The economic evaluation of control and eradication of epidemic livestock diseases

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Summary
Many countries have implemented strategies to control and eradicate epidemic diseases. These strategies are usually based on either stamping-out or routine vaccination, sometimes complemented by emergency vaccination. The authors describe these strategies, using examples to illustrate each one. The economic evaluation of control and eradication of epidemic diseases is a complex matter. The authors provide further insight into this area by describing the various elements involved in both the ‘non-outbreak periods’ and the ‘outbreak periods’. In addition, a system of categorisation of the direct costs and consequential losses is suggested for the calculation of costs and losses incurred by outbreaks. The economic impact of epidemic diseases on farmers and the livestock sector as a whole differs; these differences may be influenced by the control and eradication strategies applied. An attempt is made to provide a basic framework for economic evaluation on various economic levels.

Keywords

Introduction
Epidemics of highly contagious animal diseases may have enormous consequences in terms of the dramatic effects these diseases can have on livestock productivity, and the high costs of control or eradication. Striking examples are the recent epidemics of classical swine fever (CSF) (hog cholera) in the Netherlands in 1997 and 1998 and foot and mouth disease (FMD) in Taipei China in 1997. Epidemics affect not only farmers, but also the agricultural industry and the national economy (6). Consequently, many countries have implemented eradication and control programmes to combat epidemics and prevent the (re-)introduction of contagious disease agents.

The term epidemic is used to describe an unexpected and substantial increase in the number of cases of an infectious disease in a population (21, 34). Diseases are classified as being endemic when usually present in a population, although the level of incidence may vary (3). Both terms have Greek roots, epidemic meaning ‘upon the population’ and endemic meaning ‘within the population’. This terminology implies that whether an observed frequency of any particular disease constitutes an epidemic varies from one area and population to another. An epidemic relates to a clustering of disease in space and time (33). Diseases such as FMD that are endemic in some areas of the world, may produce epidemics in others, although the number of cases is similar in both (17). Thus, the disease is not the determining factor of the resultant endemic or epidemic, but rather the interaction of that disease with the (animal) population and the environment. A disease could originate as an epidemic disease but then become established in the population (at a certain level) thereby becoming endemic.

This paper focuses on the epidemic occurrence of diseases and the economic impact of such epidemics. The paper aims to provide an overview of the various elements involved in the evaluation of the economic impact of epidemic diseases. The occurrence of epidemics around the world is briefly presented, using the Office International des Epizooties (OIE) List A diseases as a basis for discussion. The economic impact of epidemics is determined by characteristics such as the size of the affected area, the number of affected animals and farms, and the duration of the epidemic. Control and eradication strategies may influence these characteristics and reduce the
economic consequences of epidemics but also imply an additional cost aspect. The paper describes various prevention and control strategies and proposes a checklist of aspects to be considered when evaluating the economic impact of epidemics. A basic framework for economic evaluation on various economic levels is provided. The paper concludes with discussion of the issues raised, followed by some concluding remarks.

Epidemics around the world

The OIE has compiled a list of diseases that are highly contagious and have the potential to cause substantial economic losses. These are termed OIE List A diseases, which are defined in the OIE International Animal Health Code as being transmissible diseases which have the potential for very serious and rapid spread, irrespective of national borders, which are of serious socio-economic or public health consequences and which are of major importance in the international trade of animals and animal products (22, 23). List A comprises the following fifteen diseases:
- foot and mouth disease
- vesicular stomatitis
- swine vesicular disease
- rinderpest
- peste des petits ruminants
- contagious bovine pleuropneumonia
- lumpy skin disease
- Rift Valley fever
- bluetongue
- sheep pox and goat pox
- African horse sickness
- African swine fever
- classical swine fever (hog cholera)
- highly pathogenic avian influenza
- Newcastle disease.

List A diseases occur throughout the world. Most of these diseases are not confined to specific regions or continents, but are widely spread by international trade, among other means. Diseases transmitted by arthropods (such as midges) are usually restricted to areas within a certain latitude. For example, bluetongue (the most widespread arthropod-borne viral disease) is present in countries between approximately 40°N and 35°S and African horse sickness is limited to Africa, with the exception of presence recorded in the Near and Middle East and in the Iberian peninsula (24, 26). Table I presents the distribution of List A diseases throughout the world in 1997, by continent. All List A outbreaks reported to the OIE are listed. The data clearly show that topographically isolated countries and regions (such as Oceania) are in a favourable position regarding these diseases. The most frequently reported List A diseases are Newcastle disease, FMD and CSF. The most widespread diseases in 1997 were FMD (59 countries with one or more outbreaks), sheep and goat pox (35 countries), CSF (38 countries), and Newcastle disease (87 countries).

All List A diseases have the potential to occur as epidemics. Some have also managed to establish themselves within populations and have become endemic, a prime example being FMD (which is epidemic in most European countries, but endemic in many Asian and African countries).

### Table 1

<table>
<thead>
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<th>Disease</th>
<th>Africa</th>
<th>Asia</th>
<th>Oceania</th>
<th>Europe</th>
<th>North America</th>
<th>Central America</th>
<th>South America</th>
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<td>318</td>
<td>11,797</td>
<td>0</td>
<td>80</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>16</td>
<td>0</td>
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<td>16</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
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<tr>
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<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>13</td>
<td>33</td>
<td>0</td>
<td>0</td>
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<td>595</td>
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<td>23</td>
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<td>652</td>
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<td>1</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>Newcastle disease</td>
<td>759</td>
<td>1,388</td>
<td>0</td>
<td>78</td>
<td>3</td>
<td>28</td>
<td>43</td>
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<tr>
<td><strong>Total number of outbreaks of List A diseases</strong></td>
<td><strong>3,220</strong></td>
<td><strong>14,328</strong></td>
<td><strong>1</strong></td>
<td><strong>1,230</strong></td>
<td><strong>385</strong></td>
<td><strong>719</strong></td>
<td><strong>828</strong></td>
</tr>
</tbody>
</table>
Eradication and control strategies

The economic impact of epidemic diseases is largely influenced by the methods used by countries to control and eradicate outbreaks. In general, most eradication and control programmes are based on one or more of the following three elements:

a) routine vaccination
b) stamping-out
c) emergency vaccination.

Routine vaccination

For many countries, routine vaccination is the only feasible strategy to prevent (extensive) epidemics of List A diseases. Intensive vaccination campaigns are known to be useful control strategies for many important List A diseases, including FMD, contagious bovine pleuropneumonia, CSF and Newcastle disease (11, 31). Routine vaccination is generally adopted by high-risk countries (i.e. countries surrounded by areas in which the disease is endemic and countries importing animals from endemic areas). In these cases, outbreaks might occur very regularly, making stamping-out too costly and disruptive.

Vaccination triggers protective immunological mechanisms that are used by the animal to combat subsequent infection. Successful vaccination programmes prevent major epidemics of infectious diseases by generating 'herd immunity', which results when too few susceptible animals remain in the population to sustain disease transmission (36).

Sufficiently high antibody titres will prevent multiplication and therefore spread of infectious agents. If vaccination is not performed adequately (the vaccination frequency or coverage is too low or the vaccine is not sufficiently effective), clinical signs of disease may be obscured while pathogen multiplication still takes place. As a result, a proportion of the vaccinated animals which encounter the pathogen are likely to become carriers, and thus pose a risk to any susceptible animals. This effect is known to occur in FMD (7) and Newcastle disease (1). To prevent serious epidemics, vaccination strategies thus have to reach certain minimum levels regarding vaccination frequency and vaccination coverage. These minimum levels are dictated by the efficacy of the vaccines used. The establishment of herd immunity is complicated where strain variation of the infectious agent or varied host response to vaccination exist and where vaccines that provide only partial protection for a limited period of time are used. Woolhouse et al. demonstrated that in some cases, vaccines providing short-term protection are unable to prevent epidemics of highly transmissible pathogens (36).

For some diseases, the seasonal timing of vaccination may be equally important as vaccination frequency or vaccination coverage. For seasonal viral infections transmitted by midges, such as African horse sickness, annual prophylactic vaccination is most effective when carried out during a specific period of the year, just before the beginning of the 'disease season' (28).

Routine vaccination is sometimes seen as the first step towards eradication of a disease. Experiences in Europe show that CSF can be eradicated from endemic areas by using stamping-out measures together with a systematic and intensive vaccination programme (32). Based on the success of these methods, the European Union (EU) has been able to cease vaccination for CSF. In contrast, for Newcastle disease, some Member States (e.g. the Netherlands) still rely on routine vaccination for maintaining disease-free status.

Stamping-out

Stamping-out refers to the eradication of outbreaks by the destruction of animals. Usually, all susceptible animals on the infected farm are slaughtered in an attempt to deprive the disease agent of a means to survive and multiply. Sometimes herds that have been in close contact with the affected farm are also slaughtered.

A stamping-out strategy is usually applied against diseases for which no vaccines are available, such as African swine fever and swine vesicular disease (11, 25, 27, 32), or when the disease has reached very low incidence following other forms of control. In other cases, countries may rely on stamping-out because the country is normally free of the disease or is attempting to obtain or maintain access to certain export markets.

The EU, one of the largest meat producers and exporters, provides an illustration of the influence of trade issues on decisions related to disease eradication and control.

Within the EU, free movement of people, goods and services has always been a major objective. Within the animal health field, this required the establishment of common standards for the control and eradication of diseases. In the late 1980s, a major obstacle to free trade in live animals within the EU (then the European Community) was the different control and eradication methods used for FMD. Four countries (Denmark, Greece, Ireland and the United Kingdom [UK]) relied entirely on stamping-out while the remainder employed routine vaccination complemented by partial herd slaughter in the case of outbreaks. The four Member States listed above, which were free from FMD, barred the entry of FMD-susceptible, vaccinated livestock. In 1991, the EU abandoned vaccination against FMD (2). The following year, the EU ceased preventive vaccination against all List A diseases except Newcastle disease. Vaccination against Newcastle disease is still compulsory in the Netherlands and some other European countries, and these countries now have
a less favourable disease 'status' than those, such as Denmark, that adopted a non-vaccination policy, and this could influence the trade opportunities of the latter.

Within the EU, the non-vaccination policy implies a strict stamping-out strategy. Outbreaks are eradicated in accordance with strict prescriptions, including measures such as the eradication of infected herds and contact herds and the establishment of movement restriction zones. Countries are allowed to apply stricter measures if necessary. Such extra measures may include larger movement restriction zones and pre-emptive slaughter of herds within a certain radius of an infected as well as a detected herd (35).

Emergency vaccination
If an outbreak occurs in a country that relies on routine vaccination as the prevention strategy, this implies that the vaccination coverage, frequency and/or vaccine efficacy was insufficient. In these cases, therefore, routine vaccination is normally complemented by emergency vaccination. Emergency vaccination is sometimes termed 'ring vaccination' (all susceptible animals on farms within a certain radius of the farm on which infection has been detected are vaccinated in an attempt to limit the spread of the disease agent). Diseased animals may be treated or destroyed. The former is the case in many tropical countries (e.g. Thailand [8]). The latter was the strategy used by many countries of the EU before adoption of the non-vaccination policy for FMD (2). Member States that still vaccinate against Newcastle disease use partial or total slaughter of flocks in the case of an outbreak, sometimes in combination with emergency vaccination (35).

In principle, emergency vaccination could also be used to increase the efficacy of a stamping-out strategy. However, within the EU, emergency vaccination is not normally allowed if a non-vaccination strategy has been adopted for the disease in question. Only when the epidemic cannot be contained, may a country ask the EU Commission for approval to vaccinate. Vaccination in these circumstances will often lead to an export ban because vaccinated animals are not distinguishable from animals which have recovered from a field infection. This is also the main reason why many importing countries only allow imports of live animals and unprocessed (fresh, chilled or frozen) animal products from countries that maintain a disease-free status and have adopted a non-vaccination policy.

Additional support measures
Both routine vaccination and stamping-out are unlikely to be successful disease control measures without sufficient attention to the additional support measures detailed below.

Movement control
Movement control is aimed at preventing contacts between infected and susceptible animals. Movement control can be one of the most important support measures, in addition to routine vaccination and stamping-out. Where animals are kept in nomadic husbandry systems or travel freely over long distances, movement control can be extremely difficult (11).

Quarantine stations and border inspections are important elements of movement control within and between countries. Within countries, movements can be reduced by promoting more closed husbandry systems and fixed contacts between, for example, breeding and fattening farms.

Identification and recording systems
As clearly shown by Saatkamp (among others), effective identification and recording systems can be regarded as important instruments in the control of contagious animal diseases, by providing information to support those involved and the measures taken (29). For diseases transmitted by animal to animal contact, effective identification and recording systems will help to limit the extent of epidemics by early tracing of infected animals.

Public awareness
Horst used computer simulation modelling to study the economic impact of epidemics of FMD and CSF in the Netherlands and demonstrated that the duration of the high-risk period (the interval between infection and detection) is one of the most important factors determining the final impact of an epidemic (12). One of the most important methods of reducing the duration of the high-risk period might be to increase public awareness of diseases. Veterinarians and farmers have to be trained in recognising the clinical signs and encouraged to report suspicious cases. Most countries that apply stamping-out strategies compensate farmers for losses incurred from the destruction of infected animals or herds. Such compensation programmes stimulate early reporting.

Hygiene and biosecurity
Alexander states that good hygiene and biosecurity measures are of paramount importance in preventing the introduction of Newcastle disease to poultry farms and that vaccination must be regarded as a complement, but never an alternative to these measures (1). Hygiene and biosecurity are important in the prevention of all contagious animal diseases at the farm level. Since several highly contagious epidemic diseases (e.g. CSF, FMD and Newcastle disease) can be transmitted by manure, cleaning and disinfection of vehicles are most important (12).

Economic impact
During outbreaks, but also during the inter-outbreak periods, many actions or events related to disease prevention and eradication incur costs and losses. Without intending to be comprehensive, the following section might provide an informal checklist of the aspects that require attention when evaluating the economic impact of epidemic disease.
eradication or control. Not all aspects are valid for all countries or all prevention and eradication strategies. For instance, in the case of stamping-out, routine vaccination or animal treatment do not need to be included in the economic impact calculations.

Inter-outbreak periods

During an inter-outbreak period, the aspects detailed below may be considered.

Routine vaccination

Vaccination costs depend on the number of animals to be vaccinated, the frequency of vaccination, the cost of the vaccines and the labour and distribution costs. Costs may differ considerably between countries and diseases. Davies estimated the costs of a hypothetical EU-wide vaccination programme for FMD to be conducted in 1987 to be approximately ECU 133 million (based on a cattle population of 80.06 million), with the costs per head of cattle ranging from ECU 0.74 (Greece) to ECU 2.66 (UK) (2).

Large differences in vaccination costs are also reported for Newcastle disease. Sen et al. estimated the costs of effective Newcastle disease vaccination for broilers in Cambodia to be US$330 per cycle in 1994 (based on 2,000 broilers and including storage and administration of the vaccine) (30). Nijdam et al. estimated total costs of Newcastle disease vaccination for the average broiler farm in the Netherlands in 1997 to be approximately US$ 5,000 annually (the average Dutch broiler farm was assumed to comprise 50,000 broilers, with 6.7 cycles per year) (20). The differences in these estimates are probably caused principally by the differences in vaccination schemes (four times a year in Cambodia compared to once a year in the Netherlands).

In many countries, costs for routine vaccination are borne by farmers. However, in several developing countries, vaccination is provided at low cost or free of charge by the government for certain diseases. In Thailand, for example, the government provides free FMD vaccines for all livestock, except those of large commercial pig farms.

Additional support measures

The various support measures described in the previous section are difficult to evaluate precisely on a 'per disease' basis. Hygiene measures aimed at preventing the introduction of CSF to a pig farm will also reduce the probability of introducing FMD. Improving the traceability and movement control of pigs will contribute to the eradication of outbreaks of both diseases. Even if an education campaign is aimed at a specific disease, general disease awareness is likely to be improved, not only awareness of the target disease of the campaign.

Contingency plans

Many countries use inter-outbreak periods to develop and maintain contingency plans and to organise emergency training activities. Within the EU, contingency plans are compulsory (13).

Funds

Some countries have allocated funds to reserve money for outbreak periods. Individual farmers contribute to these funds by paying an annual levy per animal or animal product (e.g. per unit of milk produced). In Belgium and the Netherlands, the recent CSF epidemics led to the establishment of annual levies that are no longer fixed but based on the individual contribution of the farmer to the overall disease risk. Aspects included are, for example, the number of multiplier herds from which a fattener buys fattening piglets and the location of the farm (within or outside a pre-defined 'pig concentration area') (13).

Horst used simulation modelling based on literature, historical data and expert knowledge to estimate average expected annual losses of approximately US$ 15 and US$35 million due to FMD and CSF epidemics, respectively, for the Netherlands (12). These figures might contribute to discussions on the amount of the annual levies. However, the average CSF epidemic was estimated to cause losses amounting to approximately US$70 million, with only a very low probability of losses over US$300 million. As explained later, the epidemic which occurred in the Netherlands between 1997 and 1998 incurred much greater costs than these estimates. Currently, the levies in the Netherlands are set at a level which will result in an annual income for the Animal Health Fund of approximately US$ 55 million (13).

Outbreak periods

In the case of an outbreak, many events and actions will result in costs and losses. These costs and losses may be categorised as direct costs and consequential losses.

Direct costs

Direct costs are the costs related to diseased animals (in a vaccination situation) or affected farms (if stamping-out is resorted to) including farms affected by movement controls, and the costs related to the organisation of the eradication campaign.

Direct costs related to diseased animals

Mortality

Losses due to mortality are usually calculated on the basis of the expected future profitability of the animal, had the animal remained in the herd until the moment of optimal replacement (14). In the case of mortality due to contagious animal diseases, the value of the dead animal usually equals zero (no slaughter value).
Morbidity: effects on (re)production

Growth and yield of products such as milk, wool and eggs are often reduced by disease. Reproductive capacity may be reduced due to an increased abortion rate or decreased fertility. Epidemics may also lead to altered production of manure. In Asia and Africa, cattle manure is a vital source of cooking fuel, and in much of the developing world manure is an important fertiliser. Therefore, epidemic diseases that cause high mortality rates in cattle will not only influence human nutrition directly, due to reduced meat and milk production but also indirectly, due to a lack of manure supplies (19). Worldwide, the single most important use of manure is still as a source of traction (19). Diseased animals are not able to work, resulting in higher production costs where draught power is hired, or in reduced crop yields for human consumption if no other source of draught power is available.

Treatment costs

No specific treatment is available for many List A diseases. Therapy is usually only symptomatic. Antibiotics may be used to avoid secondary infections.

Direct costs related to affected farms

Depopulation

Depopulation is applied to infected herds, contact herds and to herds located within an eventual pre-emptive slaughter area. Depopulation includes elimination of the herd and disinfection of the premises. In most countries, farmers are compensated for these costs. Therefore, depopulation costs may be based on the compensation paid for the animals and materials (e.g. feed) destroyed. Usually, compensation is based on the market value of the animals. In some countries (e.g. the Netherlands and Belgium) no compensation is given for dead animals and only partial compensation is given for diseased animals, thereby promoting early reporting of disease.

Welfare slaughter or market support

Animals which originate from herds located within movement restriction areas cannot be traded internationally. Within the EU, meat from these animals might be marked (so-called ‘cross-marked meat’) and traded on the national market. Currently, this strategy is only used for outbreaks of Newcastle disease (for example in the Netherlands in 1992) and will often lead to decreasing market prices on the national market (20). To prevent severe disruptions of the national market, governments may also decide to buy and destroy the meat. In the case of very long-term outbreaks, the national government may also decide to purchase pigs from herds within movement restriction areas in order to prevent excessive welfare problems due to limited housing capacity. The measure includes animals that are ready to be delivered to the slaughterhouse or to fattening farms. This welfare measure was applied on a large scale during the 1997 CSF epidemic in the Netherlands (18).

The costs for welfare slaughter or market support can be calculated based on the compensation paid to farmers. Compensation prices are usually linked to the market prices.

Breeding prohibition

In the case of long-term outbreaks, a breeding prohibition may be adopted. Such prohibition is aimed at preventing welfare problems (and costs of welfare slaughter) in the long term but also reduces the animal population available for multiplication and spread of the infectious agent.

Direct costs related to organisation of the eradication

Emergency vaccination

The costs of emergency vaccination are directly related to the cost of the vaccine, the vaccination strategy applied (size of the area to be vaccinated), and the density of susceptible animals in that area.

Tracing and diagnostic activities

Tracing of animal movements to and from infected farms is necessary in order to detect secondary infections at an early stage and thus limit the extent of the epidemic. An effective identification and recording system will simplify and reduce the costs of this task. Costs for tracing and diagnostic activities (including laboratory tests) are related to the extent and duration of the outbreak, the animal and farm density in the area and the pattern of animal movement.

Establishment and control of movement restriction zones

Initial costs are incurred by the labour and equipment used to establish movement restriction zones and to communicate the restrictions to the inhabitants of the area. Thereafter, compliance with the restrictions has to be verified. Costs are directly related to the size of the restricted area, the farm and animal density in that area and the duration of the restrictions.

Organisation of depopulation and other on-farm activities

This aspect covers costs such as valuation of animals to be destroyed, cleaning and disinfection of farm buildings, and costs of lethal injections or electrocution equipment.

Consequential losses

The consequential losses can be subdivided into two categories: idle production factors and trade disruptions.

Idle production factors

Large epidemics combated with stamping-out measures supported by long-term movement restrictions may lead to idle production for various producer groups. Depopulation (stamping-out) leads to farms being completely empty for a certain period. Repopulation is not possible for the farms located within a movement restriction zone until the zone is declared free of the disease. Welfare slaughter and breeding prohibitions may also lead to idle production (in these cases, farms will only be partly empty). Movement restrictions may cause supply and delivery problems, especially in the
intensive livestock sectors such as the commercial pig and poultry sectors. Furthermore, a temporary reduction in animal populations will cause losses for slaughterhouses, animal traders, and feed suppliers.

Trade disruptions
Movement restrictions alone cause a reduction in the scale of exports, however export markets might be closed completely for a part of the affected country. Until 1992, any outbreak of a major exotic disease in a country led to the entire country being considered as infected under international (OIE) guidelines (10). Disease-free status could be reclaimed only after the disease had been eliminated for a specified period of time. International initiatives through the OIE have led to the acceptance of guidelines on the principles of zoning for disease control. The outbreak of FMD in Italy in 1993, where the existence of an infected zone in an otherwise disease-free country was recognised, is an example of the application of this new approach (10). Although zoning will reduce the effect of export bans, the prolonged effects of large epidemics may still be severe, especially for areas that rely heavily on exports or operate in a very competitive market. Markets may be appropriated by competitors and regaining these markets will be both difficult and costly. In addition, competitors may increase production capacity while the affected country is not able to export. This will lead to oversupply of the market once the affected country returns to original production capacity. Price reductions and prolonged market disruption could result.

The economic impact of two recent epidemics

Foot and mouth disease in Taipei China
Until 20 March 1997, Taipei China, which at that time had a pig population totalling approximately 14 million and annual exports to Japan of approximately 6 million pig carcasses, had been free of FMD. By the time the epidemic had been controlled, over 6,000 farms had been affected, over 4 million pigs slaughtered and over 13 million doses of vaccine applied. The economic consequences of this epidemic are likely to persist into the next century, as the country endeavours to re-establish export markets (15). The rapid re-establishment of the trade position of Taipei China will not be hampered by the fierce competition within the pork market, but by the use of emergency vaccination. Japan and other markets do not accept pig products containing antibodies against FMD.

Classical swine fever in the Netherlands
The recent major CSF epidemic in the Netherlands (1997-1998) showed that the economic impact of an epidemic under the current EU eradication policy (stamping-out and non-vaccination) can be enormous (18). As the epidemic occurred in an area with an extremely high density of pigs and because of the long delay before control of the outbreak, drastic eradication measures were taken during the course of the outbreak. The compulsory EU measures (9) were complemented by the following:
- pre-emptive slaughter: destruction of pigs on farms located within a 1-km radius of an infected farm
- welfare slaughter: destruction of pigs to avoid welfare problems on farms located within a movement restriction zone
- breeding prohibition, aimed at the prevention of welfare problems in the long term.

In cases of welfare slaughter, animals are destroyed (rendered), therefore any meat or meat products are not used for consumption.

The CSF epidemic in the Netherlands led to the destruction of 11 million pigs. The short-term economic impact totalled over US$2 billion (13, 18). Table II provides an overview of the economic aspects that were included in this calculation. Evaluation of the figures leads to the conclusion that important parameters which determine the economic impact of an outbreak of CSF are the spatial distribution of the secondary outbreaks (a more widespread distribution means an increase in pre-emptive slaughter) and the duration of the epidemic (an outbreak of long duration leads to an increased requirement for welfare slaughter).

The prolonged effects of this epidemic are difficult to estimate but are expected to be immense. The export of live pigs was banned for over a year, thereby allowing competitors to claim markets and increase production. In late 1998/early 1999, an oversupply of pigs and pork, coupled with reduced demand, led to historically low meat prices, jeopardising the financial position of pig farmers in many EU Member States.

Evaluation on various economic levels

Basic framework
As described above, the economic impact of control and eradication of epidemic diseases comprises many aspects. Costs and losses are experienced on various economic levels, namely: the individual primary producers (farms), the related industries (traders, slaughterhouses), the livestock sector as a whole, the consumers, the national level and the international level.

Dijkhuizen et al. provide an interesting categorisation for losses due to animal diseases at various economic levels (4). Using these ideas, Table III presents a basic framework that might serve to evaluate the economic impact of epidemic diseases. The framework can be applied to situations in which routine vaccination as well as stamping-out are used.

Routine vaccination
As explained earlier, the costs for routine vaccination against certain diseases are borne by the government in many developing countries. In the case of an outbreak, the
Losses incurred during the epidemic of classical swine fever (hog cholera) in the Netherlands between 1997 and 1998

<table>
<thead>
<tr>
<th>Category</th>
<th>Aspect</th>
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<tr>
<td>Direct losses</td>
<td>Depopulation: stamping-out of infected herds</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>Depopulation: pre-emptive slaughter</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>Welfare slaughter: pigs ready to be delivered</td>
<td>805</td>
</tr>
<tr>
<td></td>
<td>Welfare slaughter: weaned piglets</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>Welfare slaughter: 3-17 day-old piglets</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>Breeding prohibition</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Costs of organisation</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>1,321</td>
</tr>
<tr>
<td>Consequential losses for farmers</td>
<td>Idle production factors: depopulated farms</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>Idle production factors: other farms</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td>Supply and delivery problems</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Losses from repopulation: depopulated farms</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>Losses from repopulation: other farms</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>423</td>
</tr>
<tr>
<td>Consequential losses in related industries</td>
<td>Slaughterhouses</td>
<td>228</td>
</tr>
<tr>
<td></td>
<td>Animal traders</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Feed suppliers</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>Breeding organisations</td>
<td>211</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>597</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2,340</td>
</tr>
</tbody>
</table>

The government also provides emergency vaccination. Costs related to diseased animals (mortality, production losses and treatment) are usually borne by the farmer and thus are included in the cost price of the products. Thus, the resulting losses are carried over to the consumers. On an aggregated level, supply and demand force market prices for animal products to fluctuate over time according to several variables, including the average disease level. In a sufficiently large market (such as the EU), the relation between the extent and severity of these diseases and the average income of livestock owners is negligible. However, this is not true for the individual farmer. The costs incurred by the farmer as a result of an outbreak may be greater than the compensation in the form of the average 'disease margin' included in the market price.

In cases when routine vaccination is used, outbreaks are usually limited, creating only minor repercussions for the related industry. The effects of any outbreak are assumed to be passed on to the consumer through higher prices. The inefficient use of resources resulting from a disease outbreak may be seen as a loss for the national economy as well as for the international economy.

Both farmers and consumers benefit from an effective vaccination strategy. Smallholders benefit from reduced direct losses and therefore lower production costs. The latter lead to lower prices and thus gains for the consumer (5, 16). Export-oriented producers may benefit to a greater extent because a successful strategy may lead to enhanced trade opportunities.

Stamping-out (with emergency vaccination or a non-vaccination policy)

In the case of stamping-out, the economic impact might differ for countries that apply emergency vaccination compared to countries that adopt a non-vaccination strategy. In both situations, farmers who own affected animals will suffer major losses due to loss of herds. However, losses might be carried over to the government if compensation is paid for destroyed animals. Both the non-vaccination strategy and the emergency vaccination strategy will lead to losses due to idle production factors for both farmers and related industry, because with both strategies, animals on infected farms will be destroyed and movement restrictions imposed. The extent of these losses will be determined by the extent and duration of the epidemic and thus by the effectiveness of the strategy applied. This effectiveness might be influenced not only by the strategy employed but also by the characteristics of the affected area (animal and farm density) and by the duration of the high-risk period (interval between the first infection and the detection of infection). These two aspects determine the size of the epidemic at detection and hence the timing of the beginning of the eradication campaign.

Trade disruptions will cause high losses for exporting countries in both situations. Farmers not directly affected by the outbreak (farms not infected and not located within
movement restriction zones) will also be affected by these trade restrictions. If export is restricted, prices in countries that normally export extensively will drop substantially due to an oversupply of the domestic market. This reduction in price causes losses that may greatly exceed the direct losses from the disease owing to, for instance, mortality and morbidity. Unaffected farms also suffer from this drop in market prices. Consumers will benefit. Some related industries will suffer from the export restrictions (e.g. international traders), others will benefit from the price reduction (e.g. slaughterhouses and retailers).

Market support and welfare slaughter may reduce market disruptions on the internal (national) market but impose extra costs for the government.

Losses due to prolonged trade disruptions will normally be elevated in the case of emergency vaccination because export bans will be lifted later. However, large and prolonged epidemics may also cause major and long-lasting trade disruptions if a non-vaccination policy is adopted because markets will be claimed by competitors.

### Case study

The 1997/1998 epidemic of CSF in the Netherlands clearly illustrates the importance of evaluating cost and benefits on each economic level for a stamping-out strategy. If no compensation had been awarded, most losses would have been borne by primary farmers (to the value of 11 million pigs, plus consequential losses). However, the Government compensated farmers for destroyed herds. Losses due to idle production factors on farms and in related industries, such as slaughterhouses, traders and feed suppliers, located within movement restriction zones, were not compensated. A proportion of the money used for compensation was provided by the 'stamping-out fund', a fund which was contributed to by Government and private industry on a 50:50 shared basis. However, the compensation costs far exceeded the monies available in this fund (US$100 million).

The Government of the Netherlands was subsidised by the EU for a portion of the organisational costs and costs for compensation paid to farmers.

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### Table III
Framework for the evaluation of the economic impact of outbreaks of epidemic diseases, at various economic levels

<table>
<thead>
<tr>
<th>Economic level</th>
<th>Routine vaccination</th>
<th>Emergency vaccination</th>
<th>Stamping-out</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case study</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3. Sector</strong></td>
<td>Losses if prices not adjusted to disease level. Within a sufficiently large market, virtually no link between disease level and average income in the sector, due to price adjustments.</td>
<td>Losses, depending on possible compensation, duration of export bans and degree of price adjustments. Prolonged trade disruptions.</td>
<td>Losses, depending on possible compensation, duration of export bans and degree of price adjustments.</td>
</tr>
<tr>
<td><strong>4. Consumer</strong></td>
<td>Losses due to higher prices (higher cost price).</td>
<td>Incidental advantage due to lower prices.</td>
<td>Incidental advantage due to lower prices.</td>
</tr>
<tr>
<td><strong>5. Government</strong></td>
<td>Costs of emergency vaccination, possible compensation and organisation.</td>
<td>Costs for organisation and possible compensation.</td>
<td>Costs for organisation. In the case of compensation for destroyed animals, much higher costs than in case of emergency vaccination.</td>
</tr>
<tr>
<td><strong>7. International economy</strong></td>
<td>Losses due to insufficient use of resources.</td>
<td>Temporary losses due to inefficient use of resources. Losses increased if national government is subsidised by a supranational government (e.g. European Union). Profits in those countries that have appropriated markets.</td>
<td>Temporary losses due to inefficient use of resources. Losses increased if national government is subsidised by a supranational government (e.g. European Union). In the case of extensive outbreaks: higher compensation. Profits in those countries that have appropriated markets.</td>
</tr>
</tbody>
</table>

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### Economic level

1. **Farm (individual producer)**
   - Annual vaccination costs (some countries subsidised)
   - Direct relation between loss and degree of severity of the disease on the farm (usually no compensation for diseased/dead animals).
   - High individual losses for infected farms and farms within movement restriction zones. Possible compensation for destroyed animals. For exporting countries, major losses for unaffected farms due to long-term trade restrictions.
   - High individual losses for infected farms and farms within movement restriction zones. Short-term losses even greater than in the case of stamping-out with emergency vaccination because of idle production factors. Long-term losses lower because trade restrictions only short-term. Possible compensation for destroyed animals.

2. **Related industry**
   - Outbreaks usually limited, therefore of minor impact. Price changes might be carried over to consumers.
   - Short-term epidemics: losses passed on to consumers. Considerable losses for export-oriented industries (traders) due to prolonged export bans.
   - Short-term epidemics: losses passed on to the consumers. Long-term epidemics: considerable losses due to movement restrictions and trade bans.

3. **Sector**
   - Losses if prices not adjusted to disease level. Within a sufficiently large market, virtually no link between disease level and average income in the sector, due to price adjustments.
   - Losses, depending on possible compensation, duration of export bans and degree of price adjustments. Prolonged trade disruptions.
   - Losses, depending on possible compensation, duration of export bans and degree of price adjustments.

4. **Consumer**
   - Losses due to higher prices (higher cost price).
   - Incidental advantage due to lower prices.
   - Incidental advantage due to lower prices.

5. **Government**
   - Costs of emergency vaccination, possible compensation and organisation.
   - Costs for organisation and possible compensation.
   - Costs for organisation. In the case of compensation for destroyed animals, much higher costs than in case of emergency vaccination.

6. **National economy**
   - Losses due to inefficient use of resources. In some countries: vaccination costs.
   - Consumer advantages usually lesser than sector disadvantages. Prolonged trade disruptions may weaken the livestock sector.
   - Consumer advantages normally lesser than sector disadvantages. Weakened sector in case of very extensive epidemics.

7. **International economy**
   - Losses due to inefficient use of resources.
   - Temporary losses due to inefficient use of resources. Losses increased if national government is subsidised by a supranational government (e.g. European Union). Profits in those countries that have appropriated markets.
   - Temporary losses due to inefficient use of resources. Losses increased if national government is subsidised by a supranational government (e.g. European Union). In the case of extensive outbreaks: higher compensation. Profits in those countries that have appropriated markets.

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This case study shows that losses are not always financially covered by the economic levels from which they originate. Calculations by Meuwissen et al. showed that the budgetary consequences of the 1997/1998 epidemic for the Government of the Netherlands and the EU were 47% of the total loss of US$2.3 billion. Farmers bore 28% of the costs (US$664 million) and related industries bore 25% (18).

These calculations only include the short-term or direct losses described in Table II. Market disruptions due to export bans, price reductions and markets appropriated by competitors were not taken into account but would certainly have increased the losses for the livestock sector and related industries.

**Conclusion**

**Diseases**

This paper focuses on the economic impact of the eradication and control of epidemics caused by diseases in OIE List A. These diseases often cause major epidemics which have an enormous impact on the countries involved, because of the high morbidity and mortality among the infected animals and the consequential economic losses, both the direct costs (e.g. mortality, morbidity and treatment costs) and the consequential losses (idle production factors and trade disruptions). However, diseases other than those in List A can also have an epidemic pattern (e.g. Aujeszky's disease, infectious bovine rhinotracheitis and porcine reproductive and respiratory syndrome). The economic impact of epidemics of these diseases is currently not comparable with that of epidemics of List A diseases, primarily because the diseases not in List A do not create trade restrictions. However, many countries strive for freedom from the above-mentioned diseases and might, in the future, use disease-free status as a trade barrier. These diseases might, therefore, increase in importance in the near future.

**Vaccination**

The prospect of prolonged trade disruptions often eliminates the possibility of using emergency vaccination in the control of major epidemics. This was the case with the recent CSF epidemics in the Netherlands, Germany and Belgium. However, the enormous economic impact of these epidemics re-opened discussion of this point in the EU. Vaccination might be useful in slowing the spread of disease when the outbreak is expected to become so extensive that pre-emptive slaughter on all farms within a 1-km radius of infected farms is not feasible because of limited destruction capacity. This may be the case when FMD (or even CSF) occurs in a densely populated livestock area, for instance, the southern part of the Netherlands which has a pig density of over 1,000 pigs per square kilometre. Furthermore, vaccination, if applied early and within a sufficiently large area (the vaccinated area must cover the epidemic area), might help to stop the spread of the epidemic and therefore help to reduce the duration of the epidemic. The experiences of the Netherlands show that the duration of an epidemic is one of the most important parameters which determine the direct economic impact of epidemics (because of the need for welfare slaughter). The recent development of marker vaccines has also revitalised the discussions. When these vaccines are employed and are complemented by serological tests, vaccinated animals can be distinguished from animals that have recovered from natural infection. This may mean that in the future, trade and export bans will no longer be necessary for vaccinated animals.

**Economic evaluation**

Control and eradication of epidemic diseases is a complex issue in which many factors are involved. The success of a certain strategy depends on many aspects that may differ for each outbreak (e.g. virus strain involved, extent of the epidemic at the moment of detection [duration of the high-risk period], season [interaction with animal movement pattern] and reaction of farmers). Therefore, to provide a generic overview of the economic impact of various strategies is almost impossible. However, the checklist given earlier provides aspects which require consideration. The basic framework might help to analyse the economic impact on various economic levels. Such evaluations are rarely found in the literature but can be very interesting. For instance, in developing countries the national government often bears the costs for routine vaccination. In these cases, an effective vaccination campaign will imply costs for the government but benefits for farmers and consumers. Within the EU, the practice of compensation causes a final distribution of costs and losses among the economic levels that does not reflect the origins of these costs and losses. The distribution of costs and benefits from prevention, control and eradication over the various economic levels will often be determined in part by political ideologies and choices.
Évaluation économique de la prophylaxie et de l’éradication des épidémies

H.S. Horst, C.J. de Vos, F.H.M. Tomassen & J. Stelwagen

Résumé
L’évaluation économique de la prophylaxie et de l’éradication des épidémies est une tâche difficile. Les auteurs apportent un éclairage nouveau sur cette question en présentant les différents éléments à prendre en compte en « période de foyer » ainsi qu’en « période d’absence de foyer ».
Ils proposent ensuite un système de classement permettant de calculer les coûts directs et les pertes indirectes associées aux foyers. Les épidémies n’ont pas le même impact économique pour l’éleveur individuel ou pour le secteur de l’élevage pris en général, et cette différence peut être inféchie selon les stratégies de prophylaxie et d’éradication appliquées. Les auteurs s’efforcent de donner un cadre général d’évaluation qui prenne en compte plusieurs niveaux d’analyse économique.

Mots-clés

Evaluación económica de la lucha contra epidemias y su erradicación

H.S. Horst, C.J. de Vos, F.H.M. Tomassen & J. Stelwagen

Resumen
Muchos son los países que han implementado estrategias para controlar y erradicar épidemias, basadas por regla general en el sacrificio o en vacunaciones sistemáticas, a veces complementadas con vacunaciones de urgencia. Los autores describen estas estrategias, sirviéndose de ejemplos para ilustrar cada una de ellas.
La evaluación económica de la lucha contra las epidemias y su erradicación es un tema complejo. Los autores profundizan en este campo describiendo los diversos elementos que entran en juego tanto en las fases ‘de ausencia de brote’ como en las fases ‘de brote’.
A continuación proponen un sistema de clasificación para el cálculo de los costes directos y las pérdidas indirectas que resultan de los brotes. Las consecuencias económicas de las enfermedades epidémicas son distintas según
se considere únicamente a los productores o al sector ganadero en su conjunto, diferencia que depende hasta cierto punto de la estrategia de control y erradicación aplicada. Los autores sugieren un sistema básico de referencia para realizar la evaluación económica a distinto niveles económicos.

**Palabras clave**

References


