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Benefits and costs of measures to tackle the outbreak of African swine fever in Sweden

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ABSTRACT

A common rule in many countries for mitigating the damage caused by African swine fever (ASF) is to eradicate the virus at the outbreak in order to prevent its dispersal and the associated social costs of depopulating infected domestic pigs. The economic performance of this practice, as measured by five different evaluation criteria (net present value, benefit-cost ratio, rate of return, internal rate of return, and payback time), depends on the type of control cost and the spatial and dynamic allocation of benefits, i.e. avoided losses from infected domestic pig farms. The present paper calculates the direct and indirect costs of immediate control measures during an ASF outbreak in wild boars in Mid Sweden. The direct costs include expenses incurred for surveillance, laboratory tests, depopulation of wild boar etc., while the indirect costs are borne by firms and people in the area in relation to movement restrictions. The calculations showed that the total cost of control measures amounted to 28 million euros, with indirect costs making up 40 % of this figure. The benefits were greatly dependent on the speed of ASF dispersal and assumptions about pig farmers' investment responses, which implied large variations in each of the five evaluation criteria.

1. Introduction

Domestic animals are essential for food provision and security, with approximately 1.3 billion people depending for their livelihoods on livestock, which also play an important role in the economy and cultural traditions (FAO Food and Agriculture Organisation., 2024). Disease poses a threat to these values, and some of the most challenging issues are presented by diseases transmitted from wild to domestic animals, such as African swine fever, classical swine fever, and foot and mouth disease (Brown et al., 2021). African swine fever (ASF) represents a global threat to pig farms and the pork industry. It is caused by a virus which is believed to have evolved in eastern Africa, and can spread long distances through contacts between wild and domestic pigs, with material contaminated by the virus, people movements and ticks (Penrith, 2009). It was introduced into Georgia in 2007, before spreading to eastern and central Europe until 2015 and China in 2018, with further dispersal into east and southeast Asia, before reaching Haiti and the Dominican Republic in 2021 (Ackerman, 2022). The virus is not zoonotic, but there exist no vaccines and the mortality rate is almost 100 % in susceptible domestic and wild pig populations.

The economic effects of ASF can be substantial for local farmers, the pig industry and other sectors in an economy. For example, the results of You et al. (2021) indicate that the ASF outbreak in China during 2018–2019 reduced the country's gross domestic product (GDP) by approximately 0.8 %, while Nguyen-Thi et al. (2021) showed that the outbreak in Vietnam in 2019 resulted in a decrease in GDP of at least 0.3 %. Huang et al., (2021) reported a price increase by 200 % of live pigs in China after the actual outbreak in 2018. Mason D'Croz et al. (2020) calculated the global implications of this outbreak by projecting global price increase of pork by up to 85 %. Tozooneay et al. (2023) predicted an increase by 13 % of the retail price of pork of a potential outbreak in the USA. Such effects can be mitigated by different types of eradication and prevention measures. However, control measures, such as decreases in feral and domestic pig populations, containment, and movement restrictions for people, can be costly. An important economic question is whether the benefits presented by the measures in terms of avoided losses for firms and sectors are greater than the cost of the measures. While there is a large body of literature on the transmission and risks of ASF (reviews in Brown et al., 2021; Ackerman et al., 2022), only a few studies have calculated the benefits and costs of measures to

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control ASF.

Benefit-cost analysis as a tool for evaluating and comparing the economic outcomes of projects has a long tradition in economics and can be traced back to the early 18th century (reviews in Persky, 2001; Jiang and Magraff, 2021). The literature offers a range of criteria for ex ante or ex post evaluation of projects, of which net benefits, benefit-cost ratios, return on investment, internal rate of return and payback time are the most common (e.g. Boardman et al., 2011). The benefit-cost ratios show the relationship between total benefits and costs, which is related to the rate of return which measures the overall net benefit as a percentage of the cost. The internal rate of return reflects the annual rate of return and the payback time shows the number of years necessary for the benefits to equate to the costs. The different criteria have their advantages and disadvantages, and it is generally suggested that several criteria be used to evaluate animal disease projects (Erb, 1988).

Calculations of the benefits and costs of measures to control animal disease outbreaks are more recent and have been applied to mad cow disease, foot and mouth disease and African swine fever (reviews in Ngategize and Kaneene, 1985; Bennett, 1992; Pritchett et al., 2005; Kappes et al., 2023). Common to all the studies, irrespective of the type of disease and regional application, has been the difficulty of calculating the benefits of control measures, i.e. avoided losses due to intrusions of the disease. This requires information about the spatial and dynamic dispersal of the disease and associated costs on the farms, in the value chain, for consumers and the access to export markets. In general, the costs of control measures, such as expenditure on surveillance, laboratory analyses and depopulation of livestock on affected farms, depend on the type of disease and are regarded as relatively easy to calculate. However, ASF can be controlled by targeting the vector of the disease, wild boar populations and/or the farms with detected outbreaks. The targeting of wild boar populations prevents intrusion onto pig farms, but generates costs in terms of losses in recreational values when restrictions are imposed on people's movements, and in incomes for companies in different sectors (e.g. forestry, tourism) operating in the controlled region.

Four earlier studies have calculated the benefits and costs of measures to control ASF (Bech-Nielsen et al., 1993; Rendleman and Spinelli, 1999; Fasina et al., 2012; Slatyer et al., 2023). They applied to different regions and considered different time perspectives when calculating benefit-cost ratios, showing a wide variation within and between the studies (Table A1 in the Appendix). Only Slatyer et al. (2023) considered the control of ASF in populations of wild boar and the domestic pig production system, and calculated the costs and benefits of controlling potential outbreaks in Australia. Benefits were calculated under different scenarios concerning the dispersal of the virus to domestic pig farms using a pig sector model. Bech-Nielsen et al. (1993) estimated the costs of different programmes to control ASF in Spain and calculated their benefits by combining epidemiological data on the spread of the virus with a pig sector model. Rendleman and Spinelli (1999) also integrated an epidemiological model of virus dispersal with a pig sector model to calculate the benefits and costs of an existing swine health programme under five different scenarios of ASF outbreaks on pig farms in the USA. Fasina et al. (2012) performed a farm-level benefit-cost analysis of control measures in Nigeria.

The purpose of the present study is to calculate the benefits and costs of measures implemented to control an actual outbreak of ASF in wild boar in September 2023 in a small area of Mid Sweden. Several types of actions were implemented immediately upon detection of the virus, which included surveillance, enrolment of hunters to find and kill wild boar, carcass removal and laboratory tests, plus movement restrictions. Similar to earlier studies, the benefits of the control measures are calculated by combining a scenario analysis of the dispersal speed and time perspective of the virus with an agricultural sector model for Sweden. The benefits are determined by the avoided losses in the pig and pork sector due to a successful eradication of the virus by the control measures, high losses give high benefits and vice versa. The losses depend on firms' risk perception and preferences, economic performance, and access to mitigation and adaptation measures (e.g. Duong et al., 2019; Garcia et al., 2024). There exist no studies of farmer responses to ASF outbreaks, and a simple assumption applied in previous benefit-cost studies is that the losses correspond to the profits without virus infections. This assumption is also used in the present study, but we add calculations of the benefits of control measures when farmers make adjustments in investments.

The main contribution to the literature on benefit-cost analyses of ASF is fourfold: i) it is the first study to include, not only budget costs for the control measures, but also the costs to people and firms affected by movement restrictions in the controlled region, ii) economic performance is not only measured by net present value and benefit-cost ratios, as was the case in the other studies, but also by the rate of return, internal rate of return and payback time, which are common evaluation criteria in benefit-cost analysis (e.g. Boardman et al., 2011), iii) the study calculates benefits and costs of eradicating the virus in the wild boar population which has been made by only one study (Slatyer et al., 2023), and iv) scenario analysis is introduced on the impacts of pig producers' investment responses, which has not been made before.

2. Methods and materials

2.1. Conceptual framework

The total costs of actual prevention and eradication, C, are calculated as the sum of the direct and indirect costs of control measures implemented during the first year, M^j, where $j=1,\ldots n$ measures in the breakout region. The direct costs refer to expenses, e.g. for surveillance and the hunting of wild boar, laboratory analyses and fencing of the area. Indirect costs include losses for people and firms caused by movement restrictions in the controlled region. The total cost is then written as:

$$C = \sum_j C^{jD}(M^j) + C^{jID}(M^j) \tag{1}$$

where $C^{jD}(M^j)$ and $C^{jID}(M^j)$ are the functions for the direct and indirect costs, respectively, which are assumed to be increasing and convex in their arguments.

The basic assumptions in the present study are that the control measures are successful at eradicating ASF in the outbreak region, and that all domestic pigs would have died in infected regions without any control measures. The benefits of the control measures are then the avoided costs of damages from the implementation of mitigation strategies, which are calculated as the difference in economic welfare in the food sector with and without ASF. Following the practice in the agricultural economics literature (Nehrey et al., 2019), economic welfare is calculated as the sum of producer and consumer surplus. The producer surplus (PS) reflects producers' profits, and consumer surplus (CS) is the consumers' value of the food in excess of the purchasing cost. The economic welfare from the food sector in time t in each region r, where $r=1,.n$ regions, is then written as $PS^{tr} + CS^{tr}$. The annual economic benefit from the control measures in a region, W^{tr}, is then the difference in total economic welfare in the food sector with and without the ASF outbreak, which is written as:

$$W^{tr}=(PS^{tr} + CS^{tr}) - (PS^{tr,ASF} + CS^{tr,ASF}) \tag{2}$$

where the superscript ASF denotes producer and consumer surplus with the outbreak.

The total benefits of the control measures in a region then depend on when ASF hits a region, t^r, and the time perspective T. This, in turn, is determined by the speed of dispersal, v, which is assumed to be constant, and the distance of the region from the outbreak location, d^r, which implies that $t^r=t^r(v,d^r)$. It is assumed that the control measures in the outbreak region are successful in eradicating the virus until the chosen time perspective of T years, and that there are no outbreaks in any region. In practice, only a few countries have been able to eradicate the virus without any subsequent outbreak (review in Danzetta et al., 2020). In Sweden, no further virus has been detected one year after the outbreak in September 2023, and an application for being declared as virus free was submitted to the European Commission in September 2024 (Swedish Board of Agriculture, 2024a). The member states in the Standing Committee on Food and Feed at the EU voted for an approval of the application, and Sweden can then be regarded as free of the ASF virus. Given no further outbreak, the benefits of control measures in each region in Sweden, B^r, are then obtained during the time period between t^r and T when ASF is present, which is written as:

$$B^r = \sum\nolimits_{(t=t^r)}^{T} W^{tr} \rho^t \tag{3}$$

where $\rho^t = 1/(1+i)^t$ and i is the social discount rate.

In benefit-cost analysis, the economic performance of the eradication project can be evaluated by five commonly applied criteria: net present value (NPV), benefit-cost ratio, return on investment (ROI), internal rate of return (IRR), and payback time (e.g. Boardman et al., 2011). The net present value is calculated as the difference between the sum of total discounted economic benefits over all regions minus the cost of the control measures in the outbreak region, which is written as:

$$NPV = \sum\nolimits_r B^r - C \tag{4}$$

Note that the cost of control measures occurs only in the break out region in the first year and is therefore not discounted. The benefit-cost ratio of the control measures in the breakout regions is calculated by summing the benefit over all regions and dividing it by C according to:

$$Benefit - cost\ ratio \equiv \frac{\sum_r B^r}{C} \geq (\leq) \quad 1 \tag{5}$$

A ratio below unity implies that the costs exceed the benefits, and vice versa. The ROI is related to the benefit-cost ratio, which is written as:

$$ROI \equiv (\sum_r B^r - C)/C \tag{6}$$

The IRR shows the constant annual rate of return when total current value benefits equate to C according to:

$$\sum\nolimits_{t=0}^{T} \sum\nolimits_r W^{tr}/(1+IRR)^t \quad - \quad C \quad = 0 \tag{7}$$

IRR is negative when the benefits do not cover the cost, and vice versa. Note that the benefits are not discounted, which implies that the investment is relatively unfavourable when the IRR is below the discount rate of 3 % since the rate of return is lower than the long-term growth rate in society.

Unlike all other evaluation criteria, the payback time may differ from the time perspective of the entire period T. It shows the number of years needed for the cumulative discounted benefits to equate the costs, i.e. when $NPV=0$.

2.2. Study region

The Swedish Board of Agriculture announced the detection of ASF on 6 September in 2023 in Fagersta, which is located 145 km northwest of Stockholm (Swedish Board of Agriculture, 2024a). It is not clear how the virus entered the region. A hypothesis is that wild boars had access to contaminated pork originating from a country with the virus and disposed at a garbage dump in the region. Restrictions were imposed on 7 September 2023 across an area of 996 km^2 on activities for firms and people, which involved bans on hunting, disposal of food, recreation and non-urgent travel, and a requirement for the cleaning of clothes and equipment. Hunters were enrolled to depopulate wild boars and search for carcasses to deliver to laboratories.

The controlled area was reduced to 617 km^2 at the end of November, and divided into a core region of 148 km^2 with the rest as an outer area (Fig. A1 in the Appendix). There are nature reserves in both regions: one in the core region and several in the outer area. The movement restrictions in both regions were relaxed on 22 February 2024, but in slightly different ways. In the outer area people were not allowed to have dogs off leash, hunt wild boar, keep pigs or engage in any kind of forestry. These activities were also forbidden in the core region, along with bans on driving vehicles and using machinery and on participation in organised competitions and events. All these restrictions were lifted on 6 June 2024.

The benefits from the control measures are obtained by pig and pork producers from avoided losses due to ASF infections. In 2022 there were approximately 1.4 million pigs in Sweden at 1173 pig rearing farms (Swedish Board of Agriculture, 2023a). Slaughter pigs, piglets and sows account for 64 %, 26 % and 9 %, respectively of the total number of pigs. An interview study of pig farms indicated that approximately 40 % of pig farms use an integrated system rearing pigs from birth to sale weight (Göransson and Lundqvist, 2023). However, there are no data on the local allocation of the different pigs, but only on the density of pigs in 2020. A map of this density shows a relatively high concentration of pig producers in the south of Sweden (Fig. 1).

The pig farms are concentrated in Mid and southern Sweden, where the density exceeds 20 pigs/km^2. The main concentrations of pig farms are thus found to the south of the outbreak in Fagersta. The distance to the nearest high pig concentration region is around 100 km, and approximately 500 km to the intensive pig farming found in the south of Sweden.

The total Swedish production of pig meat was approximately 254 000 tonnes in 2022, of which 11 % was exported (Swedish Board of Agriculture, 2023b). The production in Sweden accounted for 82 % of the total consumption of 309 000 tonnes.

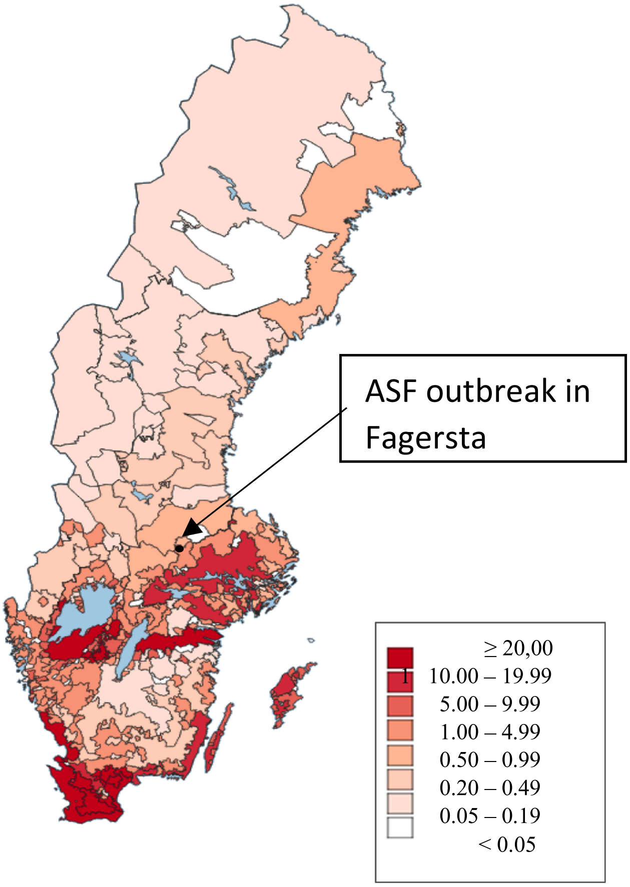

Fig. 1. Density of domestic pigs in Sweden in 2020 (pigs/km^2). Source: Swedish Board of Agriculture (2021).

2.3. Costs of control measures

Data on direct costs were obtained from the Swedish Board of Agriculture (2024b) for payments to hunters for surveillance, the detection and depopulation of wild boar, laboratory costs, the destruction of carcasses, and for the costs of management and coordination of control measures. The Swedish government commissioned the Swedish Traffic Agency to construct and build fences for containment in the core region with a budgeted cost (Government Offices of Sweden, 2023). It is assumed that the total budget was used to erect the fences. Some of the data on indirect costs are also provided by the Swedish Board of Agriculture (2024b) related to applications for compensation payments by firms in the region. These firms include farms without pigs, forest management, sawmills and others, such as restaurants and tourist attractions.

Data on indirect costs in terms of the impacts of ASF restrictions on recreational values are not readily available. Therefore, calculations are made in the present study based on the benefit transfer of close-to-home recreational values and data on human population size in the region. One study, Ezebilo et al. (2015), estimated recreational values for close-to-home outdoor recreation in Sweden using the contingent valuation method. Respondents in a random sample of Swedish citizens aged 18 or over answered questions on their willingness to pay (WTP) to maintain the right to public access to close-to-home nature for recreational purposes. Close to home was defined as a distance of less than 100 km from home and a stay of less than 24 hours at the recreational site. The average distance was 12.8 km and the average stay was 3.4 hours. The results indicate a WTP of 840 euros per year per person (at 2023 prices), which includes the costs of recreational activities, such as expenses for transport and equipment. The recreational value in excess of the costs corresponds to 68 % of the reported WTP, which gives a welfare value of 1.60 euros per person and day.

The losses of recreational values are calculated by multiplying the recreational value per day per person by the number of days with restrictions for the population aged 18 or over in the control regions. The duration of restrictions in number of days and population sizes during the period of restrictions is then classified into three periods, as described in Section 2.2 (Table A2 in the Appendix).

2.4. Benefits of control measures

The calculation of benefits of the control measures in the outbreak region requires data on the costs of virus infection in domestic pigs, the speed of ASF dispersal, and the distance between the outbreak location and other regions. An ASF intrusion on pig farms in a region will not only affect farmers, but also firms in the value chain because of decreases in the supply of pigs to slaughterhouses in the region. This may generate an increase in demand for pigs in other regions, with the associated increase in transport costs and sales prices of pig meat. This dispersal of impacts is calculated using an existing agricultural sector model, the Swedish Agricultural Sector Model (SASM), which is described in Jonasson (2018). Specific to SASM compared with other agricultural sector models is the regional solution that allows for the calculation of costs of ASF in different regions and time periods.

SASM is static and divided into three spatial layers: a local level with 81 local regions where primary production takes place, a regional level with six market regions where dairies and slaughterhouses are also located, and the national level for trade in inputs such as fertilisers and fuel. Data for the investment cost, production and demand function are based on official statistics and updated to 2023 prices. Depending on the relationship between demand and supply, trade occurs between market regions and internationally, which incurs a transport cost. Similar to other sector models, producers are assumed to maximise profits and consumers to maximise net utility (Nehrey et al., 2019). Sweden is a small open economy and changes in supply of pigs will not affect international prices of exports and imports. Pork producers can then increase imports of pigs at an unchanged import price when the supply of pigs produced in Sweden decreases due to the ASF virus. A simplification is also made by assuming that consumers are indifferent to whether foods have been imported or produced in the country. This means that price increases of foods produced in Sweden shift demand towards imports at an unchanged import price.

There are no data on the speed of ASF dispersal for Sweden, but they do exist for some other European countries (Boklund et al., 2018; Lentz et al., 2023). Both studies estimated the dispersal of actual ASF outbreaks among wild boar in terms of radius km per day or per year, but arrived at different results. The results of Boklund et al. (2018) indicate a range of between four and 63 km per year for different countries (Lithuania, Estonia and Latvia). Lentz et al. (2023) show that the speed was non-linear in the number of days after an actual outbreak in Germany. While the speed can be 0.6 km per day during the first 50 days of an outbreak, it reduces to 0.03 km per day after 300 days. In the present study, velocity on an annual basis is used, which is available from Boklund et al. (2018). They did not quantify the transmission paths, but hypothesized that the high speed could be caused by human-mediated dispersal and the lower through wild boar interactions. Calculations of benefits are then made by: i) matching the locations of the pig farms in Fig.1 with the 81 local regions in the SASM and ii) determining the timing of the intrusion in a region with information on dispersal speed.

There has been a long-running discussion on the appropriate level of the social discount rate (e.g. Weitzman, 2001). A common practice in benefit-cost analysis is to choose the long-term growth rate of gross domestic product (e.g. Boardman et al., 2011) since this reflects the average rate of return on investment. The growth rate amounts to approximately 3 % per year for the period 1950–2018 (NIER National Institute of Economic Research., 2019), which is used here to calculate the present value of the benefits of the control measures.

2.5. Scenarios

While the costs of control measures are incurred only in the break out region for a short period of time, the benefit streams depend on assumptions about the virus dispersal rate and farmers' investment behaviour. Boklund et al. (2018) showed a wide range in virus dispersal speed of between three km/year to 63 km/year for different European countries. In the present study, calculations are made for three alternative speeds within this range: 12.5 km/year, 25 km/year and 50 km/year. The impact on benefits is related to the choice of time perspective. In a very short space of time, the virus may not reach regions with high concentrations of pig farms. The variation in chosen time perspective has been large in previous studies, ranging from three to 30 years (Table A1 in the Appendix). Three time perspectives have been chosen here that are within the range of these studies: five years, 10 years and 20 years. It is assumed that there are no re-introductions of the ASF in any region within these time perspectives.

In regions unaffected by ASF, the farmers' investment in and maintenance of pig stables might depend on the occurrence of the virus in affected regions. In principal, there are two polar cases: i) investment as usual, without giving any consideration to a future ASF intrusion and ii) no investment because of an anticipated intrusion. The costs under investment as usual are included in the partial equilibrium model and based on official statistics on pig farmers' costs (Jonasson, 2018). The choice of option can be motivated by beliefs about whether ASF will be eradicated in the affected regions. The choice will have impacts on producers' profits since the cost of investment is avoided but the income from future sales of pigs is lost. There are no prior expectations about the farmers' choice, and calculations are therefore made for both investment choices.

In all, calculations are thus made for combinations of 18 different scenarios, which are summarised in Table 1.

SASM is a static partial equilibrium model and the economic impact of future ASF infection in different regions is solved by the recursive

Table 1
Description of scenarios for calculations of benefits from control measures in Fagersta.

Scenario	Description
Speed of ASF dispersal from the outbreak in Fagersta	12.5, 25 and 50 km/year
Time periods	5, 10, and 20 years
Investment decision	Investment as usual or adjusted investment in stables and equipment in unaffected regions as a response to ASF in affected regions

approach (Stokey et al., 1989). This implies that the model maximises national producer and consumer surplus at reduced stocks of domestic pigs in different time periods and regions. The model is solved using GAMS (General Algebraic Modelling System) software with the Conopt solver (Rosenthal, 2008). Data are available upon request.

3. Results

3.1. Benefits and costs

The total annual economic welfare in the food sector without ASF intrusion amounts to 6867 million euros, as calculated using SASM. The producer surplus accounts for 15 % and the consumer surplus for the remaining part of the economic welfare. The incidence of ASF implies a reduction in pig production within Sweden, but pigs and pork can be imported from other countries. This implies that the annual losses, which vary between 0.785 and 49.175 million euros in current value, are borne by the pig producers. The maximum decline in total discounted benefits with the intrusion is 503 million euros, which occurs with the time perspective of 20 years, and at the fastest dispersal speed with no investment adjustments (Table 2).

The difference in benefits between the virus dispersal speeds for all time periods and both investment adjustments depends on when the virus hits Mid and South Sweden, where there is a high concentration of pig farms. The benefits of an early hit are greater than a late hit because of the discount rate. The virus reaches all regions after 10 years when the speed is 50 km/year, after 20 years when the speed is 25 km/year, and after 40 years when the speed is 12.5 km/year.

Except for the time period of five years, the benefits are greater for all dispersal speeds when pig farmers are assumed to invest as usual, compared with making adjustments owing to the virus outbreak in neighbouring regions. The lack of investments reduces costs, but also the number of pigs, which decreases income. In the short term, the decline in incomes can be lower than the avoided investment cost that occurs when the dispersal speed is 25 km/year.

A further investigation of the development of benefits over time shows some differences between the two investment adjustment scenarios. Without investment adjustments, there are two waves of benefits when the virus hits Mid and South Sweden, where there are high pig farm concentrations (Fig. A2 in the Appendix). The first wave occurs when the virus has reached the high pig density region in Mid Sweden, and the second wave when the virus hits the south of Sweden. The annual benefits in the peak of the second wave at the fast and medium speeds are approximately twice as large as in the first wave because of the high concentration of pig farms in the south of Sweden. With investment adjustments there is only one peak in benefits since farmers avoid the costs of replacing equipment and pig stables (Fig. A3 in the Appendix).

Table 2
Total discounted (3 % discount rate) benefits of control measures in Fagersta for different combinations of virus dispersal speed, time periods and farmers' investment adjustments (NO no adjustment and A adjustment), million euros at 2023 prices.

Speed of virus dispersal	5 years:		10 years:		20 years:	
	NA	A	. NA	A	NA	A
12.5 km/year	7	7	27	26	111	73
25 km/year	14	18	64	66	240	153
50 km/year	57	33	185	124	503	260

The estimated cost of control measures amounts to 28.4 million euros (Table 3), which is below the benefits in most scenarios.

The results given in Table 3 indicate relatively high indirect costs, which correspond to 65 % of the direct costs. Losses in recreational values of 7.7 million euros are the largest single cost item, followed by the costs of coordination and crisis management.

3.2. Net present value, benefit-cost ratio, ROI, IRR and payback time

In order to construct the five evaluation criteria, the development in annual benefit-cost ratios over time is illustrated in Fig. 2.

Each line in Fig. 2 shows the development in benefit-cost ratios for each combination of scenarios. The benefits are then the accumulated annual benefits until the respective year. At the 'break-even' straight line in Fig. 2, the net present value is zero.

The five evaluation criteria are presented for a time perspective of 20 years since the virus covers the whole of Sweden at all dispersal speeds except the slowest one (Table 4).

Except for payback time, common to all criteria is the relatively high values at high speed and no investment adjustment. The NPV, benefit-cost ratio and ROI are approximately five times larger with the highest than the lowest speed under both investment behaviours. Similarly, the IRR is approximately three times larger and the payback time considerably lower with the highest speed. As expected, the benefits of the control measures are reduced when farmers respond to the virus by adjusting investment. The NPV, benefit-cost ratio and ROI are approximately one half and the IRR is lower and payback time longer with investment adjustments compared with no adjustments for all three virus dispersal speed.

The payback time varies between four and 11 years, being shortest for the highest speed dispersal and no investment adjustments. This implies that the project will not pass the benefit-cost rules in all scenarios when the time perspective is less than 11 years, which occurs for the five and 10 years perspective. The benefit-cost ratio is below unity and the other evaluation criteria are negative for the dispersal speeds of 12.5 and 25 km/year when the time period is five years, and for the speed of 12.5 km/year when the time perspective is 10 years (Tables A3-A4 in the Appendix). It can also be noted that the range in NPV, benefit-

Table 3
Direct and indirect costs of control measures against the ASF virus in the outbreak region (million euros at 2023 prices).

Type of cost and measure	Million euros
Direct costs:	17.2
Payments to hunters for surveillance and inventory of infected feral pigs[a]	2.7
Payments to hunters for depopulation of feral pigs[a]	1.1
Fencing of core area[b]	5.2
Destruction of carcasses[a]	1.0
Laboratory analyses[a]	0.3
Coordination and crisis management at SBA[a]	6.9
Indirect costs:	11.2
Compensation payments to farmers[a]	0.4
Losses in forestry[a]	2.0
Losses in other business sectors[a]	1.1
Welfare losses of close-to-home outdoor recreational values[c]	7.7
Total	28.4

[a] Swedish Board of Agriculture (2024b)

[b] Government Offices of Sweden (2023)

[c] € 1.60 per day per person from Ezebilo et al. (2015). Duration of restrictions and population size in Table A2 in the Appendix.

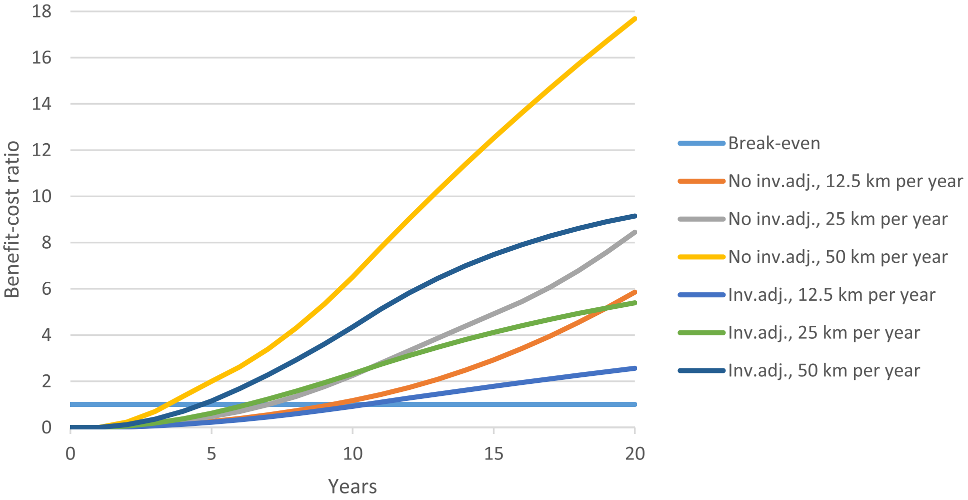

Fig. 2. Benefit-cost ratios for different combinations of scenarios on virus dispersal speed and farmers' investment decision.

Table 4
NPV, benefit-cost ratio, ROI, IRR and payback time for alternative combinations of virus dispersal speed and farmers' investment adjustment (NA no adjustment and A adjustment) for a period of 20 years.

Virus dispersal speed, km per year	NPV, million euros:		Benefit-cost ratio:		ROI, %:		IRR, % per year		Payback time, years:	
	NA	A	NA	A	NA	A	NA	A	NA	A
12.5	84	44	4	3	296	159	15	12	11	11
25	215	126	9	5	755	445	24	22	6	7
50	480	234	18	9	1686	823	43	33	4	5

cost ratio and ROI depending on virus dispersal speed and farmers' investment choice is larger than those for IRR.

4. Discussion and conclusions

The purpose of this study was to evaluate the economic performance of the measures implemented in Fagersta to eradicate the ASF outbreak. A specific feature of the study was the division of costs into two categories: direct and indirect. The results showed that the indirect costs can be relatively large, corresponding to approximately 65 % of the direct costs. The losses in value of close-to-home recreational activities make up the majority of the indirect costs. This is partly due to the fact that the Swedish legal system allows individuals to have unlimited access to recreational activities on forest land even if the land is privately owned.

The benefits from implementing the control measures were highly dependent on assumptions about the speed of ASF dispersal in Sweden, farmers' decisions about investing in and maintaining pig stables, and the time perspective. Depending on the scenario, the benefit-cost ratio ranged between 0.2 and 18, being small (large) for the slow (fast) dispersal speed and with (without) investment adjustments by the farmers. When compared with other studies, the ratios are larger than those obtained by Bech-Nielsen et al. (1993), but lower than those reported by Fazina et al. (2012), Rendleman and Spinelli (1999), and Slatyer et al. (2023) (Table A1 in the Appendix). Similar to the wide variation in benefit-cost ratios in Rendleman and Spinelli (1999) and Slatyer et al. (2023), the range in the present study is partly explained by the spatial dispersion of ASF, but in different ways. While those two studies created scenarios on the scale of outbreaks in pig farms (from local to national), the present study used different dispersal speeds of the virus in wild boar populations, which introduced the discount rate and time perspective as determinants of the benefits.

The payback time of the control cost varied between four and 11 years, and the IRR ranged from from -28 % to 43 %. There are no other studies on ASF with which these results can be compared. However, a similar study was conducted on the eradication of Aujeszky's disease in Sweden for which a government programme was implemented (Andersson et al., 1997). The study revealed an IRR in the range of 3–5 %, depending on assumptions about productivity gains due to the absence of disease. The results may also be compared with the social discount rate of 3 % used in the present study, which is also required by municipalities and county boards in Sweden based on the costs of borrowing capital for public investment (SALAR, 2024). Using this as the reference rate, it can be concluded that the IRR of the control measures is insufficient at the slowest dispersal speed and short time perspective, but very good at the medium and fastest dispersal speeds.

However, the results are based on several assumptions in the calculation of both the benefits and costs of control measures, which affect the evaluation criteria in different directions. One assumption was that the control measures lead to the complete eradication of the ASF virus. If this is not achieved, the benefits from avoided losses in the pig sector would decrease with an associated reduction in all economic performance metrics. However, violation of the assumption on consumers' indifference between imported and domestically produced pig meat would increase benefits since consumers would be willing to pay a higher price for the meat produced in Sweden. A factor not considered in the study is that countries importing pigs and pig meat from Sweden might respond with an immediate ban on their import when the outbreak is announced. Several countries responded in this way, which affected 50 % of pig meat exports at an estimated cost of 4.4 million euros (Wahlberg, 2023). If the control measures mitigated such responses, the avoided losses would be higher, which would increase the economic performance.

Regarding the estimation of the control costs, the depopulation of wild boar implies a net social cost or benefit since the animals provide recreational values of hunting in the region and a food security value in times of crisis, but also generate costs due to traffic accidents and damage to agricultural fields. Mensah and Elofsson (2017) and Engelman et al. (2018) reported recreational values of wild boar hunting in Sweden of 252 euros/animal and 32 euros/animal, respectively, and the results of Gren et al. (2024) indicate a food security value in the range of

12–450 euros per animal depending on the expected scenario on disturbances to the trade in agricultural products. These values are lower or higher than the sum of costs of damages to crop fields of 303 euros/animal (Gren et al., 2024), and of traffic accidents of 105 euros/animal (Gren and Jägerbrand, 2019). It might then be concluded that the impact on the evaluation criteria is indeterminate and depends on the estimated food security value.

The control measures targeted wild boar, which generated relatively high indirect costs. One alternative, which is examined in other studies, is to target outbreaks on pig farms that do not generally generate costs to actors outside the pig sector. The control costs are then reduced, which would improve all the five evaluation criteria. However, there might be a risk of new ASF outbreaks if the virus prevails in the wild boar population, with an associated decrease in the performance criteria.

Nevertheless, although the present study was applied to an outbreak in Sweden the results highlight the importance of considering the indirect costs of control measures, virus dispersal speed, farmers' investment behaviour, time period and alternative criteria for evaluating the economic performance of animal disease control measures. Indirect costs in terms of losses in recreational values in other countries could be either higher or lower than the direct costs depending on population density, preferences for and access to recreational activities. It also raises a question on the allocation of benefits and costs between different actors. Whereas the benefits of the control measures in the present study were obtained by the pig producers, the public authorities' costs of measures were borne by tax payers, and the decrease in recreational value and profits were faced by people and firms in the control region. While affected firms are compensated for losses due to control measures in several countries, there are no similar compensation payment for lost recreational opportunities. This uneven compensation payment between actors constitutes an interesting field for policy research.

Similarly to other studies, the results in this study show that the benefits of control measures are highly dependent on the spatial allocation of the virus and chosen time perspective. This points out the need for improved understanding of the human-mediated and wild boar transmission paths, data of which were not available for the present study. We also highlighted the importance of including farmers' investment responses to the virus outbreak Adjustments of investments reduce the losses from a virus outbreak and thereby the benefits of control measures. Closely related to this is the possibility to reduce risks of ASF intrusions at pig farms, and thereby the benefits of measures controlling the virus in the wild boar populations. The risk factors of ASF incursion differ between domestic pig farming systems, where e.g. free-ranging pig farms are susceptible to wild boar contacts and commercial pig farms to failing biosecurity measures (Bellini et al., 2021). The cost of such measures at pig farms should then be compared with the cost of control measures for prevention of ASF dispersal in wild boar populations for a cost-efficient mitigation of damages of the virus. This has not been made by any published study and provides an important arena for future research.

Irrespective of the calculation of costs and benefits of the control measures, the different evaluation criteria for economic performance may respond in different ways to the choice of scenarios. The qualitative results of all criteria in the present study were similar where they indicated relatively bad or good performance as measured by the principle of proportionality in public investment. This principle is envisaged by the law in Sweden and in other countries in the European Union (EU, 2016), since it indicates that the benefits of the outcome are greater than the control cost. However, the quantified range in NPV, benefit-cost ratio and ROI depending on scenario was considerable larger than that of IRR and payback time. This highlights the need for a well-motivated choice of criteria in the evaluation of the economic performance of control measures to tackle animal disease outbreaks under different scenarios, which is another interesting arena for future research.

CRediT authorship contribution statement

Ing-Marie Gren: Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation, Conceptualization. **Lars Jonasson:** Writing – review & editing, Software, Resources, Methodology, Data curation. **Hans Andersson:** Writing – review & editing, Methodology, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests of personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. : Tables A1-A4 and Figures A1-A3

Table A1
Regional application, method, time perspective and results of studies calculating benefit-cost ratios for measures against ASF (in chronological order)

Study	Country, actual or potential outbreak	Method, time perspective	Benefit-cost ratio
Bech-Nielsen et al. (1993)	Spain, actual	Coupling of virus spread model with a pig sector model, 20 years	23. −1.47
Rendleman and Spinelli (1999)	USA, potential	Coupling of a transition matrix of virus spread with a dynamic programming pig sector model, 10 years	0.9–450
Fasina et al. (2012)	Nigeria, actual	Pig farm-level study, 3 years	29
Slatyer et al. (2023)	Australia, potential	Scenarios on an outbreak in feral or domestic pigs combined with a pig sector model, 5 and 30 years	5–60

Table A2

Timing and duration of movement restrictions and population size in the controlled regions

Period	Days	Human population size > age of 18 years
07/09/23 – 30/11/23	85	31,000[a]
01/12/23 – 22/02/24	84	15,000[b]
23/02/24 – 05/06/24	103	10,000[b]

[a] Swedish Statistics (2024)

[b] Swedish Board of Agriculture (2024)

Table A3

Net present value, benefit-cost ratios and ROIs for 5 years time perspective for different combinations of virus dispersal speed and farmers' investment adjustments (NA is no adjustment and A is adjustment).

Virus dispersal speed. km/year	Net present value, million euros		Benefit-cost ratio:		ROI %:		IRR % per year:	
	NA	A	NA	A	. NA	A	NA	A
12.5	−22	−22	0.2	0.2	−76	−77	−28	−28
25	−15	−11	0.5	0.6	−52	−38	−15	−9
50	27	4	2.0	1.1	100	15	23	6

Table A4

Net present value, benefit-cost ratios, ROIs and IRRs for 10 years time perspective for different combinations of virus dispersal speed and farmers' investment adjustments (NA is no adjustment and A is adjustment).

Virus dispersal speed. km/year	Net present value, million euros:		Benefit-cost ratio:		ROI %:		IRR, % per year:	
	NA	A	NA	A	NA	A	NA	A
12.5	−1	−2	1.0	0.9	−3	−8	2	1
25	36	38	1.3	2.3	125	132	15	16
50	157	95	5.5	4.4	551	335	40	29

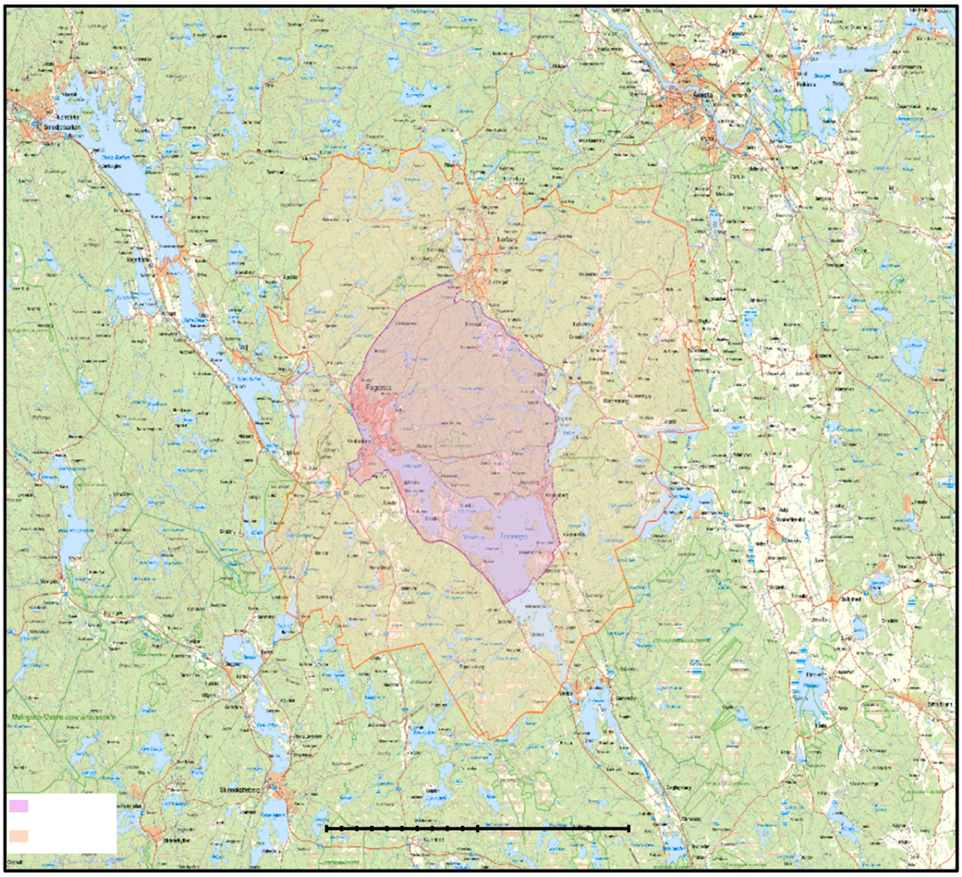

Figure A1. The infected zone, with a core region (red) and an outer region (yellow). Source: Swedish Board of Agriculture (2024a)

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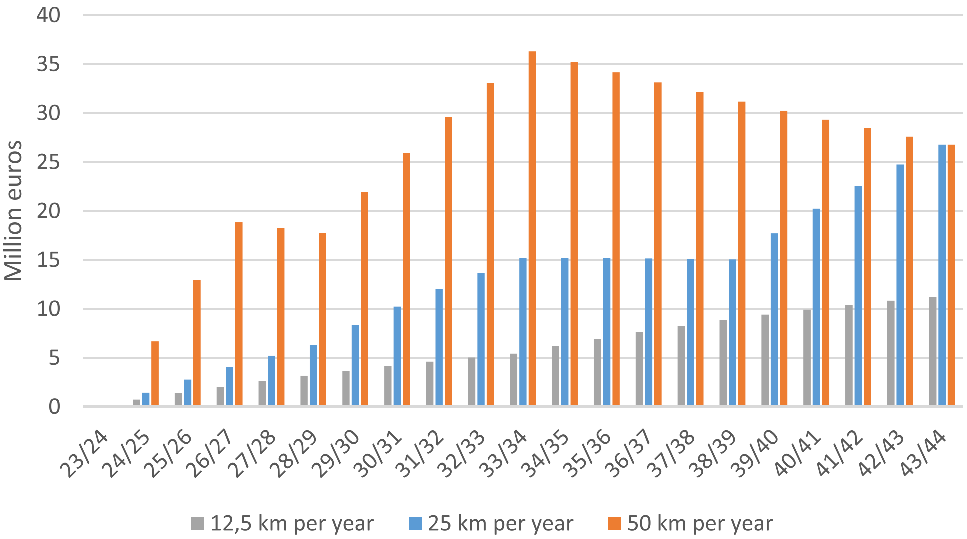

Figure A2. Discounted annual benefits without investment adjustments from control measures in Fagersta with dispersal speeds of 12.5, 25 and 50 km/year (million euros)

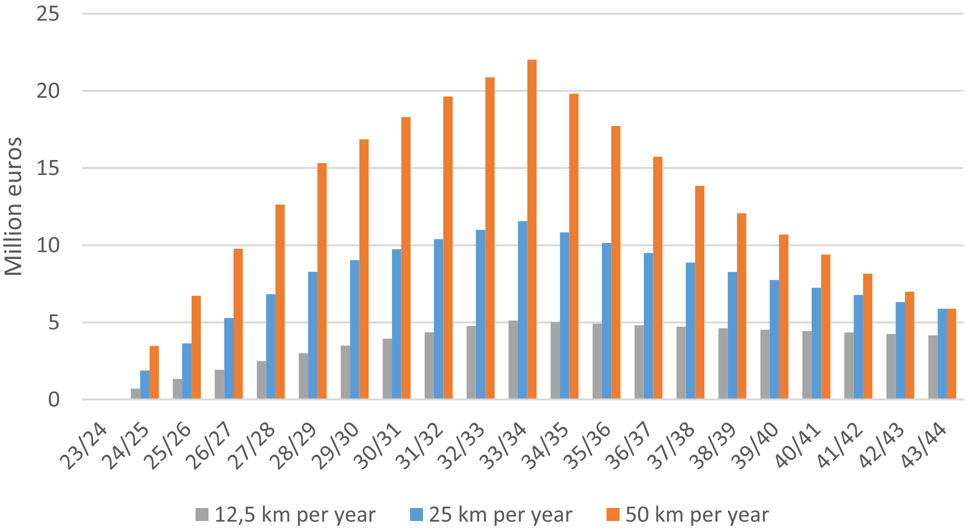

Figure A3. Discounted annual benefits of control measures with investment adjustments under alternative dispersal speeds (million euros)

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