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Simulated epidemiological and economic effects of measures to reduce piglet supply during a classical swine fever epidemic in the Netherlands

M.-J.J. Mangen (1), M. Nielen (2) & A.M. Burrell (3)

(1) Wageningen University, Department of Social Sciences, Farm Management Group, Hollandseweg 1, NL-6706 KN Wageningen, The Netherlands (now working at the Agricultural Economics Research Institute, Business Park 36, 6708 PW Wageningen, The Netherlands)
(2) Wageningen University, Department of Social Sciences, Farm Management Group, Hollandseweg 1, NL-6706 KN Wageningen, The Netherlands (now working at Utrecht University, Faculty of Veterinary Medicine, Department of Farm Animal Health, Yalelaan 7, 3586 CL Utrecht, The Netherlands)
(3) Wageningen University, Department of Social Sciences, Agricultural Economics and Rural Policy, Hollandseweg 1, NL-6706 KN Wageningen, The Netherlands

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Summary

The effects of additional measures adopted during a classical swine fever (CSF) epidemic to reduce piglet supply, namely, an insemination ban, abortion of sows and killing of young piglets, are studied using a stochastic, spatial, dynamic epidemiological simulation model of the pig sector in the Netherlands. The piglet supply derived from the epidemiological model is used as input for a sector-level market and trade model that simulates the pig market in the Netherlands. Changes in the economic welfare of different stakeholders are measured, as is the net welfare effect for the economy in the Netherlands. Sensitivity analysis is performed on parameters such as destruction capacity constraints and the duration of the high-risk period.

Additional measures to reduce piglet supply are found to have no epidemiological impact, but they do involve larger economic welfare changes for stakeholders and a larger net welfare loss for the economy in the Netherlands. These findings do not support the use of the additional measures. Moreover, sensitivity analysis shows that such measures do not solve the problem of a shortage in rendering capacities.

Keywords

Classical swine fever – Economic analysis – Epidemiological model – Insemination ban – Piglet – Sector-trade model – Slaughter and rendering capacity – The Netherlands.

Introduction

During the 1997-1998 classical swine fever (CSF) epidemic which took place in the Netherlands, an insemination ban and the killing of very young piglets were imposed in much of the infected area to reduce overcrowding on farms. These additional measures were also regarded as a solution to the problem of insufficient rendering capacity (rendering involves the disposal of animals slaughtered on-farm and in slaughterhouses in rendering plants), which became evident in April 1997 (16). Pig farming is highly specialised and intensive in the Netherlands, where breeding, multiplication and fattening are usually carried out on separate farms. Producers do not have the facilities to house animals longer than necessary for their normal production cycle and therefore need to deliver pigs frequently to other farms and/or slaughterhouses. Once the transport ban was enforced, most farms became overstocked with pigs within a few weeks (16). Overstocking leads to cannibalism and fighting and pen floors may break due to the over-weight animals. The authorities in the Netherlands, supported legally and financially by the European Commission, implemented a programme to buy pigs from overstocked farms for slaughter (hereafter referred to as welfare slaughter). As regulations prevent the marketing of these animals for human consumption, the carcasses were rendered (16).

After the CSF epidemic, these additional measures became the subject of an on-going discussion. The authorities in the Netherlands favoured the measures, and offered them to farmers again, on a 'voluntary' basis, during the foot and mouth disease (FMD) epidemic which affected the country in 2001 (15). In this case, farmers could participate in welfare slaughter schemes only if they discontinued insemination for four months and aborted their pregnant sows. Farmers, however, were hostile to the insemination ban, preferring the killing of young piglets, which was regarded as having a less disruptive impact on herd management (the killing of young piglets, unlike the other additional measures, causes very little disruption to the management of the sow herd, which is divided into subgroups based on production cycle: inseminated, pregnant, farrowing, weaned sows; a temporary breeding stop or abortion of sows disrupts the management flow of sows to the next cycle). However, veterinarians opposed the killing of young piglets for ethical reasons, preferring an insemination ban. In a court action initiated by farmers, the court ruled that the insemination ban imposed during the CSF epidemic was illegal (1). Furthermore, the European Union (EU) (4) concluded that the insemination ban applied by the authorities in the Netherlands should not be repeated in the future because large-scale synchronised insemination of sows at the end of the ban disrupted the piglet market in 1998.

The epidemiological and economic effects of an insemination ban, abortion and/or the killing of young piglets have not been studied to date. The authors analyse these effects in this paper, comparing the use of one, two or all three additional measures with a situation where none of these additional measures are implemented. The goal of the study is to describe the epidemiological consequences, particularly in terms of disease spread, and the economic consequences, as measured by direct programme costs and the extent of the disruption to the piglet market. Furthermore, sensitivity analysis of the assumptions made regarding destruction capacities (killing and rendering), the length of the high-risk period (HRP), the appearance of clinical signs, the time required to implement such measures and cyclical price variation, is used to suggest possible ways of improving the implementation and effectiveness of the additional measures.

Modelling framework and sensitivity analysis

Modelling framework

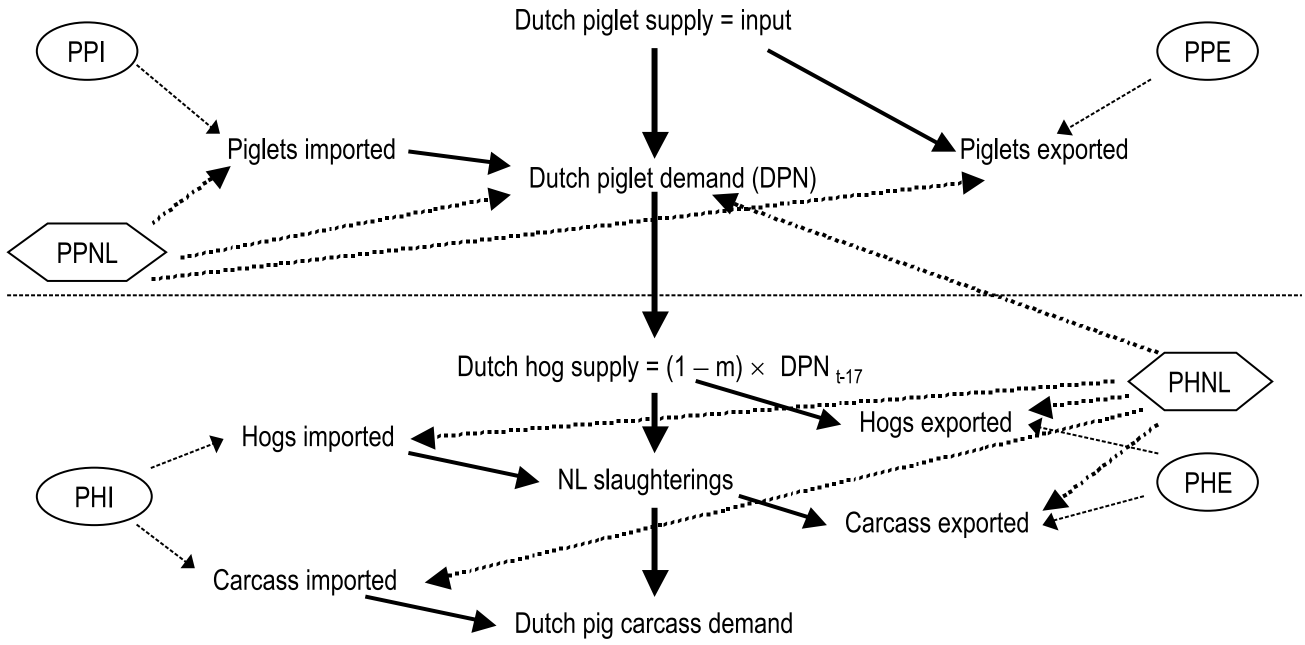
General

The modelling framework consists of a spatial, stochastic, dynamic epidemiological model (InterCSF_v3), developed by Jalvingh *et al.* (7) and further adapted by Mangen *et al.* (11) (Jalvingh *et al.* [7] developed InterCSF, based on InterSpread [6, 18] in 1997, to analyse the CSF epidemic in the Netherlands, and Mangen *et al.* [11] then adapted InterCSF to a generic CSF model). A four-part economic model developed by Mangen (9) and Mangen *et al.* is also used (12, 13).

InterCSF_v3 simulates the daily spread of disease from infected farms through three contact types (animals, vehicles and persons) and through local spread up to 2,000 m. All pig farms in the Netherlands are identified by their geographical co-ordinates, their farm type and their stock numbers. Control measures such as diagnosis of infected farms, slaughter of infected farms, movement control areas, tracing, preventive slaughter and emergency vaccination may also be simulated on a daily basis.

Preliminary analysis showed that the percentiles of the distributions of epidemic duration and number of infected farms were very stable for more than 50 replications (11, 13). Following Jalvingh *et al.* (7), the authors performed 100 replications per scenario in InterCSF_v3 in which all replications began with the same infected multiplier farm in an area with the highest pig density in the Netherlands. However, each epidemic developed differently thereafter because of the stochastic nature of the model.

A micro-economic model (EpiPigFlow) converts the daily output from InterCSF_v3 into a weekly flow of piglets, which becomes input for the Dutch Pig Market (DUPIMA), a partial equilibrium model of the pig market in the Netherlands. This model simulates weekly market prices, domestic off-take and trade flows in piglets, pigs and pig meat at sector level (flow diagram in Fig. 1) and allows the simulation of different trade scenarios (9, 11, 12, 13), although in this paper, only one scenario is presented. A second micro-economic model (EpiCosts) uses output from InterCSF_v3 and the simulated market prices from DUPIMA to calculate the programme costs incurred by the authorities in the Netherlands in controlling the epidemic. The authors assumed that the EU budget always meets 50% of the total extra expenditure on control measures. The changes in producer surplus of pig producers inside the quarantine zones were calculated in EpiCosts based on the simulated pig prices. The economic welfare changes of pig producers outside quarantine zones and of consumers were calculated in an Excel spreadsheet, using the estimated results of DUPIMA. Following Just *et al.* (8), producer surplus included only the quasi-rents accruing to inputs used in farming. Quasi-rents accruing to marketing inputs were included along with the surplus of the final consumer in consumer surplus. The category 'consumers' included the surplus changes of slaughterhouses/processing industry, retailers and final consumers. As in Mangen (9) and Mangen *et al.* (11, 12, 13), total margins of retailers were assumed to be unchanged in all scenarios. Welfare effects were measured in relation to a reference (non-epidemic) situation. Aggregation of



m = mortality (a 2% mortality rate is assumed for the seventeen week growth period from 25 kg piglets [growers] to finisher pigs [hogs])
PHE = hog price in country to which the Netherlands exports hogs or pig carcasses
PHI = hog price in country that exports hogs or pig carcasses to the Netherlands
PPE = piglet price in country to which the Netherlands exports piglets
PHNL = hog price in the Netherlands
PPI = piglet price in country that exports piglets to the Netherlands
PPNL = piglet price in the Netherlands

Fig. 1
The simulated Dutch Pig Market (DUPIMA)
Source: Mangen *et al.* (11)

the welfare changes of producers (pig producers inside and outside quarantine zones), consumers and the Government yields the net economic welfare effect for the economy in the Netherlands. A detailed description of the welfare analysis is given in Mangen (9) and Mangen *et al.* (12), or is available on request from the first author.

Simulating one scenario with 100 replications in InterCSF_v3 required, depending on the scenario, between 15 minutes to more than 8 hours calculation time on a personal computer. EpiPigFlow and EpiCosts required less and more calculation time, respectively, for 100 replications per scenario. However, DUPIMA slowed the whole process, as the model could handle only one replication at a time. The authors therefore decided to work in two steps (11, 13). First, 100 replications per simulated scenario were run in InterCSF_v3. The 100 replications were then ranked according to their epidemic size (length in days). The average of the three replications, centred on the 5th, 50th and 95th percentiles of 'size', were taken to represent 'small', 'medium' and 'large' epidemics, respectively. The mean of the last five ranked replications represents the 'worst case' epidemic. In a second step, these fourteen replications per simulated scenario were then simulated in the other modules of the modelling framework described above.

The three additional animal welfare measures

Adoption of an insemination ban stops the birth of piglets on sow farms 115 days after the start of the measure and stops the supply of growers (25-kg piglets) 185 days after the start of the measure. Aborting pregnant sows from day 0 until day 40 of pregnancy (15) avoids the birth of piglets 75 days later and stops the supply of growers 145 days after implementation. In contrast, the killing of young piglets at around ten days of age does not interrupt the flow of newborn piglets on a farm, but stops the supply of growers two months after implementation.

If all three measures are implemented together, the killing of young piglets can be applied only as long as piglets are born and the abortion of sows will take place only as long as there are inseminated sows. Moreover, the authors assume that the abortion of sows is always combined with an insemination ban resulting in, at most, a single abortion event per sow until the ban is lifted.

The authors assume that the three additional measures are lifted at the same time as the quarantine zone and that sows are re-inseminated gradually, leading to a normal supply of growers after 185 days (115 days pregnancy and 70 days for rearing). If only the killing of very young piglets is used, a normal supply of growers from the farms involved is restored after 60 days.

An insemination ban and the abortion of sows also prevent the possible birth of carrier piglets (piglets infected as foetuses that spread the CSF virus throughout their lives). The absence of carrier piglets, due to one or more of these measures, effectively eliminates all routes of spread related to carrier piglets.

The authors assume that slaughtered ten-day-old-piglets are compensated at the rate of 61% of the weekly piglet price, as in the 1997-1998 CSF epidemic. Compensation payments for sows under an insemination ban are also based on those paid during the CSF epidemic (14). For simplicity, the same compensation payments were assumed for aborted sows. The variable costs saved by not producing piglets or not raising growers, as well as the compensation payments paid, are included when calculating the economic welfare change for piglet producers inside a quarantine zone.

Simulated scenarios

In the simulations, the first infected farm is always situated in a densely populated livestock area (DPLA) and in this study, the only livestock species considered are pigs. Mangen *et al.* (9, 11) found that when the index farm is in a DPLA rather than a sparsely populated pig area, a larger epidemic will occur. Control measures are adopted comprising stamping-out infected herds, tracing all contacts, setting up quarantine zones (protection and surveillance zones) around infected herds, with movement restrictions and preventive slaughter on all farms in a radius of 750 m to 1,000 m around a detected herd (preventive slaughter is not a compulsory control measure according to EU legislation [3]). Inside the quarantine zone, the frequency of different control actions (surveillance and serological screening) is based on the contingency plan of the animal health authorities of the Netherlands for a future epidemic (17). In the case of a long-lasting movement standstill, welfare slaughter of hogs and growers to avoid overcrowding is always assumed. This constitutes the base strategy (which corresponds to the preventive slaughter strategy [PS-strategy] described in Mangen *et al.* [11]).

The base strategy is compared with three alternative scenarios. In Alternative 1 (favoured by the Government of the Netherlands), prohibition of insemination, sow abortion and the killing of young piglets are all assumed to be adopted as additional measures within movement standstill areas. In Alternative 2 (favoured by the veterinarians), only an insemination ban and sow abortion are used in addition to the base strategy. In Alternative 3 (favoured by the farmers in the Netherlands), the only measure adopted to reduce stock numbers within quarantine areas is the killing of young piglets.

For simplification, only one trade scenario was considered, in which trade was assumed to only be prohibited within quarantine zones.

Sensitivity analyses

Destruction capacity

Killing very young piglets was regarded as a solution to the shortage of rendering capacity in the 1997-1998 CSF epidemic (16) (a young piglet has a much lower carcass weight than a 120 kg pig, which might require slaughtering within the welfare slaughter measures. The killing of very young piglets was therefore expected to reduce the tonnage of carcasses to be handled by rendering plants). Pigs were either killed on the farm in the case of infected and preventively-slaughtered farms, or slaughtered in designated slaughterhouses in the case of welfare slaughter on all other farms. In the first months of the 1997-1998 CSF epidemic, all carcasses were immediately rendered. Hence, the rendering capacity rather than the slaughtering capacity was the limiting factor. The simulations of the authors assume that welfare slaughter of 'healthy' pigs (hogs and growers) always takes place in specific slaughterhouses and welfare-slaughtered pigs are rendered only when capacity is available. Control measures are given priority for available destruction capacity (killing and rendering), assuming a maximum capacity of five farms per day in the first week, rising to fifteen farms per day from the third week onwards (capacity-base = base strategy). If limited destruction capacity were used for both control measures and welfare slaughter, less capacity would be available for control measures, possibly resulting in larger epidemics. Two sensitivity analyses were therefore performed: the destruction capacity for control measures was maintained at a maximum of five farms per day (capacity-low A) and the three additional measures, aimed at increasing destruction capacity available for control measures from five to ten farms per day (all three additional measures are supposed to result in a reduction of available pigs that might have to be slaughtered within welfare slaughter measures and as such, be destroyed in rendering plants), were adopted from approximately four months into the epidemic (capacity-low B).

High-risk period

The period between the first farm in a region becoming infected and the first detected case in that region is referred to as the HRP. The HRP is one of the most important parameters for determining the size of an outbreak, defining the period in which the virus can circulate freely and is able to infect pig herds (5). For all scenarios, the authors randomly drew a HRP from a truncated lognormal curve (21-100), with 49 days as mean (HRP-base = base strategy). For sensitivity analyses, the whole curve was displaced to the left (HRP-short) and right (HRP-long) by fourteen days to obtain shorter and longer HRPs with, as possible consequences, smaller or larger epidemics. The base and three alternative scenarios are simulated with the shorter and longer HRPs.

Clinical signs

Adult pigs show less clear clinical signs than young pigs (2). Measures to interrupt the flow of piglets, as simulated in this paper, will lead to a reduction of the number of young piglets on the farm. Consequently, the probability of clinical detection on farms might decrease as well. For sensitivity reasons, the authors therefore decreased the probability of detection based on clinical signs for the base scenario by 10% for all farms and for the whole epidemic. To be in line with the earlier applied sensitivity analysis (9, 11), a 10% decrease of the simulated values of the base scenario was chosen.

Deciding when to implement such measures

The hypothesis of the authors is that using additional measures to reduce pig numbers only makes sense when a large epidemic is expected. The epidemics simulated under the base strategy are therefore used to determine if and when a large epidemic might be predicted, based on the number of detected farms to date. InterCSF_v3 output provides the daily number of detected farms. The cumulative detected cases by the end of the first week and the sixth week after detection are calculated. The correlation between those two criteria and the length of the epidemic is examined. For each replication, the authors checked whether a threshold level of five, ten or fifteen detected farms within the first week, or of 40, 50 or 60 detected farms within the first six weeks, was met. This procedure was repeated for all 100 replications of base (HRP-base), as well as for base (HRP-short) and base (HRP-long). All 100 replications were ranked according to the epidemic length and divided into quarters. For each quarter, the number of replications that met the threshold is reported. The number of replications that met the threshold and that were ranked according to the epidemic length to be among the five or ten longest were also reported.

Cyclical variation

The net economic welfare effects were calculated using a high pig price year (model calibrated to produce 1996 price levels in a non-epidemic situation) and a low pig price year (model calibrated to produce 1999/2000 price levels).

Results

Epidemiological results

Comparison of the base strategy with Alternatives 1, 2 and 3, assuming the base HRP showed no difference in the size and/or the length of the simulated epidemics. Prohibition of insemination, abortion and/or the killing of young piglets thus have no effect on disease spread.

Economic results

General

Table I summarises the economic welfare effects for the different stakeholders (pig producers, consumers and the Netherlands Government funds) and the net economic welfare effect for the economy of the country relative to a non-epidemic situation. These effects are calculated for a low and high pig price year. Although some small differences in the different economic welfare effects between low and high pig price years can be observed, the general conclusion is the same. Therefore, only the results for the low pig price year are shown.

For all four scenarios (base strategy, Alternatives 1, 2 and 3) in general, the reduction in national supply is not matched by a drop in total demand. Therefore, pig prices outside quarantine zones rise. Hence, as found by Mangen *et al.* (9, 11, 12, 13), consumers lose and producers gain collectively, although the overall gain to pig producers hides the fact that producers inside quarantine zones lose. Moreover, pig producers inside a quarantine zone are not a homogeneous group, being either piglet, hog or breeding stock producers. If piglet producers are not destocked, they may continue to produce and sell their

Table I
Changes (in millions of euros) in producer surplus (PS), consumer surplus (CS), public funds in the Netherlands and the net welfare of small, medium, large and worst case epidemics (ranked according to the length of the epidemic) for four scenarios, assuming a trade ban imposed on the quarantine zones only and a low pig price year

Scenario	Base-strategy				Alternative 1				Alternative 2				Alternative 3			
Epidemic size	Small	Medium	Large	Worst	Small	Medium	Large	Worst	Small	Medium	Large	Worst	Small	Medium	Large	Worst
Welfare change in PS	79	169	261	313	99	224	322	374	87	203	320	374	91	196	283	339
Welfare change in CS	–45	–102	–171	–203	–62	–175	–312	–362	–45	–136	–270	–318	–62	–145	–237	–274
Public funds in the Netherlands	–25	–61	–102	–125	–30	–74	–117	–139	–27	–67	–112	–135	–28	–68	–111	–133
Net welfare effect	9	6	–12	–15	6	–24	–108	–127	14	–1	–62	–79	1	–16	–65	–68

ready-to-deliver piglets for welfare slaughter. In this case, they are compensated based on weekly pig prices and therefore they may gain as well. Piglet farms that are destocked because of control measures receive no compensation for their idle capacity. Producer losses are measured after payment of any offsetting compensation.

However, when production on piglet farms is interrupted because of measures to reduce livestock numbers for welfare reasons, they are assumed to receive compensation to cover part of their losses. For specialised fattening farms (hog producers), welfare slaughter leads to empty stables after approximately four months under quarantine restrictions.

Piglet supply disruption

All three additional measures were lifted at the same time as the quarantine zone. Depopulated infected and preventively-slaughtered farms were assumed to restock gradually after the lifting of the quarantine zones, regardless of the scenario simulated. However, piglet farms where production was interrupted by measures under Alternatives 1, 2 or 3 required some additional time after the lifting of the quarantine zone before being able to supply the market with growers again. This resulted in larger welfare changes for producers and consumers due to longer disruption of the piglet supply. Alternative 3 (killing of young piglets) showed the smallest decrease in net economic welfare and the least additional time before normal supply was restored. After the end of the epidemic, Alternative 1 required the most additional time before supply was normalised.

Direct costs

Table I shows the programme expenditure share of the Netherlands (equal to 50% of the total programme costs). Total expenditure increases with the size of the epidemic. Compensation payments for welfare slaughter schemes are always the largest share of total costs. These payments are highly related to the length of the epidemic and the number of farms in quarantine zones. With the use of additional measures to reduce piglet supply, total programme costs are higher than with the base strategy, even for the worst case epidemics. This is because the slight drop in compensation payments for destocked, infected and preventively-slaughtered farms and in organisation costs, is outweighed by additional compensation payments for the additional measures for reducing piglet supply.

Sensitivity analyses

Destruction capacity

When the destruction capacity allocated to control measures is reduced by competition from welfare slaughter carcasses, larger epidemics are obtained (Table II). Allowing the three additional measures for reducing piglet supply to increase the destruction capacity available for control measures from four months onwards (capacity-low B) has an effect relative to the capacity-low A scenario only for the worst case epidemics, but still results in larger epidemics than in the base scenario. Table II shows the mean, the 95 and the 100 percentiles for several output parameters based on 100 replications of InterCSF_v3.

Figure 2, based on the longest epidemic from the 100 replications, illustrates that welfare slaughter can cause an enormous logistic problem, regardless of the scenario simulated, even when assuming that welfare-slaughtered pigs are stored until rendering capacity becomes available. Compared to the base scenario, the use of additional measures (Alternatives 1 to 3) does not lead to a decrease in the large number of welfare-slaughtered pigs within the first weeks of an epidemic (Fig. 2). Furthermore, the large number of pigs slaughtered in the first weeks greatly exceeds the calculated reduction in destruction capacity of approximately ten farms per day. Consequently, if carcasses of pigs slaughtered due to control measures are not given priority over those arising from welfare slaughter, even larger epidemics than simulated under scenarios A and B would result.

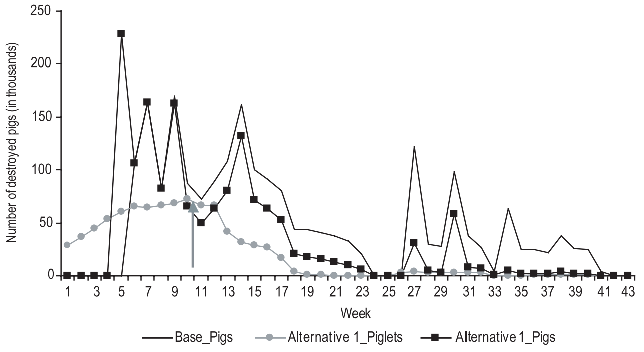
Figure 2 shows that Alternative 1 begins to reduce the total number of pigs slaughtered for welfare reasons in week 10

Table II
Effects of varying destruction capacity (farms/day) available for control measures: average effects and effects for the simulations ranked 95 and 100 according to the corresponding epidemiological outcome

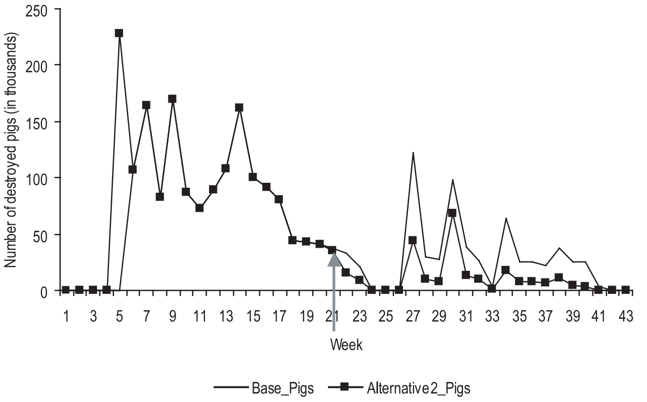
Scenario	Base			Reduced destruction capacity					
				Capacity-low A			Capacity-low B		
Mean/ percentile	Mean	95%	100%	Mean	95%	100%	Mean	95%	100%
Number of infected farms	46	92	244	62	95	1,031	57	95	750
Number of detected farms	29	65	150	45	70	962	39	70	619
Duration (days)	134	210	280	138	226	444	136	219	331

Base: Week 1 = 5 farms/day
Week 2 = 10 farms/day
From week 3 = 15 farms/day
Scenario A: 5 farms/day
Scenario B: week 1-17 = 5 farms/day
From week 17 = 10 farms/day

a) Base-strategy versus Alternative 1



b) Base-strategy versus Alternative 2



c) Base-strategy versus Alternative 3

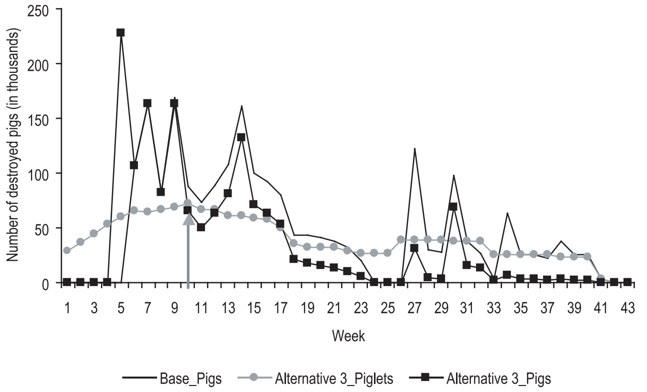


Fig. 2
Number of pigs and of young piglets welfare-slaughtered and rendered per week for the longest epidemic of the base scenario
The arrow indicates the first week in which the number of welfare-slaughtered pigs is lower with the alternative than with the base strategy

compared with the base strategy. However, in Alternative 1 a significant number of young piglets are also killed. Even more young piglets are killed under Alternative 3 (killing of young piglets only). Alternative 2 involves no killing of young piglets, but the insemination ban plus abortion reduces the number of welfare-slaughtered pigs compared to the base strategy only from week 20-21 onwards. In all the alternative scenarios, the highest weekly incidence of welfare slaughter occurs before any of the additional measures for reducing piglet supply show an effect. In other words, the duration of the simulated epidemics is too short to allow any benefits from these measures.

High-risk period

Changing the average HRP has the predicted impacts on epidemic size and length (Table III). All results show the mean, the 5th, 50th and 95th percentiles for several output parameters based on 100 replications of InterCSF_v3. Results are exactly the same for the base strategy as for Alternatives 1, 2 and 3. Only by forcing the model to simulate large and long-lasting epidemics (multiplying transmission probabilities by 1.5), was a slight impact of the additional measures on epidemic size and length observed. However, the impact was limited to the worst cases only (95th percentile and higher). If Alternative 1 and Alternative 3 were applied and compared with the base strategy, the number of infected farms decreased slightly from 404 (95th percentile) and 653 (100th percentile), respectively, to 379 and 648, respectively. The length of the epidemic decreased from 316 days (95th percentile) and 657 days (100th percentile), respectively, to 309 days and 455 days, respectively. Comparing Alternative 2 with the base strategy, a slight but insignificant decrease in the number of infected farms was observed, only for the 100th percentile (from 653 to 648).

Clinical signs

A 10% lower probability of detection based on clinical signs throughout the epidemic results in a slightly higher average number of infected farms, 48 versus 46 (base strategy), and a slightly longer average epidemic, 141 versus 134. Given that serological screening is used monthly on farms situated in a quarantine zone, the reduced clinical detection rate is probably covered by subsequent detection based on serology.

Use of detected cases as a prediction for epidemic length

Results are identical for the base strategy and for Alternatives 1, 2 and 3, so only results for the base strategy are shown. For the scenario with the base HRP, a significant positive correlation is found between the two criteria and the length (in days) of an epidemic, with the number of detected cases after six weeks showing a higher correlation coefficient (0.54) than the number of detected cases within one week (0.45). A higher positive correlation (0.72 and 0.89) is found between the two criteria and the size of an epidemic measured in terms of the number of detected farms. Table IV shows that the overall probability of at least five cases in the first week is 0.37. This probability is, however, 0.7 for the ten largest epidemics and one for the five largest epidemics. For a long HRP, these indicators are less decisive. When a short HRP is assumed (results not shown), none of the replications reach these thresholds.

Table III
Effects of varying the length of the high-risk period (HRP) given the base strategy: average effects and effects for the simulations ranked 5, 50 and 95 according to the corresponding epidemiological outcome

Scenario	Base HRP				Shorter HRP				Longer HRP			
Mean/percentile	Mean	5%	50%	95%	Mean	5%	50%	95%	Mean	5%	50%	95%
Number of infected farms	46	9	38	92	22	2	18	53	83	25	68	192
Number of detected farms	29	4	25	65	13	1	11	32	56	14	46	142
Number of preventive slaughters	136	40	113	281	72	27	58	154	246	80	203	575
Duration (days)	134	65	127	210	109	50	104	176	145	93	138	213

Discussion

Epidemiological effects

If measures are used to interrupt the flow of piglets, the number of young piglets on a farm will decrease, and the probability of clinical detection will therefore also decrease. However, assuming a lower probability of clinical detection for the whole epidemic (as was carried out in the sensitivity analysis) led to only a slight increase in the number of infected farms and in the length of the epidemic. Moreover, the measures only decrease the number of young animals over time, so clinical detection remains high at the beginning of the epidemic. These strategies, combined with monthly serological screening, do not seriously hamper the detection of infected farms.

Economic effects

The use of one, two or all three additional measures had a more negative economic impact on the pig sector in the Netherlands than the base strategy. All measures increased the number of piglet producers unable to produce for a longer period and caused a longer disruption of the piglet supply beyond the end of the epidemic in the Netherlands. The assumption of gradual restocking and re-insemination probably results in an underestimation of the likely piglet supply disruption. In particular, small hog producers tend to re-stock their hog farms all at once (all-in, all-out system), whereas larger farms have a more continuous flow of tradable pigs. Furthermore, at the end of an epidemic the restrictions are lifted from a large number of farms (Fig. 3). A synchronised significant group of producers that practice all-in, all-out restocking, which together may have a significant market effect, may result in a long-lasting cycle of market disruption. However, the framework used here, does not permit the reproduction of such long-lasting market disruption effects.

All three measures are intended to stop the supply of growers during an epidemic and, as such, the supply of hogs. However, this effect is only visible at a late stage and hence can be of no,

Table IV
Number of replications for ranked groups of 25, 100, 10 and 5 replications for high-risk period (HRP)-base and HRP-long, given the base strategy, that meet various thresholds regarding number of detected farms one week and six weeks after the first detection, respectively

Scenario	Base HRP				Long HRP					
Criterion	After one week		After six weeks		After one week			After six weeks		
Threshold[a]	≥ 5	≥ 10	≥ 40	≥ 50	≥ 5	≥ 10	≥ 15	≥ 40	≥ 50	≥60
1-25 ranked replications (n = 25)	3	0	0	0	16	7	0	4	2	0
26-50 ranked replications (n = 25)	7	0	0	0	22	9	2	9	6	2
51-75 ranked replications (n = 25)	13	2	2	0	22	13	6	14	9	6
76-100 ranked replications (n = 25)	14	5	5	2	20	15	8	14	10	6
Total (n = 100)	37	7	7	2	80	44	16	41	27	14
10 largest replications (n = 10)	7	3	3	1	8	6	5	6	5	2
5 largest replications (n = 5)	5	2	2	0	4	2	1	2	1	1

a) number of detected infected farms one week and six weeks after the first detected case, respectively

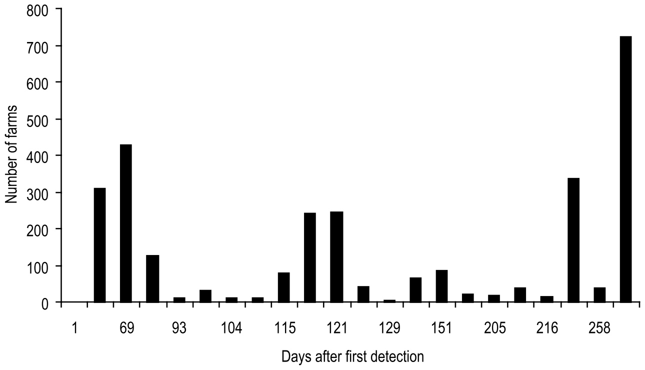


Fig.3
Number of farms per day becoming free of restrictions (longest simulated epidemic)

or only minor, importance in reducing the number of welfare-slaughtered healthy pigs. Thus, the compensation payments for regular welfare measures are hardly reduced at all. These compensation payments comprise the biggest share of public expenditure occasioned by an epidemic. The extra compensation paid for very young piglets killed and/or for sows under an insemination ban or aborted further increases the total compensation paid. Thus, using the additional measures increases the total programme costs of an epidemic.

Welfare slaughter and limited destruction capacities

Logistic and ethical reasons may favour the combined insemination ban and the abortion of sows, since these measures prevent later killing of piglets or hogs. In contrast, the killing of young piglets will not reduce the number of pigs killed, but will reduce only the total tonnage of slaughtered animals. In addition, this measure does not disrupt the sow herd management. The killing of young piglets, as favoured by farmers, may therefore solve some logistic problems as well as later animal welfare problems, although the measure may raise ethical objections.

A lower piglet supply inside quarantine zones due to the use of the additional measures is only visible, at the earliest, two to three months after implementation. Using such additional measures will not solve the often acute shortage of destruction capacity at the beginning of an epidemic, resulting from competition for rendering between carcasses slaughtered due to control measures and those due to welfare slaughter schemes. Other options are therefore needed to solve the capacity problem. Designation of specific slaughterhouses inside quarantine zones for welfare slaughter and storage of welfare-slaughtered carcasses until rendering capacity is available, from the beginning of an epidemic, are probably the best options for overcoming shortages in destruction capacity. On-farm killing and rendering capacities would then be reserved in priority for destruction due to control measures. In the 1997-1998 CSF epidemic, specific slaughterhouses were designated for welfare slaughter, but as welfare-slaughtered pigs were rendered simultaneously with pigs killed due to control measures, rendering capacity was insufficient. Only later during the epidemic was the problem partly solved by cold-storage of the welfare-slaughtered carcasses (16).

Other options that might reduce the number of pigs slaughtered and rendered under the welfare slaughter option are: a smaller radius for quarantine zones, a shorter movement standstill period, or, as applied first in Belgium in the 1994 CSF epidemic (19), controlled slaughter of pigs (instead of welfare slaughtering) in the 3 km-10 km zone for market outlets. Controlled slaughter refers to slaughtering in designated slaughterhouses where the meat is marked and can then be sold as fresh meat. The first two options may be risky as they could favour the spread of the disease, especially as long as the epidemic is not under control. However, assuming strict sanitary controls, marketing of meat from controlled slaughter, involves only minimum risk, as the probability that an infected farm will not be detected is rather small. Although this option requires some complicated logistics, it would reduce the number of carcasses to be rendered as well as compensation expenditure. Furthermore, the short-run market disruption due to imposition of quarantine zones might also be reduced since fewer pigs will be taken out of the market.

Timing of the implementation decision

This study supports the hypothesis that additional measures should only be implemented when an extremely large epidemic is expected. Mangen *et al.* (9, 11) showed that pig density around the first detected outbreaks is a good indicator of whether a large epidemic might be expected. In this study, where all outbreaks begin in a high-density area, a positive correlation was found between the number of detected farms in the early weeks and epidemic size. The more cases are detected in the first six weeks, the more likely the epidemic is to be large. In addition to pig density and number of early detections, other indicators are required to provide better forecasts of epidemic size. The length of the HRP could be a good indicator. Certain indicators may be more reliable than others for predicting epidemic 'size'.

Conclusions

The use of an insemination ban, the abortion of sows and the killing of very young piglets had no impact on the size and the length of the epidemic. Whether pig prices were high or low, these measures resulted in higher direct costs and greater disruption to piglet supply on farms after the lifting of all restrictions. However, ethical and logistic reasons may favour some of the measures. This study suggests that these measures could increase the overall cost to society by 250% to 700% for the largest epidemics, or turn a small net gain into a loss for a medium-sized epidemic. Decision-makers need to weigh these costs against public acceptance. In any case, an insemination ban is recommended for ethical reasons in the case of an emergency vaccination campaign if all vaccinated herds have to be ultimately slaughtered and rendered (10).

This study indicates that, on economic grounds, the additional measures should be used only when an extremely large epidemic is expected, and they should also be implemented from the very start of the epidemic. Future research is required to help find indicators of the expected size of an epidemic at a very early stage.

Finally, this study shows that control measures (stamping-out infected herds and preventively slaughtering neighbouring farms) should have a priority claim on destruction capacity. Decision-makers should be aware of the need for alternative solutions to dispose of animals that are killed and rendered for welfare reasons.

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Simulation des effets épidémiologiques et économiques de mesures adoptées durant une épizootie de peste porcine classique aux Pays-Bas pour réduire l'offre de porcelets

M.-J.J. Mangen, M. Nielen & A.M. Burrell

Résumé

Les auteurs présentent un modèle stochastique, spatial et dynamique de simulation épidémiologique de la filière porcine néerlandaise. Ce modèle permet d'étudier les effets des mesures complémentaires (l'interdiction de l'insémination, l'avortement provoqué des truies et l'abattage des jeunes porcelets) introduites durant une épizootie de peste porcine classique pour limiter l'offre de porcelets. Déterminée par le modèle épidémiologique, cette offre est utilisée comme paramètre d'entrée dans une modélisation du marché sectoriel et des échanges commerciaux simulant la filière porcine néerlandaise. Les auteurs ont évalué l'impact des changements sur le bien-être économique des acteurs de cette filière, de même que leurs effets nets sur la santé économique des Pays-Bas. Divers paramètres, comme les contraintes liées aux capacités de destruction et la durée de la période à haut risque, ont été soumis à une analyse de sensibilité.

Les auteurs ont constaté l'absence d'impact épidémiologique des mesures destinées à restreindre l'offre de porcelets. En revanche, elles ont porté un sérieux coup au bien-être économique des parties concernées et ont pesé encore plus lourdement sur l'économie néerlandaise. Ces résultats n'encouragent donc pas à prendre de telles mesures. De plus, l'analyse de sensibilité démontre leur incapacité à résoudre le problème du manque de stations d'équarrissage.

Mots-clés

Analyse économique – Capacité d'abattage et d'équarrissage – Interdiction de l'insémination – Modèle épidémiologique – Modèle filière-commerce – Pays-Bas – Peste porcine classique – Porcelets.

■

Simulación de las consecuencias epidemiológicas y económicas de las medidas destinadas a reducir la producción de lechones durante una epidemia de peste porcina clásica en los Países Bajos

M.-J.J. Mangen, M. Nielen & A.M. Burrell

Resumen

Los autores describen la aplicación al sector porcino neerlandés de un modelo de simulación epidemiológica estocástico, espacial y dinámico con el que se estudiaron los efectos de las medidas complementarias adoptadas durante una epidemia de peste porcina clásica para reducir la producción de lechones, a saber: prohibición de inseminaciones, realización de abortos en cerdas y sacrificio de lechones. Los datos sobre la producción de lechones obtenidos con el modelo epidemiológico se introdujeron en un segundo modelo que simula el mercado y el comercio porcinos en los Países Bajos. Así pudieron cuantificarse los cambios en el nivel de bienestar económico de distintos sectores del ramo, así como el efecto neto de las referidas medidas sobre el bienestar económico del país. Se aplicó un análisis de sensibilidad a parámetros tales como los factores limitativos de la capacidad de destrucción o la duración de la fase de alto riesgo.

El estudio revela que las medidas complementarias para reducir la producción de lechones no surtieron el menor efecto epidemiológico, aunque desde el punto de vista económico acarrearan cambios importantes para los distintos sectores del ramo e importantes pérdidas netas para el país. Estos resultados no avalan la aplicación de medidas complementarias. El análisis de sensibilidad, además, pone de manifiesto que esas medidas no resuelven el problema de la insuficiente capacidad de procesamiento de cadáveres animales.

Palabras clave

Análisis económico – Capacidad de sacrificio y de procesamiento de cadáveres animales – Lechones – Modelo de comercio sectorial – Modelo epidemiológico – Países Bajos – Peste porcina clásica – Prohibición de inseminación.

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