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Management of Disease-triggered Shocks in Complex Value Chains: An *Ex Ante* Analysis of Market Effects of HPAI Control in the Dutch Egg Supply Chain

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ABSTRACT

External shocks, such as disease occurrence, can be very disruptive in complex food producing value chains. To analyze this, a vertically linked dynamic partial equilibrium model was used to analyze market effects of outbreaks of Highly Pathogenic Avian Influenza (HPAI) in The Netherlands. Various shock inducing scenarios were analyzed, e.g control strategy, demand shocks and trade bans. The results showed that in densely populated poultry areas (1) market effects usually outweigh direct control costs, (2) vaccination could help mitigating total disease costs, particularly if (3) channeling to industrial processing is included. Moreover, large, and in some cases opposing differences in market effects between the various stakeholders could be observed. The result suggest a number of important policy factors that should be considered in HPAI control, e.g. the poultry density, the production structure and differentiation of stakeholders, the dependency on international trade and the potential capacity of industrial processing of eggs. General implications for other food producing value chains are discussed.

Keywords: *Highly-Pathogenic Avian Influenza, market effects, egg supply chain, policy*

1 Introduction

Today, food is produced in complex supply chains, which include a multitude of stakeholders which are vertically interlinked, however each with different features and preferences. External risks, e.g. diseases and contaminations, are a continuous thread. In case of occurrence, management and control of these risks usually involves measures which affect supply, both between chain levels and overall output of the supply chain (see: Longworth et al., 2014ab). Additionally, believes and risk perception, particularly of consumers, will drive (changes in) demand as well. Both contradictory effects usually result in a complex set of supply and demand shocks throughout the value chain, which in some occasions and for some stakeholders respectively, enhance each other, whereas in other situations they can mitigate each other. As a consequence, externally-triggered (disease) shocks can be devastating for the supply chain as a whole or for some specific individual stakeholders, whereas other individual stakeholders might (temporarily) benefit (Longworth et al., 2018). Hence, understanding this complexity, and awareness of important driving factors, is important to improve management of these risks. In turn, such awareness could contribute to reducing the impact for the value chain as a whole as well as for individual stakeholders.

The general aim of this article is to explore and elaborate this value chain problem through an *ex ante* analysis of outbreaks of Highly Pathogenic Avian Influenza (HPAI) in naïve and non-vaccinated populations. These outbreaks usually cause an epidemic spread resulting in large numbers of diseased animals, high mortality and other negative production effects (Swayne, 2008). Within the European Union (EU), and hence The Netherlands, HPAI control is based on AI Directive 2005/94/EC, which outlines the minimum control measures member in the event of an outbreak: culling of infected farms, establishment of movement restriction zones (MRZ) and marketing restrictions for poultry and poultry products originating from affected areas. Dutch experiences indicate, that, particularly in densely populated poultry areas (DPPAs) more stringent measures are required to control the outbreak, such as pre-emptive culling, vaccination and restocking restrictions; even then, millions of animals have to be culled (Stegeman *et al.*, 2004). Moreover, the massive control measures, particularly pre-emptive culling, can have a large impact on the entire society (Anonymous, 2004).

An important choice problem in HPAI control is: control with or without emergency vaccination. Strategies based on vaccination are able to control HPAI in DPPAs; this holds also for non-vaccination strategies provided they include pre-emptive culling (Marangon and Capua, 2006; Backer et al., 2011; Longworth et al., 2014ab). Longworth et al. (2014ab) compared the Direct Costs (DC) and Direct Consequential Costs (DCC)[1] of both type of strategies, and concluded that non-vaccination strategies that included pre-emptive culling outperform vaccination strategies on these two criteria. However, vaccination strategies have a better 'image' and are more accepted by the general public (Van Asseldonk et al., 2005). The main reason of not applying vaccination strategies is that they entail a larger trade risk (i.e. export bans), reduced producers' prices, particularly in net-exporting countries, and hence market induced Indirect Consequential Costs (ICC) for producers. The latter was demonstrated e.g. for cattle production by Berentsen et al. (1992) and for pig production by Mangen and Burrell (2003). Moreover, in most cases ICC outweigh DC and DCC (see: Dijkhuizen and Morris, 1997; Saatkamp et al., 2000). Furthermore, economic effects are not necessarily distributed evenly between all production chain levels (Gohin and Rault, 2013; Longworth et al., 2018). Hence, a thorough analysis of the market effects of HPAI control strategies *and* ways to mitigate devastating economic impacts is in the interest of veterinary policy makers and all production chain participants.

Regarding the ICC, there exists at least four determining factors related to the behaviour of private actors and governments (Longworth et al., 2018):

- Supply shocks, caused by the disease and the control measures (see: Longworth et al. (2014ab);
- A temporary reduced demand by (domestic) retail and/or consumers because of fear caused by the zoonotic character of HPAI (Flach, 2006);
- Temporary trade bans can be imposed (Swayne, 2008); within the EU the freedom of member states to impose such a ban is limited, hence at first particularly third countries are of interest in this respect;
- Channeling, i.e. temporary commodity shifts from table eggs to industrial eggs.

The first three factors have a potential increasing impact on the ICC, whereas the aim of the latter is to reduce these impacts.

[1] For a complete overview of costs resulting from epizootic disease outbreaks, their rationale and complexity reference is made to Saatkamp et al., 2016.

Either single or simultaneous occurrence of these factors will have an impact on market, and hence on the producers' prices and the ICC of the HPAI outbreak. Longworth et al. (2018) described a vertically linked dynamic partial equilibrium model capable of analyzing this complex problem for the entire egg production chain. The aim of this article is to apply this model to HPAI control in The Netherlands, in order to analyze of the impact of the main determining market factors on the ICC of HPAI outbreaks. This could be helpful decision support information for disease control authorities and others involved in HPAI control.

2 Material and methods

2.1 Integrated model structure

To explore the market effects of HPAI epidemics in the Netherlands, three models are used in an integrated manner as shown in Figure 1. Epidemiological outputs for a given control strategy and index farm are generated by the simulation model InterSpread Plus parameterized for HPAI epidemics in the Netherlands. The epidemiological model is described in Longworth et al. (2013[a]). The output of the epidemiological model is used subsequently as an input for a conversion model, which analyses the output and calculates the direct costs and consequential losses for affected farms (see Longworth et al., 2014b for further details). In addition, the conversion model generates weekly shock parameters for the partial equilibrium (PE) model DutchLAY.

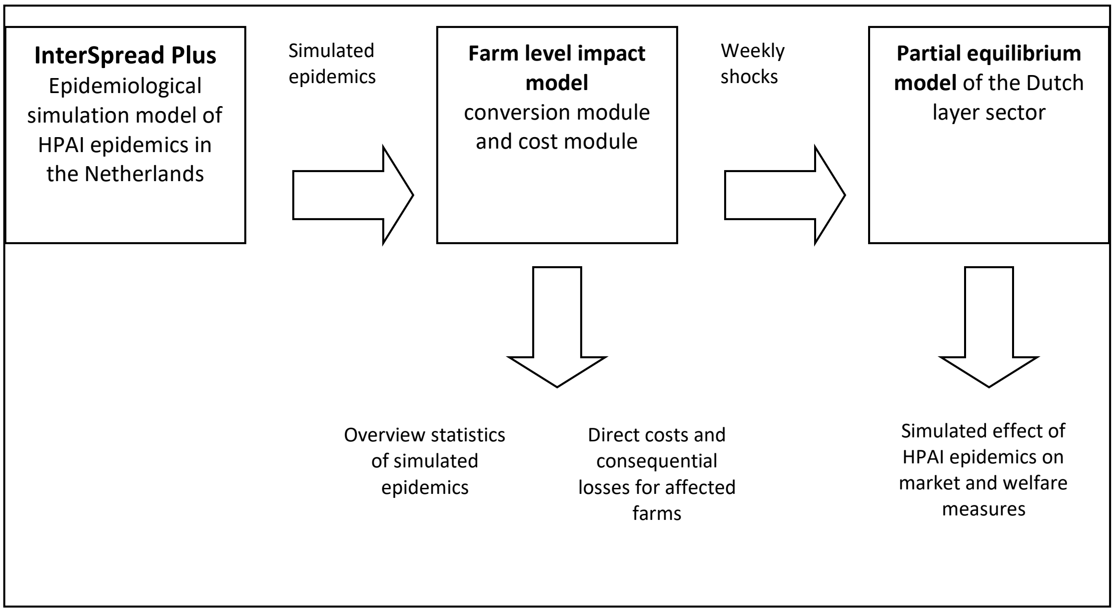

Figure 1. Integrated modelling approach to simulate the economic effects of HPAI epidemics in the Netherlands.

2.2 Multi-level dynamic partial equilibrium model

Figure 2 provides a stylized representation of the PE-model of the Dutch layer supply chain, covering the stages from breeding of parent stock to the consumption of eggs. The supply chain is structured as follows: 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 maximize 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.

All agents are assumed to follow a profit maximization approach, taking into account a production technology constraint. The production technologies have a Leontief character, reflecting agronomic relationships between input and output. The various stages of the supply chain are interlinked by markets which always clear, but with price signals influencing supply of the upstream and demand of the downstream stages. 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. For a detailed description see Longworth (2018).

As Figure 2 shows, the model distinguishes between flow variables and stock variables (parent stock, day old chickens, reared layers and layers), which is a typical characteristic of animal production. 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.

With respect to the closure of the model it should be noted that a few prices are assumed to be 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 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. Finally, also 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.

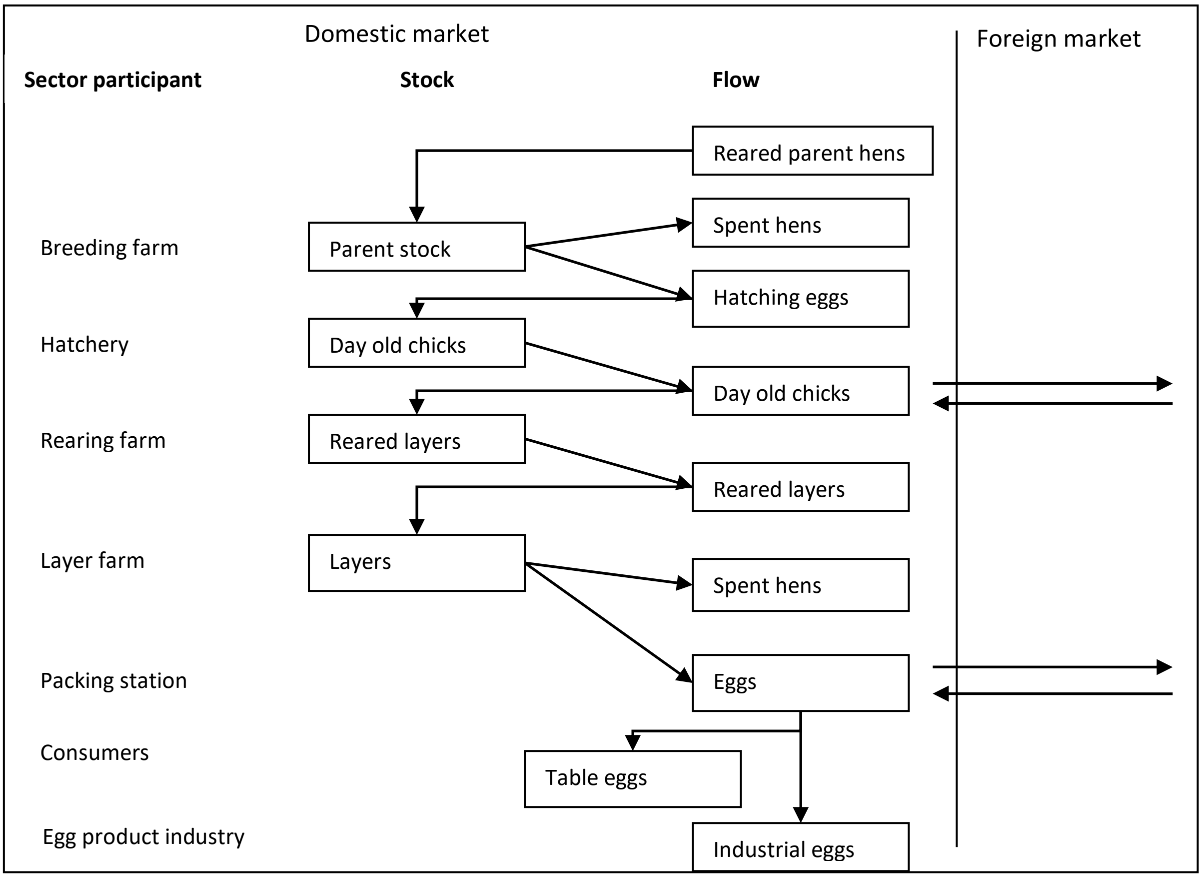

Figure 2. Structure of the partial equilibrium model DutchLAY

2.3 Modelling shocks associated with the control of HPAI epidemics

The model incorporates supply shocks, domestic and foreign 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 behavioral equations and/or as additional constraints, following from trade policy measures that are assumed to overrule demand.

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).

2.4 Scenarios and approach

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 (see: Table 1): strategy, density, size, channeling policy, basic demand shock, vaccination demand shock, export demand shock and trade ban. The first two variables dictate which scenario is implemented in the epidemiological simulation model, the third which raw input is generated by the farm level impact or 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 PE- model of the Dutch layer sector, based on the inputs from the farm level impact model. For each scenario, the shocks are constructed over time for the relevant products similar as discussed in Longworth (2018).

Table 1.
Description of variables used to generate scenarios.

Variable	Options	Description	Values/action
Strategy	BaseNL RV3+1km	The control strategy used in the epidemiological simulation model.	culling culling + vaccination
Density	DPPA SPPA	Represents the farm density surrounding the index farm used in epidemiological simulations.	>300 farms/10 km^2 <35 farms/10 km^2
Size	OutbreakMED OutbreakLAR	Represents the iteration for which output of the epidemiological simulation model is used as input to shocks. Iterations are ranked according to number of infected farms.	50^{th}percentile 95^{th}percentile
Channelling policy	CompONLY VacDOM VacPRO	Represents the marketing restrictions on poultry and products either vaccinated or originating from the movement restriction zone (MRZ).	
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, i.e. foreign amplifier of 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 (values 0.33 and 0.66) or not implementing (value 0.00) trade bans.	0.00 0.33 0.66

The analysis is structured as follows: A reference scenario (baseline) is constructed, which reflects the normal or default response (culling all animals within a 1 km radius around an infected flock) to an HPAI outbreak in The Netherlands. It is assumed that such an outbreak will most likely take place in a densely populated production area, will be of a medium size, has a length of the epidemic of about four month (128 days). For the reference scenario it is assumed that all third countries implement a trade ban lasting for one year after the epidemic, but that there are no domestic demand shocks. Subsequently four groups of scenario's are simulated and evaluated against the constructed baseline (default response). The scenario's distinguish themselves from the baseline in four respects: i) the impact of different type of outbreaks (with or without additional emergency vaccination), ii) the impact of a trade ban; iii) the impact of demand shocks; and iv) the impact of channelling. Whereas ii) and iii) imply changes in the external environment (coming from consumers or foreign policy makers), iv) focuses on a particular policy response from the domestic authorities, aimed at reducing further harm coming from foreign and domestic demand reactions to vaccinated products.

When comparing the scenario's the focus is on the economic aspects with the aim to add this as an additional dimension in the disease combatting strategy, which often is strongly driven by veterinary considerations. The key indicator is then changes in costs and benefits accruing to different stakeholders as well as to society as a whole. These are measured by changes in consumer surplus and producer surplus, properly aggregated over the time period in which the consequences of the disease outbreak are felt and have to be dealt with.

It has been realized that a nearly infinite number of counterfactual scenarios could be chosen to demonstrate the impacts. Here a selection has been made of the most relevant epidemic outbreak-scenario's. In order to save length, discrete steps with respect to key parameters are taken, rather than endless nearly continuous variation in parameters.

2.5 Epidemiological input for the analysis

All analyses are based on simulations of HPAI epidemics in The Netherlands, taking account for e.g. poultry density of the region and control strategy. Based on Longworth et al. (2014ab) two strategies were included: BaseNL, which includes culling within a 1 km radius around an infected flock, and RV3+1km which, alongside the culling, includes additional emergency vaccination in a radius of 3 km. Moreover, two areas were included: DPPA and sparsely populated poultry area (SPPA). The epidemiological input provided by these simulations is presented in Table 2. Only medium (MED) and large (LAR) outbreaks were included.

Table 2.
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	1,339
RV3+1km	DPPA	MED	194	110	1,023
BaseNL	DPPA	LAR	371	155	1,514
RV3+1km	DPPA	LAR	316	113	1,640
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

3 Results

Results are presented as percentage changes from the baseline for a time horizon of 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.

3.1 Basic scenarios with only supply shocks, compulsory channeling and export bans by third countries

In the first group of scenarios that were analyzed, only the compulsory channeling measures are applied, there are no domestic demand shocks, all third countries implement a trade ban lasting for one year after the epidemic. In Table 3, the economic welfare effects, measured in thousand euros, are presented. It can be observed that in all cases the loss to producers outweighs and dominates the welfare effect to consumers. The total welfare loss to society (resulting from aggregating total consumer surplus CS and producer surplus PS) varies from €3 million (scenario's 3 and 7) to €68 million (scenario 2). Scenario's 1, 2, 5 and 6 imply a net welfare loss to society of €40 million or more, whereas for scenario's 3, 4, 7 and 8 it is substantially less than €10 million. Note also that relatively low net welfare losses to producers correspond with relatively low welfare losses to consumers (see scenario's 3, 4, 7 and 8).

Table 3.
Welfare effects of different HPAI outbreak scenarios for various stakeholder groups involved (thousand euro).

No.	Strategy	Density	Size	CS	PS	HAT	IND	LAY	PACK	PAR	REAR
1	BaseNL	DPPA	MED	-18338	-38865	-4751	-7165	23345	-60472	4177	6000
2	RV3+1km	DPPA	MED	-14324	-25888	-4309	-3965	25651	-51024	2601	5158
3	BaseNL	DPPA	LAR	-22189	-45850	-5292	-8373	21017	-71522	3383	14937
4	RV3+1km	DPPA	LAR	-17220	-38886	-4212	-7095	17116	-56218	3891	7632
5	BaseNL	SPPA	MED	12472	-15772	-5559	1223	-30151	28576	-2349	-7511
6	RV3+1km	SPPA	MED	12472	-15772	-5559	1223	-30151	28576	-2349	-7511
7	BaseNL	SPPA	LAR	10231	-16982	-6065	1145	-21768	20770	-1633	-9429
8	RV3+1km	SPPA	LAR	12232	-16157	-5607	935	-30804	29344	-2845	-7180

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.

In Table 4, these effects are presented as percentage deviations in producers and consumer surplus compared to the pre disease outbreak level. As the percentage change in total producer surplus indicate producers in the laying hen sector can lose on average up to 20% of their profits. However, the losses can be quite different depending on the stage of the supply chain and to the extent an individual farm is affected. As Tables 5 and 6 show 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 affected 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 6 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 effect on welfare of consumers and producers. Note that 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, for strategy RV3+1km the simulated results for producer and consumer surplus are presented for scenarios representing different trade bans (see third column). Other scenario variables, such as channeling policy, basic demand shock, vaccination demand shock, and export demand shock were kept constant for these simulations. Hence, these scenarios represent situations 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 for control strategy RV3+1km.

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.

As can be seen from table 5 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 turns out to have very little effect on the aggregate consumer and 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. Other scenario variables were kept constant, e.g. density (DPPA), size (MEDIUM), channeling policy, basic demand shock (NONE) and trade ban (all third countries imposing a trade ban).

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 anegative domestic demand shock of 20 per cent of the initial demand in response to the HPAI epidemic but no consumer 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. Comparing Tables 6 and 5 it becomes clear that the impact of demand shock can have serious consequences for the producers: in the worst case analysed (Table 6, scenario 26) producers together loose nearly one third of their surplus which is about double the amount of all third countries imposing a trade ban (Table 5, scenario 4). In monetary terms (not reported in the Table) in scenario 26 the total welfare loss of consumers and producers is close to €100 million. The response of domestic consumers to the vaccinated product has a significant impact on aggregate welfare: the difference of the average monetary impact of the MEDIUM with respect to the NONE vaccination scenario's is €33 million.

3.4 Potential impact of channeling policies for vaccinated products

Channeling 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 channeling policy is a set of 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 (CompONLY). Moreover in the reference case it is assumed that 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 channeling policy has no effect on either domestic demand, export demand or the trade ban. Scenario B represents a potential situation where the channeling policy leads to a smaller export demand shock; while scenario C leads to a lower trade ban. Scenario D represents a situation where the channeling 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 channeling policy; a similar situation is represented by scenario H but with channeling 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 channeling 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 channeling strategies for vaccinated eggs in terms of their difference from the CompONLY policy (scenario 27). If the channeling policy has no effect on demand; then both producers and consumers gain marginally under the VacDOM policy (same as CompONLY with as an additional restriction that products from vaccinated poultry are restricted to the domestic market). while there is no difference under the VacPRO policy (VacPRO is the same as CompONLY with the additional restriction that products from vaccinated poultry are restricted to the processed market). 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 channeling 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 (channeling 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 channelings 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 channeling 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.

The results in Table 8 suggest that channeling 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, channeling 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 current study aimed to analyze the impact, management and control of an external trigger hitting a complex food producing value chain. Occurrence of HPAI in a egg producing value chain causes a variety of technical (i.e. disease control) effects which go along with demand and supply shocks. These shocks can be directly caused by the external trigger (e.g. disease control measures such as transport bans) or have a more autonomous nature (e.g. demand shocks caused by consumers). The practical focus was to (1) analyze the impact of important market factors on the market effects of HPAI outbreaks, and (2) derive policy guidelines to minimize these costs. In this discussion, first narrow issues regarding HPAI control in egg supply chains will be discussed. Thereafter, some more general insights will be presented applicable in a broader area of value chain management.

4.1 HPAI in egg value chains

Overall results

Results presented in this article 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.

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

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

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 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.

The results show, that 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 (see also Gohin et al, 2013). 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.

Region, trade bans and demand shocks

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 widely vary and 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.

Demand shocks have an strengthening impact on the changes in producers and consumers surplus. However, the *additional* impact, i.e. on top of the basic scenarios, is rather limited. Moreover, 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. In these cases, layer farms and sometimes also rearing farms lose as a result of the epidemic.

Channeling

Channeling aims to reduce the negative impacts of the factors described above. Therefore, the potential of two channeling 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 channeling 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 channeled. 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.

Management implications

The results as a whole suggest some important factors which influence the market effects of HPAI epidemics: (1) location of epidemics in terms of farm density, expected size and length of epidemics, (2) production structure and degree of vertical integration and market power at the different levels, (3) 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.

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 leads to opportunities to alleviate the effects of HPAI epidemics. 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.

4.2 General insights for complex food value chains

Most current days food value chains share quite some similarities with the egg supply chain used as subject for analysis in the current study, e.g. a multi-level and inter-linked structure, different processes along the chain, and an international embedment with im- and export. Moreover, they share a similar vulnerability for external triggers such as diseases and contaminations with toxic substances. Hence, some general insights obtained in the current study are valuable for these value chains as well, which will be discussed briefly below.

First, there might occur a paradox between chain participants. Adverse external events can disrupt the value chain operation as a whole, being devastating for a large part of the chain participants, whereas at the same time temporary benefits might occur for some participants. Two factors play a role in this regard. First, if a certain chain level is affected relatively harder than others (e.g. breeding animals compared to production animals), a relative shortage of these breeding animals might be the result, provoking a price increase; those chain participants which are still in business will benefit from the latter. Second, between different chain levels differences in timing of production cycle will be the case (e.g. between production of breeding animals and production animals). Once the external trigger is gone (e.g. eradication of the disease), starting-up 'slower' production cycles might cause temporary relative shortages in supply provoking price increases and relative benefits to some participants. In this regard, the position in the value chain also might be important: a relative high position might imply some degree of independence, whereas participants down the value chain much more depend on others, with price risks as a result.

Second, the international orientation of the value chain might be of importance. A high degree of export dependency implies that foreign customers have an important impact on possible demand shocks. I.e. their risk attitude and resulting purchase behavior plays an important role in the eventual price changes and consequently the economic impact.

Third, channeling and building buffer stocks, aiming at (temporarily and artificially) reducing supply and price effects, might be an important temporary instrument in mitigation of the effects of supply and demand shocks. Unfortunately however, current value chains are focused on 'just-in-time' principles, thereby reducing potential (costing) buffer capacity as much as possible. Nevertheless, recent crises show that establishing a minimum buffer and channeling capacity offers appropriate instruments for risk management, particularly with regard to short-run price fluctuations.

Fourth, and finally, some kind of collective management, synchronization or coordination during the starting-up phase after cessation/eradication of the external trigger (the so-called aftermath) might pay-off. Lifting of restrictive measures is an important incentive for individual chain participants that were temporarily and/or partially out of business to speed-up their affairs. However, this might provoke a temporary, short but very high demand in e.g. raw materials (e.g. breeding animals) or inputs. Depending on the price elasticities and other market features, this can result in huge price increases of these commodities (which is beneficial for the suppliers but unfavorable for the buyers). A 'synchronized' starting-up has two advantages. First, purchasing prices will increase less, resulting in a reduced increase in production costs for the buyers. Second, selling of the first batch of end-product to the final consumers will have a lower peak, hence a sharp drop in producers' price will be prevented. The combined effect is that the margins of final-product producers will be less affected. Hence, collective management should be aimed at a gradual and partial starting-up in the beginning, with less sharp price effects throughout the value chain as a result.

4.3 Conclusions

The main conclusions of this study are the following:

- 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 indirect consequential costs found are substantial and large relative to the direct costs and direct consequential costs. This provides a strong argument to alongside veterinary considerations pay more attention to market impacts when determining an optimal HPAI disease control policy;
- Our analysis shows that for a country with densely populated poultry areas when taking into account the indirect consequential costs (market effects) a disease control strategy including emergency vaccination can be more attractive than sticking to the standard non-vaccination cum pre-emptive culling strategy;
- When combining vaccination strategies with egg channeling measures it appears possible to, under plausible demand side responses, substantially reduce the economic costs of an HPAI outbreak for aggregate producers as well as for society as a whole;
- There exist large differential effects amongst different stakeholder groups along the supply chain 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 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 (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;
- The general insights provided by this study are also applicable to other highly integrated and complex food value chains.

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References

Allais, O., Nichle, V. (2007). Capturing structural changes in French meat and fish demand over the period 1991-2002. *European Review of Agricultural Economics,* **34**(4): 517-538.

Anonymous, 2004. Berenschot.

Anonymous. (2006a). Avian Influenza. TNS Opinion and Social.

Anonymous.(2006b). *Kwantitatieve informatie veehouderij 2006-2007*. Animal Sciences Group, Wageningen UR

Baltussen, W. H. M., Bolhuis, J. (2008). Ontwikkeling mengvoederproductie Noord-Brabant 2008-2013. LEI Wageningen UR. Den Haag

Beach, R. H., Kuchler, F., Leibtag, E., and Zhen, C. (2008) The effects of avian influenza news on consumer purchasing behaviour. United States Department of Agriculture, Economic Research Service.

Berentsen, P. B. M., Dijkhuizen, A. A., and Oskam, A. J. (1992). A dynamic-model for cost-benefit analyses of foot-and-mouth-disease control strategies. *Preventive Veterinary Medicine,* **12**(3-4): 229-243.

Bergevoet, R. H. M., Backer, J. A., van der Kroon, S. M. A., Hagenaars, T. J., Baltussen, W. H. M., Engel, B., Hoste, R., de Jong, M. C. M., Backus, G. B. C., and Van Roermund, H. J. W. (2007). Vaccinatie bij varkenspest; epidemiologische en sociaaleconomische effecten.

Brown, D. J., Schrader, L. F. (1990). Cholesterol information and shell eggs consumption. *American Journal of Agricultural Economics,* **72**(3): 548-555.

Brown, S., Madison, D., Goodwin, H. L., and Clark, F. D. (2007). The Potential Effects on United States Agriculture of an Avian Influenza Outbreak. *Journal-of-Agricultural-and-Applied-Economics,* **39**(2): 335-343.

Busani, L., Dalla Pozza, M., Bonfanti, L., Toson, M., Ferre, N., and Marangon, S. (2007). Intervention strategies for low-pathogenic avian influenza control in Italy. *Avian Diseases,* **51**(SUPPL. 1): 470-473.

Cornelis, M., Fischer, A. (2007). Risks, benefits, health and the food economy. Agricultural Economics Institute. Den Haag.

Dijkhuizen, A.A., Morris, R.S. (1997). Animal health economics – Principles and applications. University of Sydney, Australia: 306

Flach, B. (2006). EU-25 poultry and products. Avian influenza: impact on EU poultry trade and prices. USDA Foreign Agricultural Service.

Gohin, A., A. Rault (2013). Assessing the economic costs of a foot and mouth disease outbreak on Britanny: a dynamic computable general equilibrium analysis. *Food Policy,* **39**(2013): 97-105.

Gohin, A., J. Cordier, S. Krebs, and A. Rault (2013). Dynamic impacts of a catastrophic production event: the Foot-and -Mouth disease case. Risk Analysis, **33**(3): 480-492.

Ishida, T., Ishikawa, N., and Fukushige, M. (2006). Impact of BSE and Bird Flu on Consumers' Meat Demand in Japan. Graduate School of Economics, Osaka University. Osaka

Kalogeras, N., Pennings, J. M. E., and van Ittersum, K. (2008). Consumer food safety risk attitudes and perceptions over time: the case of BSE crisis. 12th Congress of the European Association of Agricultural Economics. Ghent.

Longworth, N., Mourits, M.C.M., and Saatkamp, H.W. (2014a). Economic analysis of HPAI control in The Netherlands I: Epidemiological modelling to support economic analysis. *Transboundary and Emerging Diseases,* **61**(2014): 199-216.

Longworth, N., Mourits, M.C.M., and Saatkamp, H.W. (2014b). Economic analysis of HPAI control in The Netherlands II: Comparison of control strategies. *Transboundary and Emerging Diseases,* **61**(2014): 217-232.

Longworth, N., Jongeneel, R.A., and Saatkamp, H.W. (2018). A vertically dynamic partial equilibrium model to analyze market shocks caused by HPAI control in the Dutch egg production chain. NJAS - Wageningen *Journal of Life Sciences* (2018), https://doi.org/10.1016/j.njas.2018.05.002

Mangen, M. J. J., Burrell, A. M. (2003). Who gains, who loses? Welfare effects of classical swine fever epidemics in the Netherlands. *European Review of Agricultural Economics,* **30**(2): 125-154.

Marangon, S., I., C., Rossi, E., Ferre, N., Dalla Pozza, M., Bonfanti, L., and Mannelli, A. (2005). The control of avian influenza in areas at risk: the Italian experience 1997-2003. Avian Influenza, Prevention and Control. G., K. and Schrijver, R. Wageningen, Kluwer Academic Publishers.

Mazzocchi, M. (2006). No news is good news: Stochastic parameters versus media coverage indices in demand models after food scares. *American Journal of Agricultural Economics*, **88**(3): 727-741.

Mazzocchi, M., Monache, D. D.,Lobb, A. E. (2006). A structural time series approach to modelling multiple and resurgent meat scares in Italy. *Applied Economics,* **38**(14): 1677-1688.

Nicita, A. (2008). Avian influenza and the poultry trade. Trade Team, Development Research Group, The World Bank.

Oczkowski, E., Murphy, T. (1999). An econometric analysis of the demand for eggs in Australia. *Australasian Agribusiness Review,* **7**.

Paarlberg, P.-L., Hillberg-Seitzinger, A., and Lee, J.-G. (2007). Economic Impacts of Regionalization of a Highly Pathogenic Avian Influenza Outbreak in the United States. *Journal-of-Agricultural-and-Applied-Economics,* **39**(2): 325-333.

Paarlberg, P. L., Seitzinger, A. H., Lee, J. G., and Mathews Jr, K. H. (2008). Economic impacts of foreign animal disease. United States Department of Agriculture, Economic Research Service.

Rich, K. M., Winter-Nelson, A. (2007). An integrated epidemiological-economic analysis of foot and mouth disease: Applications to the Southern Cone of South America. *American Journal of Agricultural Economics,* **89**(3): 682-697.

Saatkamp, H.W., Berentsen, P.B.M., and Horst, H.S. (2000). Economic aspects of the control of classical swine fever outbreaks in the European Union. *Veterinary Microbiology*, **73**(2000): 221-237.

Saatkamp, H.W., Mourits, M.C.M., and Howe, K.S. (2016). A framework for Categorization of the Economic Impacts of Highly Contagious Livestock Diseases. *Transboundary and Emerging Diseases*, **63**(2016): 422-434.

Scudamore, J. M. (2007). Consumer attitudes to vaccination of food-producing animals. *OIE Revue Scientifique et Technique,* **26**(2): 451-459.

Stegeman, A., Bouma, A., Elbers, A. R. W., de Jong, M. C. M., Nodelijk, G., de Klerk, F., Koch, G., and van Boven, M. (2004). Avian influenza A virus (H7N7) epidemic in the Netherlands in 2003: Course of the epidemic and effectiveness of control measures. *Journal of Infectious Diseases,* **190**(12): 2088-2095.

Varian, H. R. (1990). *Intermediate Microeconomics; A Modern Approach*. Norton, New York.