenarios with the exception of scenario C (channelling policy leads to a relaxed trade ban). Whether vaccinated eggs are restricted to the domestic market or the processed market makes little difference to the magnitude of the welfare effects. Packing stations are generally better off when eggs are allocated to the domestic market while layer farms are slightly better off when a processing policy is followed. Scenarios D, F, G, H and J all represent situations where the channelling policy leads to a larger negative response from domestic consumers. In these situations, producers and consumers are both worse off than compared to the CompONLY policy. Scenario J suggests that if the decrease in the export demand shock is large enough, this has the potential to offset the negative effects of the domestic demand shock. Whether the channelling policy effects export demand from EU partners or the size of the trade ban from third countries also impacts on welfare of producers and consumers. Layer and rearing farms are better off if the chosen policy affects export demand, while packing stations, parent farms and hatcheries are better off if the policy affects the size of the trade ban.

Table 8. The effect on consumer and producer surplus of different channelling policies for different scenarios; change in percentage points from the base scenarios.

Scenario	PS	IND	LAY	PACK	PAR	REAR	HAT	CS
27	-14.86	-11.26	-7.10	-50.89	20.16	8.50	-59.76	-12.60
2	-12.61	-10.41	32.73	-88.19	33.21	6.59	-50.14	-16.50
	VacDOM							
A	0.02	-0.43	-2.10	3.97	0.05	-1.06	-0.37	0.37
B	1.97	-3.80	7.10	-1.99	0.38	1.78	0.81	-1.07
C	0.45	-3.69	-10.26	13.37	8.41	-0.72	11.91	0.93
D	-7.78	13.87	-28.79	5.79	2.92	-10.88	2.81	-4.17
E	2.45	-7.08	0.44	7.19	9.06	2.50	12.29	-0.54
F	-7.94	11.33	-37.48	14.74	13.56	-12.30	15.37	-3.39
G	-1.89	3.00	-18.45	15.40	-0.42	-2.98	-0.81	-5.92
H	-1.45	-0.27	-26.63	24.80	7.92	-2.62	11.49	-5.35
I	2.27	0.43	36.94	-32.44	13.11	-2.98	9.27	-3.48
J	0.39	3.58	32.64	-35.22	11.82	-4.10	8.48	-9.49
K	0.01	-0.40	-3.60	5.66	0.05	-1.08	-0.36	0.47
	VacPRO							
A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B	1.94	-3.25	10.98	-6.51	0.42	2.88	1.17	-1.50
C	0.43	-3.26	-8.13	9.36	8.35	0.34	12.29	0.56
D	-7.69	14.05	-27.80	3.68	2.86	-9.82	3.16	-4.45
E	2.41	-6.51	2.80	2.60	9.07	3.68	12.67	-0.96
F	-7.16	11.01	-34.42	13.33	13.50	-11.24	15.74	-3.87
G	-2.11	3.44	-18.84	13.39	-0.48	-1.93	-0.45	-6.11
H	-1.49	0.16	-25.11	21.40	7.87	-1.57	11.87	-5.69
I	2.15	1.06	39.61	-37.39	13.01	-2.05	9.51	-3.85
J	0.14	4.03	30.88	-35.78	11.76	-3.04	8.83	-9.60
K	-0.48	0.99	-0.73	-0.84	-0.51	-0.57	-0.34	0.27

Where CS = consumer surplus, PS = aggregate producer surplus, HAT= producer surplus for hatcheries, IND = producer surplus for egg product industry, LAY = producer surplus for layer farms, PACK = producer surplus for packing stations, PAR = producer surplus for parent farms, REAR = producer surplus for rearing farms.

The results in Table 8 suggest that channelling eggs from vaccinated layers to the domestic or processed markets is a potentially attractive strategy (for medium sized epidemics) as long as this does not lead to a negative reaction by domestic consumers. In this sense, channelling these eggs to the processed market has the lowest chance of causing an additional reaction by domestic consumers. Although this is feasible for the simulated scenarios, the market disruptions are likely to be much larger for large epidemics.

4. Discussion

The dynamics of the market effects from HPAI epidemics and their control can be separated into three distinct phases, termed here the initial, outbreak and aftermath phases. The initial phase occurs during the first few weeks of an epidemic. In this period large uncertainty exists for all market participants. A temporary export ban for all products, speculation and temporary buffers (storage) imply that the behaviour of participants is particularly difficult to anticipate and to capture in a model. In this period, market effects are unlikely to differ significantly between control strategies, since behaviour is determined mainly by the fact that HPAI is detected. The opportunities to influence market impacts during this phase are fairly limited.

The outbreak phase takes place for the remainder of the epidemic, until all surveillance zone restrictions are lifted. In this period, products originating from the surveillance zone are restricted to the processed market, and all live poultry from this zone is restricted to the domestic market. The length and the size of the epidemic (which are dependent on the control strategy) and the distribution of affected farms over the different levels in the sector have a large impact on market effects. Any demand shocks (either in response to the epidemic or in response to the vaccination strategy) from domestic and foreign consumers and trade bans from third countries will impact on prices and quantities sold. During this phase, very low prices and decreasing production due to control measures imply that most producers face large welfare losses during this period.

The final phase is entered once all movement restrictions are lifted. This phase is first characterised by restocking of empty farms and if vaccination is used then market effects directly associated with vaccinated products will continue to play a role until the last of these products leaves the market. In this phase extended trade bans also have an important effect. Massive restocking is generally characterised by high prices for live poultry. For individual farms, higher prices can be either beneficial (farms which continued in production) or lead to large losses (farms which need to restock). Although culled farms receive compensation, this is not adequate to cover restocking needs in situations of very high prices.

Results presented in this chapter indicate that not all stakeholders lose as a result of HPAI epidemics. The relative size of demand and supply shocks has important implications for which stakeholder groups gain or lose from epidemics. These relative shifts are most obvious when comparing epidemics in DPPAs and SPPAs. Consumers can gain in small epidemic situations, since any demand shifts generally dominate the supply shifts leading to lower prices. The impact for consumers is also influenced by the nature of the demand shift, since consumer surplus is directly affected by shifts in domestic demand, but only indirectly affected by shifts in export demand. For the scenarios presented, producers as a whole always lose as a result of HPAI epidemics. Even for situations where the supply shifts dominated the demand shifts leading to situations of higher prices, the loss due to lower production dominated the benefits of higher prices. Although this holds true for producers as an aggregate, this disguises large differential effects between individual stakeholder groups.

The temporal pattern of changes in stocks and prices during the three epidemic phases is dependent on the distribution of culled and empty farms across the production chain. This makes it difficult to compare ex-ante different control strategies in terms of their market effects. A spatial epidemiological model which includes the structure of the poultry industry is necessary to be able to provide any insight into the distributive effects of epidemics. The price of eggs in particular appears to be sensitive to the distribution of affected farms.

As shown by the results in this chapter, aggregate welfare measures disguise the differential effects on individual stakeholder groups. The effects for individual farms will be even more diverse and crucially influenced by the timing of the production cycle for individual farms. Within each stakeholder group there will be very large winners and losers as a result of HPAI epidemics. If losses for individual farms are sustained for a long period of time, which is often the case (results not shown) this will likely lead to situations where farms exit the industry. The current model does not account for the potential that farms will exit the industry. A gradual restocking programme may alleviate some of the extreme price fluctuations which lead to these differential effects but would also increase the length of time until pre-epidemic capacity is reached.

The simulated welfare effects of large epidemics in a DPPA are particularly complex and difficult to interpret. For epidemics in a SPPA, lower trade bans are beneficial for producers but not for consumers. For epidemics in a DPPA, lower trade bans have little effect on aggregate producer and consumer surplus, while the effect on welfare of individual stakeholder groups exhibits considerable nonlinearities. Trade bans differ from export demand shocks in that an export demand shock can to some extent be compensated through lower prices; while a trade ban is a regulatory measure for which no compensatory mechanisms exist. The Dutch layer sector is heavily dependent on export demand from EU member states (exports account for 63 per cent of production, of which 91 per cent is exports to EU member states) and is therefore more sensitive to export demand shocks than trade bans. Germany is the most important export partner. Empirical evidence to date suggests that German consumers are likely to have a larger demand response than Dutch consumers. In this sense, the export demand shock where export demand reacts more strongly than domestic demand may be relatively more likely.

In section 3.4 the potential of two channelling policies for restricting eggs from vaccinated layers to the domestic or processed market was explored. For medium sized epidemics in a DPPA, both the domestic and processed markets could absorb these quantities without major distortions. A channelling policy is an attractive option if this can lead to either a reduction in the export demand shock or a lower trade ban. However if such a policy leads to an increase in the vaccination demand shock then both consumers and producers are better off under a policy where these eggs are not channelled. Allocating eggs from vaccinated layers to the processed market may be less risky in terms of a domestic demand shock, but is also more restrictive which may cause problems if large quantities of eggs are involved.

The results as a whole suggest some important factors which influence the market effects of HPAI epidemics. These include the following factors: location of epidemics in terms of farm density, expected size and length of epidemics; production structure and degree of vertical integration and market power at the different levels; nature of and dependency on international trade in live poultry and eggs, in particular the level of intra-EU trade versus inter-EU trade; and the size of any processing or lower quality market and the potential of this market to absorb shocks.

Experience with HPAI epidemics throughout the world appear to indicate that demand shocks are greater for poultry meat than for eggs. If this is the case, then the scenarios with either no or low demand shocks maybe more likely. It is unclear however whether any potential reaction to vaccinated products will be different between eggs and poultry meat.

In comparison to a market with only one product (i.e. only table eggs), the situation of a high and low quality product complicates the interpretation of market effects but also lead s to opportunities to alleviate the effects of HPAI epidemics. If the assumption of market power at the packing station level is true, then these companies are able to influence the price of table eggs and industrial eggs which leads to different market outcomes. The current assumption is that packing stations allocate eggs to the table and industrial markets. A more realistic approach would include the allocation of eggs to the export market; this is currently modelled independent of the decision on allocation of eggs.

The partial equilibrium model is based on a number of assumptions which have implications for the results presented here. Elasticities were chosen based on literature where available and were otherwise estimates of the authors. The suite of elasticities gave reasonable empirical results when tested however the model could be strengthened if these elastictities were empirically estimated. This is particularly true for input demand and output supply elastcities in the vertically linked sectors. However empirical estimation is difficult due to a lack of data at this disaggregated level. The assumption of a constant price for reared parent hens affects the estimates of producer surplus for this subsector as does the assumption regarding a

constant margin for the egg product industry. The foreign market is modelled as one international market, although elasticities implicitly account for the dependency on the EU market. An extension to the model would involve modelling two foreign markets: an EU market and the rest of the world. The Netherlands is an important partner in the EU poultry market but much less so in the world market. This would allow the effects on these two markets to be differentiated.
The constant elasticity form implies that elasticities remain the same even in the face of large shocks. Although this is a common assumption for many studies, this may not hold true for very large shocks, such as a full export ban. This assumption is most likely to affect the results during the first phase of the outbreak.

5. Conclusions

In this chapter, a dynamic and vertically-linked partial equilibrium model of the Dutch layer sector was developed. The model was designed to allow for the implementation of different demand and supply shocks at different levels in the layer production chain which can be associated with simulated HPAI epidemics in the Netherlands.
Shocks which were included in the model were supply shocks associated with the culling of poultry farms and restocking restrictions, domestic and export demand shocks in response to HPAI epidemics or the use of vaccination, trade bans and channelling restrictions on the marketing of poultry and products originating from specified zones. To our knowledge, this study provides the most comprehensive exploration of the potential effects of different shocks associated with contagious animal epidemics. In particular, modelling marketing restrictions on particular products as a result of animal disease epidemics is an addition to the literature.
The results show large differential effects amongst different stakeholder groups as a result of an HPAI epidemic. The relative size of shifts in demand and supply has a major influence on the distribution of these effects. These differences are largest when comparing epidemics in DPPAs and SPPAs, but much smaller when comparing different control strategies for epidemics in a particular area. The temporal pattern of prices and stocks differs according to the epidemic phase. The initial phase is characterised by high uncertainty and is heavily influenced by a total export ban. The outbreak phase is characterised by low prices for live poultry if the number of farms facing restocking restrictions is larger than the number of culled farms. The aftermath phase is characterised by restocking which generally leads to higher prices (for larger epidemics).
The results suggest a number of important factors which influence the size and distribution of market effects as a consequence of HPAI epidemics. These include: (1) the location of epidemics in terms of farm density, expected size and length of epidemics, (2) the production structure and degree of vertical integration and market power at the different levels, (3) the nature of and dependency on international trade in live poultry and eggs, in particular the level of intra-EU trade versus inter-EU trade, and (4) the size of any processing or lower quality market and the potential of this market to absorb shocks. Market effects of HPAI epidemics will differ greatly among EU member states since these factors also differ significantly between member states.

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