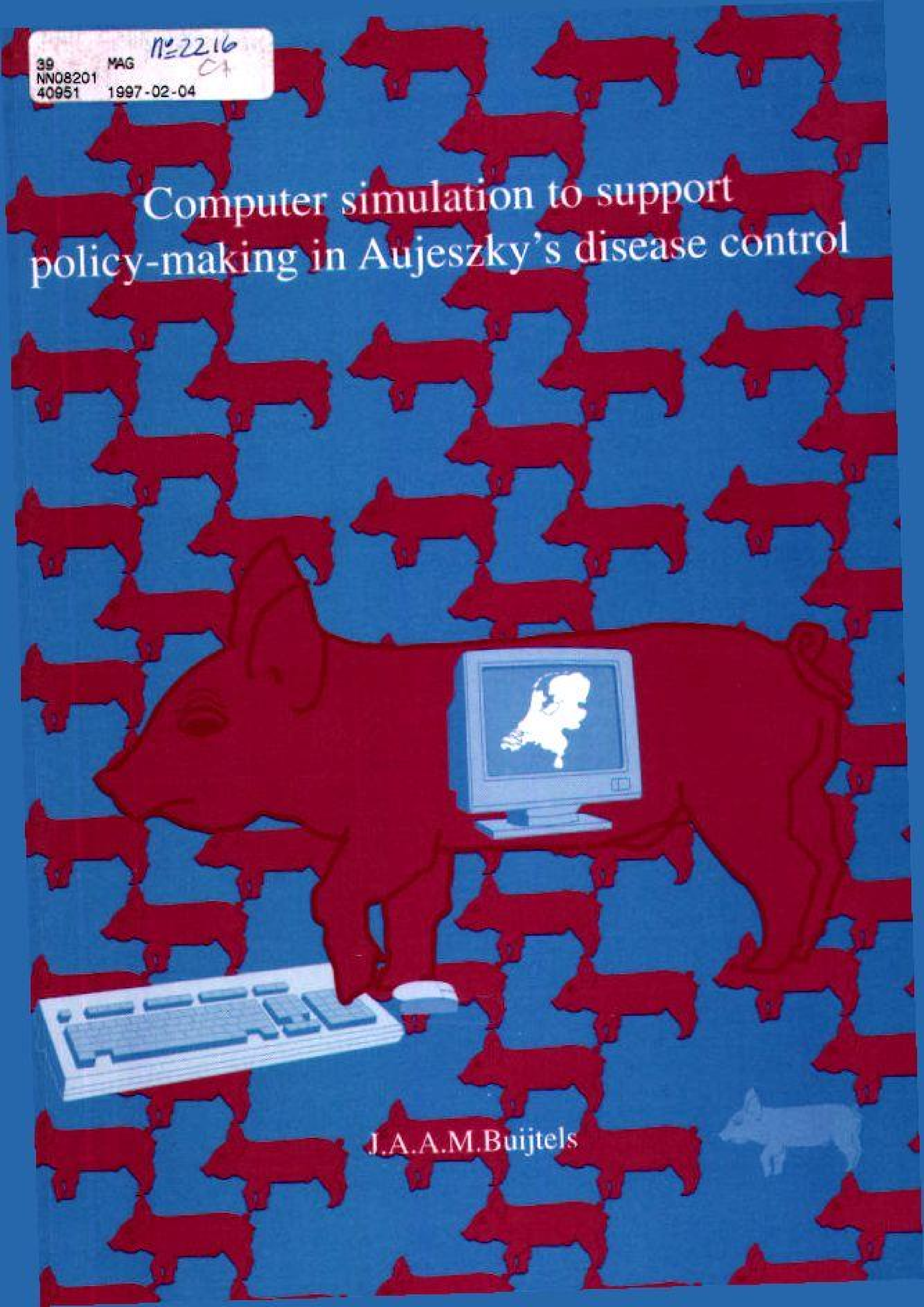
Computer simulation to support policy-making in Aujeszky's disease control



J.A.A.M.Buijtels

NN08201, 2216

Stellingen

1. In aanvulling op de reproductie ratio R is computersimulatie gewenst om te komen tot een kwantitatief inzicht in de epidemiologische en economische aspecten van de eradicatie van de ziekte van Aujeszky.
Dit proefschrift

2. Met prijsevenwichtmodellen zijn de veranderingen in prijzen van varkens, rundvee en pluimvee op zowel de korte als de middellange termijn goed te schatten. Voorwaarde is wel dat een data set met maandelijkse gegevens betreffende hoeveelheden, prijzen en voorgekomen handelsbelemmerende dierziektes tot ongeveer 10 jaar terug aanwezig is om de benodigde parameters nauwkeurig te kunnen schatten.
Dit proefschrift

3. Voor de economische rechtvaardiging van de bestrijding van de ziekte van Aujeszky is het risico van exportverliezen vele malen belangrijker dan de (directe) productieverliezen en vaccinatiekosten.
Dit proefschrift

4. Voor de huidige Nederlandse situatie ten aanzien van de ziekte van Aujeszky is het economisch gezien beter om met bloedonderzoek te starten en alle gE-positieve dieren versneld af te voeren dan door te gaan met vaccineren, mits althans het extra risico van introductie van het virus voldoende beperkt blijft.
Dit proefschrift

5. Gezien het belang van factoren als ongedierte (muizen, ratten), personen (dierenartsen, voorlichters) en materialen (bulkwagens, destructors) in de verspreiding van de ziekte van Aujeszky zijn naast vaccineren flankerende maatregelen op het gebied van bedrijfshygiëne en bedrijfsvoering gewenst om vrij te worden en te blijven.
Dit proefschrift

6. Computermodellen zijn een vereenvoudigde weergave van de werkelijkheid. Bij zowel de modelbouw als de validatie dient zo veel mogelijk gebruik te worden gemaakt van praktijkgegevens. Derhalve dienen modelbouwers in nauw contact te staan met gegevens leverende instanties (en vice versa).

7. Een verplichte vaccinatiecampagne tegen IBR in de Nederlandse rundveehouderij is economisch gezien meer dan gerechtvaardigd.

8. Hoewel de overheid volgens de economische theorie in principe risico-neutraal dient te beslissen (Little en Mirrlees, 1974) treft men in het beleid vaak een risicomijdende houding aan. Hierdoor worden nieuwe, kansrijke ontwikkelingen ten onrechte vertraagd dan wel tegengehouden.
Little, I.M.D. and Mirrlees, J.A., 1974. Project appraisal and planning for developing countries. Heinemann, London.

9. Voor de toekomst van de Nederlandse grondgebonden veehouderij is het van belang dat de boerenstand het multifunctioneel gebruik van de groene ruimte op zijn minst gaat accepteren maar liever gaat stimuleren.

10. Gezien de gerichte pogingen om de dierlijke productie in het voormalige Oostblok te verhogen wordt het voor de Nederlandse veehouder nog belangrijker om op basis van de netto toegevoegde waarde te produceren.

11. Ook van een ziektemodel kun je ziek worden.

J.A.A.M. Buijtels
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Wageningen, 4 februari 1997

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Computer simulation to support policy-making in Aujeszky's disease control

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VOORWOORD

Het promotiewerk is door mij vaak gezien als een produktiesysteem dat opgezet moet worden. Om het überhaupt op poten te kunnen zetten is financiering nodig. Met dank aan de Gezondheidsdienst voor Dieren en het Ministerie van Landbouw, Natuurbeheer en Visserij kon ik beginnen.

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Een produktieproces kan niet in goede banen worden geleid wanneer de omgeving waarin gewerkt moet worden niet goed is. Helmy, zonder de tijd en de motivatie die ik van jou heb gekregen, was me dit nooit gelukt. Daarnaast de leden van de vakgroep die toch zorgen voor een leuke sfeer, steun en medeleven zeker in de laatste fase. Hierbij wil ik ook mijn huisgenoten Jules en Ton noemen. Altijd kon ik bij jullie mijn verhaal van de dag kwijt.

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Als laatste wil ik toch even stil staan bij de gedachte hoe het überhaupt mogelijk is geweest dat ik aan de opzet van dit produktiesysteem heb kunnen beginnen. Tja dat is toch zeker door die twee die altijd achter mij stonden wat ik ook deed. Pap en mam ik weet hoe moeilijk ik ooit voor jullie ben geweest en toch was het van "doorgaan", van "kop op" en "als jij denkt dat dat goed is dan moet je dat doen". Dat heeft mij wederom tot deze volgende mijlpaal gebracht. Om dit te onderstrepen en mijn waardering voor jullie als personen te laten blijken draag ik dit produktiesysteem aan jullie op. Ouders bedankt!!!

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CHAPTER 1

GENERAL INTRODUCTION

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INTRODUCTION

Aujeszky's disease is a contagious viral disease that affects the central nervous system of pigs. In very young animals without immunity, mortality can be 100 percent. In older swine, symptoms are milder, depending on age and immune status, with about 2 percent mortality in mature animals (Gustafson, 1986; Kimman, 1995). Vaccination can reduce the effects of Aujeszky's disease and can ultimately lead to eradication, because it increases the quantity of the virus needed to cause infection and reduces the spread of the disease (Stegeman, 1995a). Various vaccination strategies are possible, however, and determining the optimum input level of different measures is to a large extent a matter of economic consideration. This not only holds for livestock owners, but also for the national government that is seeking an optimal and coordinated policy on Aujeszky's disease (Dijkhuizen, 1992).

The European Union (EU) distinguishes different groups of animal diseases, where they are classified by their nature. Foot-and-Mouth Disease, Classical Swine Fever and Swine Vesicular Disease are notifiable diseases and belong to Group 1. Outbreaks of Group 1 diseases bring about control measures at national or regional level. Aujeszky's disease is in Group 2 of the EU's animal disease classification. Under the EU rules, countries or regions that are Aujeszky-free can ban imports of breeding animals carrying antibodies of the disease; movements to Aujeszky-free areas from other areas of both breeding and rearing pigs are subject to strict conditions and controls, which differ depending on whether or not the area of origin has an EU-approved eradication program (EC, 1993). Such measures are well within current GATT rules, which recognize the concept of disease-free areas and the right of trading countries to protect such areas, providing it is done according to relevant international standards and scientific recommendations (GATT, 1994).

Major exporting countries in Western Europe are therefore under strong commercial pressure to reach Aujeszky-free status. In Germany, EU-approved programs are organized at provincial level, with some provinces already free of the disease. Sweden and Austria began EU-approved programs in 1995 (Moynagh, 1995). France launched a national vaccination program in 1990, and by the end of 1993 twenty-one *départements* in the south-east of the country qualified for Aujeszky-free status according to EU standards (Vannier et al., 1995).

Belgium began its national vaccination program in 1993, concentrating on the high-density pig-producing areas of Flanders. The southern importing countries (Greece, Italy, Spain) and the Republic of Ireland do not have comprehensive programs yet.

In the Netherlands, a three-stage program was announced in September 1993. The first stage started in December 1995, comprises compulsory vaccination and will lead to a disease-free certification program for individual herds, accompanied by regular monitoring. In subsequent stages, remaining sources of infection are traced and eliminated, after which vaccination will cease (Stegeman, 1995b). There is pressure from producers to move more quickly towards eradication, as economic pressures are building up. By mid-1995, Dutch exports of piglets to Germany were already suffering from stricter import criteria (requiring certification that the imported animals come from Aujeszky-free herds) and/or a considerable price differential for non-certified animals. If important import destinations elsewhere in Europe achieve disease-free status, exporting countries that have failed to eradicate the disease will be severely penalized. Therefore, sterner demands are to be expected considering control and eradication of Aujeszky's disease in the future. To meet these demands, a computer simulation environment has been developed in which "what-if" scenarios can be performed to explore the epidemiological and economic effects of different Aujeszky's disease control programs.

OUTLINE OF THE THESIS

Research for this thesis was carried out within the government-funded research program, entitled "Development of expertise on veterinary epidemiology and economics in the Netherlands". This program focused on relevant diseases at herd, regional and national level with Aujeszky's disease being the key subject of research. Within the program there was a close collaboration between the School of Veterinary Medicine in Utrecht, the Institute for Animal Health in Lelystad, the Animal Health Service in the Netherlands and the Wageningen Agricultural University.

Chapter 2 describes the development and contents of the basic economic framework. The framework is illustrated with an example. To obtain epidemiological information with respect to the control of Aujeszky's disease virus, a simulation model is designed (Chapter 3) and the outcome, including a sensitivity analysis of the effects of subdivision into herd types and regionalization, presented (Chapter 4). To calculate the changes in prices as a result of the changes in product supply caused by changes in infection and possible export bans, a price equilibrium model is developed and effects of export bans of different sizes are presented (Chapter 5). Lastly, a cost-benefit analysis of four control strategies, including a sensitivity analysis, is carried out (Chapter 6).

Each chapter includes a description and discussion of the objectives, methods and results of each particular part of the study. Furthermore, a summary of the study is provided at the end of this thesis.

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CHAPTER 2

BASIC FRAMEWORK FOR THE ECONOMIC EVALUATION OF ANIMAL HEALTH CONTROL PROGRAMS

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ABSTRACT

The further integration of international markets makes coordinated policies against contagious animal infections increasingly important, and more strict demands regarding control and eradication are to be expected in the future. To anticipate these demands, a computer simulation environment is desired in which "what-if" scenarios can be performed to explore the epidemiological and economic effects of various infections and control strategies.

A flexible economic framework is proposed in this article, and illustrated with an example. The framework has four elements: changes in percentage of infectious herds, changes in product quantities, changes in product prices and economic integration. Each of these elements is specifically defined and has its own input and output data, depending on the control strategy under consideration.

In an illustrative example, probability distributions of the different control strategies are compared and the optimal strategy is chosen according to the risk attitude of the decision-maker. The current framework can be considered as a new standardized approach for comparing and selecting animal health control strategies by integrating technical and economic data and principles.

INTRODUCTION

The further integration of international markets makes a coordinated policy in the control and eradication of contagious animal infections increasingly important. Moreover, profit margins in modern livestock farming are typically small relative to the resources committed to production. Therefore, control of production costs is becoming progressively more important (Marsh and Morris, 1985; Marsh, 1988; Jalvingh, 1993). Improving animal health is a key feature in this control and increasingly this is carried out through prevention programs on the principle that "prevention is better than cure" (Morris, 1988).

The application of such programs is rarely an all-or-nothing affair. Usually several programs are available, each of them offering a different degree of protection. To determine the economically optimal program, several effects, epidemiological as well as economic, must be taken into account. The optimal program in economic terms is determined according to the equimarginal principle (Morris, 1969; Ellis, 1972). This principle implies that the use of any input should be increased up to the level where the cost of an additional input equals the return from the additional output. However, policy decisions in animal health control have to be taken with imperfect knowledge. That is why a computer simulation environment is desired in which "what-if" scenarios can be performed to explore the epidemiological and economic effects of the various infections and control strategies, characterized by uncertainty, simultaneously (Dijkhuizen, 1992).

The objective of this study was to propose a standardized framework in which the most important components of animal health control, and their interrelationship, are integrated. Although the economic effects of different (levels of) infections have already been explored in the literature (e.g. Ebel et al., 1991; Houben et al., 1993), a wide range of approaches are used and this makes comparison of the outcomes difficult. Therefore, the main goal of the approach proposed here is to devise a standard framework capable of incorporating the key components (with their interrelationships) at an appropriate amount of detail.

In this chapter, first some basic underlying economic principles are described, and especially the nature of the decision-making process, the valuation of costs and benefits, and the approaches used in economic analysis. Second, the basic conceptual framework to support animal health control is presented. Special attention is paid to its four major elements: changes in percentage of infectious herds, changes in quantities produced, changes in product prices and the integrated economic model. The approach is illustrated by an example.

BASIC ECONOMIC PRINCIPLES

The decision-making process

The decision-making process is commonly considered to include five stages (Boehlje and Eidman, 1984):

1) recognizing the problem;
2) developing alternative solutions;
3) making a choice among these alternatives;
4) implementing the decision;
5) evaluating the results.

Current infection information systems focus mainly on stages 1 and 2 (Morris and Dijkhuizen, 1992). Most systems include historical data that are used retrospectively to detect and solve problems (Miller and Dorn, 1990). The attractiveness of these systems will increase when modelling tools are included to support the choice of alternatives (stage 3) and to help evaluate the results (stage 5). In all cases, the decision-maker and not the system is responsible for the decision (Anderson et al., 1977).

Valuation of costs and benefits

Policy decisions in animal health control are taken and implemented at different economic levels: herd (Ebel et al., 1991), region (Miller and Dorn, 1990), national and international (Berentsen et al., 1992; Houben et al., 1993). In this study, a framework is proposed to evaluate control programs at regional and national levels. The value of a control program can only be determined relative to that of an alternative. The economic "cost" of resources which are used in a any program in fact represents the potential returns that could be gained by employing those same resources in the best possible alternative program. Such costs are called the "opportunity costs" (Kay, 1986). Similarly, the revenues of any control program represent the extra earnings gained when such a program is implemented, in comparison to what would happen if the program were not implemented (Sugden and

Williams, 1978). Specific problems in the calculation of the costs and benefits are (Little and Mirrlees, 1974; Gittinger, 1981):

- determination of the types and categories of costs and benefits to include in the analysis;
- choosing the appropriate prices for these categories;
- choosing an appropriate discount rate to account for time preference of money.

In general, there are two methods for measuring costs and benefits which, in mathematical terms, are by integral and differential calculation. The former calculates total costs and benefits, the latter only the changes in costs and benefits (Schroeff, 1970). In the case of policy decisions in animal health control, most of the aspects after applying different strategies are incremental and therefore differential calculation is the more appropriate technique. Only the aspects which are changed have to be included. This method was used, for example, in studies by Hugoson and Wold-Troell (1983), McInerney and Turner (1989) Berentsen et al. (1990), Van der Kamp et al. (1990) and Houben et al. (1993). In these studies, only changes resulting from a certain control program were measured and evaluated.

Market prices are not always available or do not always reflect the true economic values of products to society. For instance when market prices do not account for externalities such as effluent pollution of a water course or loss of amenity due to an intensive pig installation. An economic value is the value associated with one unit of a product which indicates how much social welfare can be increased (or decreased) by the use (or loss) of a marginal unit of that product. When market values are unavailable or inappropriate, then implicit marginal values must be assigned. Such values are called "shadow prices" (Sassone and Schaffer, 1978).

Another common problem is caused by differences in the time periods over which costs and returns are distributed. The value of money (or strictly, of the real goods which money buys) varies due time preference. Therefore, a discount factor must be used to make costs and returns, distributed through time, comparable at a given point (Sugden and Williams, 1978). Also, inflation reduces the purchasing power of money, and so the social discount factor is generally calculated by subtracting the inflation rate from the market interest rate for real estate. The resulting discount rate is assumed to reflect time preference accurately (Sassone and Schaffer, 1978).

Economic analysis

There are two approaches for economic analysis: the positive (empirical) and normative (deductive) approach (James and Ellis, 1979). Both methods are useful and complementary in supporting policy decisions for animal health control. The positive approach observes the actual effects of infection. This approach is complicated by the fact that many of the relevant variables are difficult, if not impossible, to quantify. Infection data, for example, are also influenced by highly variable and often intangible factors such as climate and management. Such considerations may result in not having an appropriate set of empirical data available for analysis at the moment a policy decision must be taken. From the literature, it appears that several studies used empirical data to support policy decisions in animal health control (Power and Harris, 1973; Hugoson and Wold-troell, 1983; McInerney, 1986; McInerney and Turner, 1989). Usually a single-point outcome is obtained which needs to be interpreted for a wider range of possible circumstances which characterize the various control programs. Gathering empirical or observational data for any specific case may also be very costly and time-consuming.

The normative or deductive approach predicts effects from constructing a theoretical model of the infection (e.g. Houben et al., 1993). This approach includes mathematical models to solve either optimization or simulation problems. Optimization tries to find the optimal solution given the objective function and restrictions. By contrast, simulation is an attempt to imitate real life conditions, which may not be consistent with economists' optimising criteria. That is, a simulation model provides answers to "what if" questions. To support policy making in animal health control a wide range of possible components and frequency distributions can be calculated for both data and the various outcomes of control programs (Law and Kelton, 1991; Jalvingh, 1992). To have confidence in the conclusions, validity of the simulation model must be carefully established. Whereas the validity of using an optimization model depends on whether the optimising assumption (of, for example, linear programming) does not contradict the realities of the problem under analysis, validation of simulation models needs extra attention. Simulation is such a broad and flexible modelling approach that the assumptions are really problem-specific and, in many cases, implicit in the model and never explicitly spelled out (Dannenbring and Starr, 1981).

Epidemics and changes in prices are dynamic and stochastic in nature, and therefore subject to uncertainty in both the exact form of the dynamic relationships and the way they are influenced by external factors (Habtemariam et al., 1983; Marsh and Morris, 1985; Marsh, 1986; Liu et al., 1987). Therefore, a dynamic stochastic simulation model is preferred over a deterministic model to support policy making in animal health control.

CONCEPTUAL FRAMEWORK

The factors to be considered in supporting policy decisions in animal health control with their relations, are part of the conceptual framework (Figure 1).

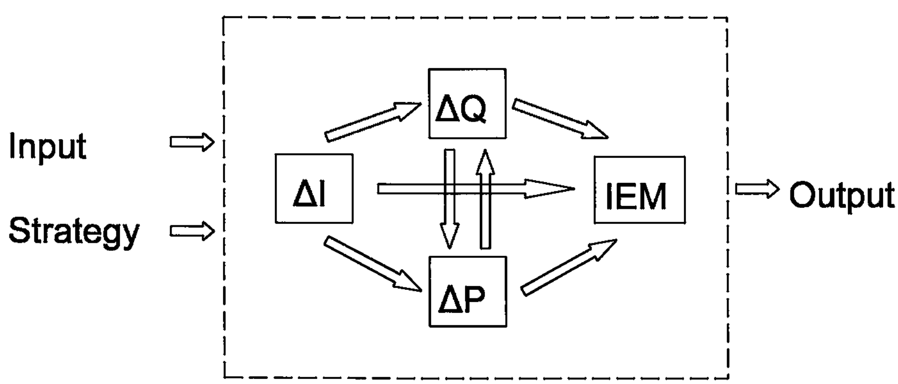

Figure 1. The basic conceptual framework

Where:

ΔI	= changes in percentage of infectious herds
ΔQ	= changes in product quantities
ΔP	= changes in product prices
IEM	= integrated economic model

As shown in Figure 1, the framework can be subdivided into four different elements: (1) "changes in percentage of infectious herds", (2) "changes in quantities", (3) "changes in prices" and (4) "integrated economic model". The four elements of the framework that are presented in detail later have their own inputs. Examples of inputs are a) the structure of the production sector on which the infection has an effect, b) the number of animal contacts between herds, c) herd density, and d) the number of export markets. Depending on the control strategy, each element gives an output. Examples of outputs are the percentage of infectious herds over time and the expected total costs (with its variation) of the control strategy. Vaccinating and culling infectious herds are examples of control strategies.

In the next sections, the different elements of the conceptual framework are described in detail and then translated into a quantitative model. A continuing example is used for illustration.

Example -- Introduction and assumptions

In this illustration a vaccination strategy (Strategy 1) is compared with the situation where no vaccination takes place (Strategy 2). Before the simulation starts, a number of conditions and parameters must be initiated. In the unvaccinated starting situation, before and at t=0, the average fraction of herds that are infectious with a particular viral infection is 25%. The infection affects the production of two complementary products (A,B), i.e. live hogs and pig meat at the Dutch market. Both products A and B are sold on a domestic market (DM). Product A is also sold on two export markets (EM1 and EM2). A week is used as time step t ($0 \leq t \leq T$, with T = 190 weeks).

Suppose that the following events occur:

For Strategies 1 and 2:

t = 20 *first steps in closing export market 1 (EM1), due to the occurrence of the infection*

t = 30 *export market 1 is totally closed*

Only for Strategy 1:

t = 45 *start of applying the control strategy*

t = 120 *infection is totally eradicated*

t = 125 *reopening of export market 1 (EM1), due to the complete eradication of the infection*

These conditions and parameters continue to be used below.

Elements of the framework

1. Changes in percentage of infectious herds (ΔI)

In general, the evolution of an infection (e.g. the percentage of infectious herds) over time is a function of two factors:

- the distribution of the agents (viruses or bacteria) which start infection;
- the susceptibility and potential infectivity of the population(s) in which the agent appears.

Both influence and are influenced by characteristics of the infection agents and the environment. For example, an infection agent may spread infection by air (airborne transmission) or by vectors, and - depending on the specific circumstances - herd density, herd type and different contacts between herds/animals become important in this process (Marsh et al., 1991; Sanson et al., 1991). These contacts (routes of transmission) can be subdivided into direct contact, transmission on fomites, airborne transmission, indirect transmission through other species, and minor disease-specific routes such as venereal or iatrogenic transmission.

The infection and environmental characteristics together with the level (animal, herd, regional, national) at which the policy decision is to be taken determine how the infection can be analyzed or simulated. To simulate an infection, a state transition approach can be used and the above-mentioned features taken into account (Bailey, 1975; Becker, 1989; De Jong and Diekmann, 1992; Houben et al., 1993). In the models here, the population is divided into a limited number of states which take the different infection agents and environmental characteristics into account. The modelling starts by allocating the modelling units (herds) over the different states. After this the simulation of the infection can start.

To determine whether a control strategy is effective, the spread of the infection is evaluated. The basic reproduction ratio (R) is used for this purpose in various kinds of studies (De Jong and Diekmann, 1992; Houben et al., 1993). R is defined as the number of secondary cases resulting from one single infectious herd. When $R<1$, the infection will certainly die out and when $R \geq 1$ there is chance that an introduction of virus results in a major outbreak and that the infection will persist after that but the infection could also die out. However, in simulations with the models used in the example the infection did always persist in the population whenever $R \geq 1$.

Example (continued) -- Changes in percentage of infectious herds

At a time period t each of the herds in the population is in one of the three states, p: (1) infectious, (2) not infectious & not immune or (3) immune. Infectious and/or infected herds are assumed to be in the state infectious. The spread of the infection agent is represented by the transmission rate (TR), defined as the average number of herds to which the virus is transferred by each infectious herd, irrespective of the status of the recipient herd. Differences in susceptibility (immune and not immune) are included by the Within Herd Susceptibility (WHS). The fraction of herds that becomes infectious at time t ($pi_{p,t}$) is:

$$pi_{p,t} = WHS_p \times (1 - e^{-TR \times fi_{t-1}}) \qquad (1)$$

where $pi_{p,t}$ is the probability of the infection for a herd with non-infection state p (not infectious & not immune and immune) in week t, WHS_p is the within-herd susceptibility for a herd with non-infectious state p and fi_{t-1} is the fraction of herds infected in the previous time period (week).

To include stochasticity, random numbers from a uniform distribution are used in the calculation of the number of non-infectious herds becoming infectious each time period t. At the same time the number of infectious herds becoming non-infectious is calculated by using transition values of a transition matrix (Anderson and May, 1985, 1991; De Jong and Diekmann, *1992). The values for TR, WHS, transition matrix and starting distribution are described in Appendix A.*

Results from this method are shown in Figure 2 in which the percentage of infectious herds per time period t are given for 2 control strategies (Strategy 1: vaccination; Strategy 2: no vaccination):

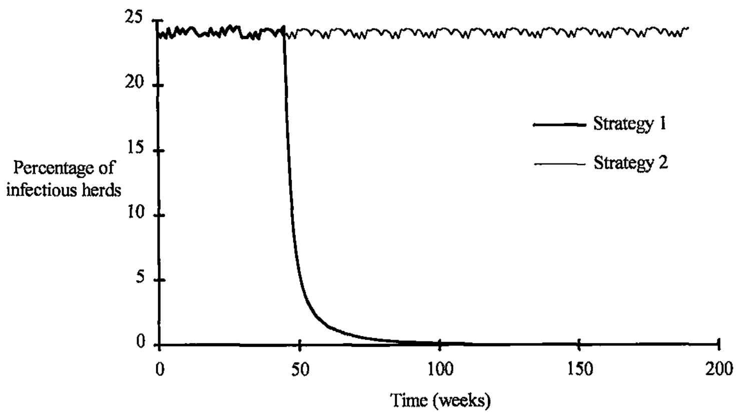

Figure 2. Percentage of infectious herds over time ($0 \leq t \leq 190$) per control strategy

Before t = 45 no vaccination was used in either of the two strategies and R = 8.75 which means that the infection would not die out without using any control strategy. This results in a steady state distribution of almost 25% infectious herds. After the start of the control program (t = 45) the percentage of infectious herds remains in the steady state for Strategy 2 and, initially, decreases rapidly for Strategy 1. This decrease is followed by a less rapid decrease after t = 55 and results in a total eradication at t = 120. That the infection would eventually be eradicated in Strategy 1 could also be deduced from R which was 0.89 when eradication measures were *included. Based on this information only, Strategy 1 would be preferred over Strategy 2 because it eradicates the infection.*

2. Changes in quantities (ΔQ)

Changes in quantities of the affected products per production unit must be determined by empirical data analysis, literature search or estimates by experts. Frequently, production data and data on the infection are recorded but they are seldomly linked, and this implies that data on the consequences of the infection are rarely complete.

Direct consequences of changes in the progress of the infection may be divided into the following:

- additional outputs realized from a certain change (i.e. control program);
- reduced inputs as a result of a change;
- reduced outputs as a consequence of a change;
- extra inputs incurred due to the implementation of a change.

For example, infected animals frequently consume less feed, or, in other words, the use of an input is reduced. By contrast, infected animals need more veterinary services and labour which represent additional inputs.

For the output, the amount and quality of milk, meat, wool, manure, or draught power will be unchanged or decreased. Of course, the nature of the products affected depends on which production sector is directly affected by the infection. Besides the possible direct effects on final products, the infection may also influence the production of intermediate products (e.g. piglets, pullets) and will, in time, influence the value of total sectoral production (including exports).

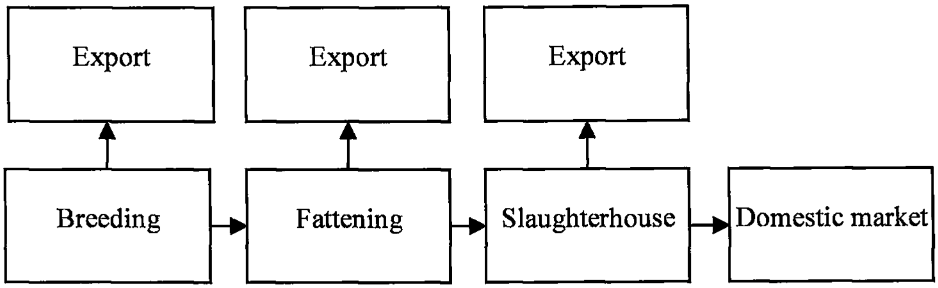

Figure 3. Example of a production sector in the meat industry

Figure 3 summarizes the principal herd types and subsectors in the process of meat production (swine, beef or poultry). If, for example, an infection influences the production of piglets in breeding herds, the supply of piglets to the fattening herds correspondingly decreases, which, in turn, results in a decrease in the supply of fattened pigs to the slaughterhouse after some time.

Besides the direct consequences within a production sector, the infection may also affect other production sectors (Berentsen et al., 1990). For example, an infection-induced fall in the supply of pig meat on a market increases its price, and this results in an increased demand for chicken meat on the same market.

Example (continued) -- Changes in quantities

Given the percentage of infectious herds (calculated in the previous stage of the model), the resulting changes in quantities of the products (A and B) are determined. Per infectious herd, the infection is assumed to cause a 5% production loss in product A and a 10% production loss in product B. Recall that due to the infection, export market EM1 starts closing its borders for product A at t = 20 and the market is completely closed at t = 30. After total eradication of the infection at t = 120 (see Figure 2), export market EM1 starts to reopen its borders at t = 125 when Strategy 1 is used. The border remains closed when Strategy 2 is used.

The general principle is that each product has a supply and demand function which includes supply and demand on both domestic and foreign markets and factors which influence supply and demand (i.e. infections). If there is no or a constant stock of products, changes in demand of products are the same as the changes in supply. Assuming also that the difference in price of a product on two different markets is accounted for by transportation costs and tariffs on international trade, the quantities and prices of products on the different markets can be calculated.

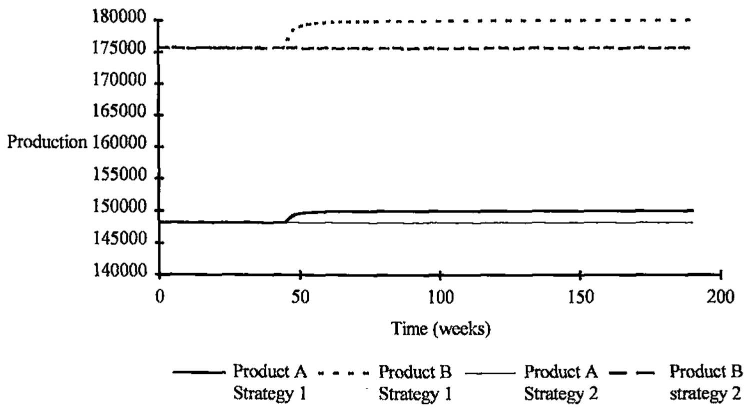

Figure 4. Availability of product A and B (supplied as well as demanded) over time under control Strategies 1 and 2

Figure 4 shows the total production of products A and B. After the borders of export market 1 (EM1) have been closed, the amount of product A available to the domestic market and export market 2 is increased. The technique used to calculate the distribution over the different markets is described in the following paragraph. At t = 45 vaccination in Strategy 1 is started which results in an increase of both products A and B. After the total eradication of the infection (t = 120), the total production of both product A and product B increases in the case of Strategy 1. Production A increases by

1,600 units (from 148,200 to 149,800), while production of B increases by 4,300 units (from 175,700 to 180,000). However, if Strategy 2 is employed, production remains the same (Figure 4).

3. Changes in product prices (ΔP)

After the changes in quantities of products have been estimated, the resulting changes in prices must be calculated. Each change in production may have a direct influence on both its own product price and, indirectly, the prices of other closely-related products in the same market. For example, a change in the number of piglets produced will be expected to have a direct influence on the prices of piglets themselves and an indirect influence on the prices of fattened pigs. Moreover, the same product can be distributed on different (e.g. export) markets. The proportions in which the products are distributed between the markets may change over time because of their own price, prices of complementary/competitive products and/or other external factors (e.g. government policies including export bans) on these markets.

In a study by Houben et al. (1993), fixed prices were used, whereas the export model described by Berentsen et al. (1990) took into account direct as well as indirect (e.g. export bans) effects of changes in product quantities on the prices of the same products. Market equilibrium models (Barten and Turnovsky, 1966; Green et al. 1978; Wohlgenant, 1989) are used in our approach because they also take cross effects of prices of other products (referred to in section 2) on the different markets into account. This method is not yet used to support policy decisions in animal health control.

Example (continued) -- Changes in product prices

The quantity of product A demanded (Q_A^D) can be divided into the demand on the domestic market ($Q_A^{D,DM}$) and the export markets ($Q_A^{D,EM1}$, $Q_A^{D,EM2}$).

$$Q_A^D = Q_A^{D,DM} + Q_A^{D,EM1} + Q_A^{D,EM2} \quad (2)$$

$$Q_A^{D,DM} = a_A^{DM} + b_A^{DM} p_A^{DM} + a_{A,B}^{DM} + b_{A,B}^{DM}\, p_B^{DM} \quad (3)$$

The quantity of product A demanded by the domestic market ($Q_A^{D,DM}$) is influenced by its own price (p_A^{DM}) and the price of product B (p_B^{DM}) where the factors a and b are fixed parameters which can be calculated from data by using simultaneous equation estimation methods.

Products A and B are complementary products which means that without any market disturbance the demand for one product will move in the same direction (but not necessarily by the same amount) as the demand for the other product.

$$Q_A^{D,EMi} = a_A^{EMi} + b_A^{EMi} p_A^{EMi} \quad (4)$$

The quantity of product A demanded on the export markets ($Q_A^{D,EMi}$ where i = 1 or 2) is influenced by its own prices on these export markets (p_A^{EMi}). But also the prices of product A on the export markets (p_A^{EMi}) are related to the price of product A on the domestic market (p_A^{DM}) because, as mentioned earlier, prices of the same product in two different countries can differ only as a result of transportation costs (T) and the effects of government policies, such as tariffs (G).

The quantity of product B demanded ($Q_B^{D,DM}$) is influenced by its own price (p_B^{DM}) and by the prices of product A on the domestic market (p_A^{DM}) and the two export markets (p_A^{EMi}) in the same way as the quantity of product A is influenced as expressed in the equations 2, 3 and 4. The prices of products A *and B can now be calculated by solving the above system of equations (Figure 5).*

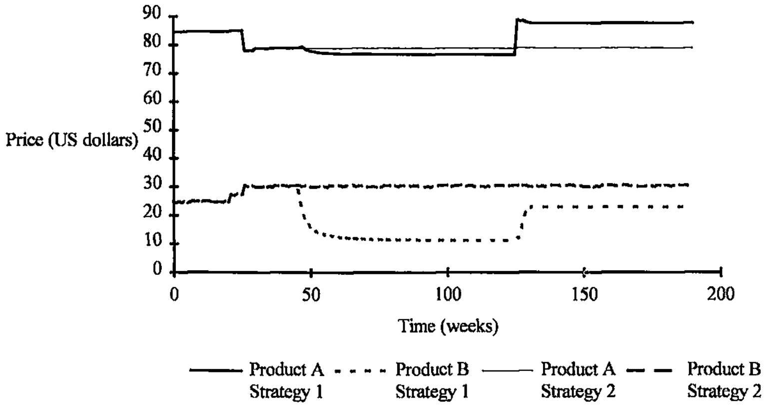

Figure 5. Price of product A and B over time on the domestic market under control Strategies 1 and 2

Because transportation costs and tariffs are kept constant during simulation, the difference between prices on the domestic market and the export market is constant. That is why Figure 5 shows only the price of product A on the domestic market. The price of product A decreases after export market EM1 has been closed (t = 20) under both strategies because of the sharp increase in supply on the other two markets (DM and EM2). The price decreases further after Strategy 1 begins (t = 45) because of the increase in production of both products A (1,600 units) and B (4,300 units). The prices increases again after reopening the export market EM1 (t = 125). What is remarkable is the way these prices decrease and increase. This is mainly caused by the no-stock assumption in this example and by the relatively short period of time between closing and reopening the export market.

After export market EM1 starts closing (t = 20), supply of product A increases on the domestic market (DM) and so does demand because price falls. Because product B is complementary to product A, the demand for product B also increases but its supply remains the same. This results in a price increase for B which is shown in Figure 5. The start of Strategy 1 (t = 45) results in an increase in the supply of product B which, in turn, results in a decrease in the price of product B. After export market EM1 reopens (t = 125) the price of product B increases but remains lower than before the closure of export market EM1.

4. Integrated Economic Model (IEM)

After the variation over time in quantities and prices of the different products for each control strategy have been calculated, the different strategies must be compared. In the literature, partial budgeting and cost-benefit analysis are commonly used for comparing different control/prevention strategies (Power and Harris, 1973; Dasgupta and Pearce, 1974; Sassone and Schaffer, 1978; Stein and Leman, 1982; Bech-Nielson et al., 1983; Habtemariam et al., 1983; Hugoson and Wold-troell, 1983; Ngategize and Kaneene, 1985; Levy and Sarnat, 1986; Dietrich et al., 1987; Van der Kamp et al., 1990). Besides the comparison of different control strategies, a sensitivity analysis of how variations in the magnitude of different parameters affect outcomes should be conducted. This provides a better insight into the relative importance of the different parameters for decision-making. Unfortunately, it is not feasible to do sensitivity analysis for all interaction terms. This sensitivity analysis is carried out by changing values of (uncertain) parameters and restarting the simulation. As soon as the most influential parameters in determining outcomes are identified, special attention should be paid to ensure that realistic values are obtained for them.

Decision makers often tend to react in a risk-averse way, fearing personal consequences of being seen to have made an incorrect decision. The uncertainties associated with control programs, however, are often small in comparison with those associated with the behaviour of the whole economy. Therefore, a decision-maker should normally use risk-neutral rules, such as the expected monetary values of the different strategies. However, non-neutral rules should be considered if consequences of control programs are not evenly spread among the population (Galligan et al., 1987; Dijkhuizen et al., 1994). Stochastic dominance is a promising approach to help to choose among alternatives under such circumstances, but requires some information about the decision-makers' preferences for outcomes (Anderson et al., 1977; King and Robison, 1984).

Example (continued) -- Integrated Economic Model

At this stage the net present value of production over time has to be calculated by using the calculated prices and quantities of products, costs per vaccination etc. As shown in Figure 6, the net present value of Strategy 1 is lower than the net present value of Strategy 2 after the strategies are implemented (t = 45). This means that in this case, and in contrast to the conclusion based only on the changes in infection, no eradication seems to be economically preferred to eradication. This outcome results mainly from the costs incurred by vaccination combined with the lower price of product A after eradication.

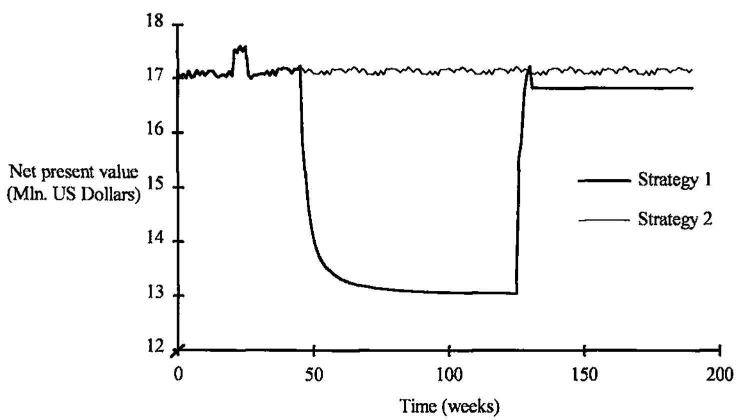

Figure 6. Net present value over time under control Strategies 1 and 2

When, for example, the economic results for each control strategy are derived from several simulation runs, a probability distribution of net present value can be calculated. Figure 7 shows the distributions for control Strategies 1 and 2.

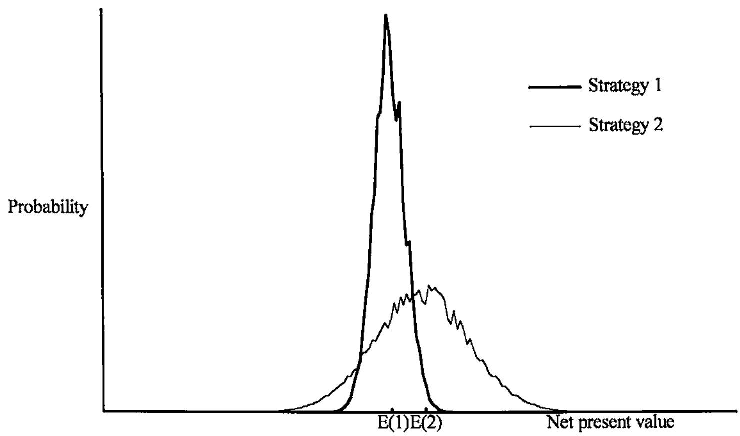

Figure 7. Probability distribution of net present values for control Strategies 1 and 2

Strategy 1 gives the lower expected net present value (E(1)) with a small standard deviation whereas Strategy 2 gives a higher expected net present value (E(2)) but with a larger standard deviation. The evaluation of the different control strategies involves a profit-risk trade-off. The outcome of this evaluation will depend on the risk attitude of the decision-maker. A risk-neutral decision-maker would opt for Strategy 2 whereas a risk averse one may prefer Strategy 1 because of its smaller variance (i.e. less risk) that results in a lower probability of "bad" net present values.

DISCUSSION AND OUTLOOK

In this article a standardized approach was proposed which integrates the technical and economic data considered to be important in supporting policy making for animal health control. Most of these aspects have already been described in the literature but only in a monodisciplinary and non-uniform way (Appendix B). The approach taken here makes it possible to refine a framework to the point where it incorporates both sufficient detail and scientific vigour to make it applicable to support policy making for different animal species and infections. Use of this approach, based as it is on an explicit, well-founded conceptual framework, therefore, helps to make outcomes more transparent and easier to interpret and compare. Particular attention should be paid to the valuation of costs and benefits, especially where the social valuations are not clear (e.g. changes in product value because of consumer demand changes arising from the infection). Another difficulty may be allowing for time preferences, which are generally unknown but nevertheless important in policy decisions which have effects spread over several years.

As shown in the example, the infection represents a dynamic stochastic process as is the closure and reopening of an export market. Therefore, the choice of a dynamic stochastic simulation as a method to analyze this class of problems seems to be more appropriate.

To model the infection, herds/animals in the example are divided into only three states. To be more realistic, more states should be defined. The number of states depends on the available knowledge about the infection and the amount of detail in which the other parts are modelled or related to the nature of the infectious agent.

Between-herd spread of the infection is difficult to model, mainly because of a lack of empirical data about the course and extent of infection as it spreads from one herd to another. Between-herd spread is primarily a function of the different ways in which contacts between herds occur, prevalence of the infection, possible carrier states and herd density. Contacts between herds can be divided into direct contact, transmission on fomites, airborne transmission, indirect transmission through other species, and minor disease-specific routes such as venereal or iatrogenic transmission. It is possible to calculate the average number of animal contacts by analyzing the frequency of animal movements in the entire production chain. To get a better insight into the impact of these contacts on the total between-herd spread, a sensitivity analysis of the relevant parameters should be conducted.

Another difficulty in modelling is estimating to what extent and in what ways product prices are influenced by, for example, changes in product quantities, prices of other products and external factors. This is particularly the case when the total market (supply and demand) is disturbed by the infection. In that case, too, a sensitivity analysis to identify the most influential parameters might provide a better insight into their relative importance.

In decision support, it is desirable to present the various decision criteria available especially when these would lead to different ranking of the control strategies (also illustrated by the example). That allows the decision-maker(s) to choose the most appropriate criterion, taking into account his/her risk preferences and attitudes. Whatever the circumstances particular to any infection, highly contagious as well as less contagious, the framework set out here can be used to support policy making in animal health control.

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APPENDIX A Parameters used to describe the infection in the example.

Transmission Rate (TR) = 10 herds week^{-1}

Within-Herd Susceptibility (WHS):

State	Within-Herd Susceptibility
Not infectious & Not immune	0.95
Immune	0.05

Transition Matrix:

	To:		
	Not infectious & Not immune	Immune	Infectious
From:			
Not-infectious & Not immune	$0.80 \times (1 - pi_{t,p})$	$0.20 \times (1 - pi_{t,p})$	$1 \times pi_{t,p}$
Immune	$0.10 \times (1 - pi_{t,p})$	$0.90 \times (1 - pi_{t,p})$	$1 \times pi_{t,p}$
Infectious	0.05	0.35	0.60

Starting distribution:

State	Percentage of herds
Not infectious & Not immune	7
Immune	68
Infectious	25

APPENDIX B Overview of the literature on the different characteristics which are important to support decision-making in animal health control.

Characteristics	Model						
	I	II	III	IV	V	VI	VII
Herd or National level	N	H	H	N	-	N	H
Normative or Positive approach	N	N&P	N&P	N	N	P	P
Simulation or Optimization	S	O	S	S	S	-	-
Dynamic or Static	D	D	D	D	D	-	-
Deterministic or Stochastic	D	S	S	D	D	-	-
Production change and effect Export bans	P&E	P	P	P	P	-	P
Fixed price changes, using Elasticities or price equilibrium models	E	F	F	F	F	-	F
Cost-benefit analysis, Sensitivity analysis	C&S	-	C&S	C&S	C&S	-	C

The corresponding references are: I (Berentsen et al., 1992); II (Carpenter and Howitt, 1988); III (Ebel et al. 1991); IV (Houben et al., 1993); V (Van der Kamp et al., 1990); VI (Marsh et al., 1991) and VII (McInerney et al., 1992).

CHAPTER 3

A SIMULATION MODEL TO EVALUATE THE SPREAD AND CONTROL OF AUJESZKY'S DISEASE VIRUS: I. MODEL DESCRIPTION

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ABSTRACT

A further integration of international markets makes a coordinated policy on contagious animal diseases increasingly important. In the future, stiffer demands are to be expected considering control and eradication of this type of infections. To meet these demands, a computer model was developed to evaluate different scenarios with respect to epidemiological and economic effects of infections and control strategies. In this chapter, the model was described and the general outcome presented for Aujeszky's disease virus in swine.

In the model, the population of herds is subdivided into four herd types: great-grandparent stock+multiplier, rearing, farrowing and fattening. Per herd type each herd is in one of 32 states. The states are based on (1) the reproduction ratio R_{ind}, which is the number of individuals infected by one infectious individual, (2) the prevalence for each value of R_{ind} and (3) the expected number of infectious animals in an infectious herd within each prevalence range of the herd. The different values of R_{ind} were based on field data and experiments where different vaccination strategies were applied.

The transition matrix with the probabilities of every transition from one state to another was calculated on a weekly basis. From this matrix the distribution of herds over states from week to week was derived. To include a non-linearity of the transmission process, the transmission probabilities from non-infectious to either non-infectious or infectious were developed dependent on the state vector. The fraction of herds that became infectious equalled one minus the number of herds that had not been infected by the virus emitted by infectious herds.

Calculations showed that infection in the Dutch swine population will not disappear without vaccination nor with a vaccination scheme in which sows are vaccinated less than 3 times a year and fattening pigs once per cycle. The infection will be eradicated within 2 to 3 years, if sows are vaccinated 3 or 4 times per year and fattening pigs twice per cycle. The outcome showed to be sensitive to the impact of other than animal contacts on the number of new effective virus introductions per time unit.

INTRODUCTION

A further integration of international markets makes a coordinated policy on contagious animal diseases increasingly important. Stiffer demands are to be expected in the future considering control and eradication of this type of infection. To meet these demands, a framework was developed in which "what-if" scenarios can be evaluated with respect to the spread and control of an infection (Dijkhuizen, 1992; Houben et al., 1993; Buijtels et al., 1996).

In general, the rate of infection from unit to unit (here: herds) in a population (here: region) depends on factors that fall into two main categories: the infectivity and susceptibility of the units, and how contacts occur among these units in the population (De Jong, 1995). The factors in the former category are influenced by, for example, vaccination of the herd, and the factors in the latter by, for example, using footwear that is worn only on the farm to be visited. Contacts between farms include animal, aerial, material, personal and other contacts (Kluge et al., 1992). Usually these kinds of contagious infections are most effectively controlled at regional or national level rather than at individual herd level.

To simulate an infection, a state transition approach can be applied (Bailey, 1975; Becker, 1989; De Jong and Diekmann, 1992; Houben et al., 1993). In these models the population is subdivided into a limited number of states to take into account the different host population and environmental characteristics. The modelling starts with allocating the modelling units (usually herds) to the different states. The number of herds in the different states are elements of a so-called state vector, and the probabilities that herds go from one state to another in the next time period are elements of the so-called transition matrix. With the initial state vector and the transition matrix the number of herds in the different states in each time period can be calculated. In the literature this method has frequently been used in simulation models to describe the spread and control of different infections (Van der Kamp et al., 1990; Berentsen et al., 1992; Houben et al., 1993). Although these models seem to simulate the infection quite well, they cannot easily be validated by empirical data because there is no direct link between the definition of the states and empirical evidence from experiments and observations. Therefore, a new simulation model for Aujeszky's disease virus was constructed in which the parameters used are based on, and validated by, results of empirical experiments. In this chapter, the structure and content of this new model are outlined and applied to the control of Aujeszky's disease virus in The Netherlands. The approach is general, however, and can easily be applied to other countries and herd conditions.

MODEL STRUCTURE AND CONTENT

Introduction

Spread of an infection can be considered within and between herds. Size and type of the herd, level of hygiene, natural mating are examples of effects within herds; the different contacts (animal, aerial, personal, material and others) are the main between-herd effects (Marsh et al., 1991). The spread of an infection between both herds and individual pigs can be characterized by the reproduction ratio R, which is the number of secondary cases (units) caused by one typical infectious unit (De Jong and Diekmann, 1992). This parameter is a yardstick measuring whether or not the infectious agent will spread: $R<1$ means that the infection will not spread and $R>1$ that it will. There are three possibilities:

a) only a minor outbreak occurs;
b) an epidemic situation occurs, which means that the virus is introduced and disappears after some time;
c) establishment of an endemic situation after an epidemic outbreak.

The R of an entire region can be calculated on a pig-per-pig and on a herd-per-herd basis. Stegeman et al. (1995) showed in their study that the pig-per-pig R (R_{ind}) in fattening herds is larger than one and thus also the R for a region is larger than one. Therefore, in this chapter the herd-per-herd R (R_{herd}) was studied.

The prevalence of Aujeszky's disease virus in a herd characterized by a particular R_{ind} value influences the situation. Therefore, it is important to define prevalence ranges within each R_{ind}. Within each prevalence range the expected number of infectious animals will also differ per situation and therefore the characterization of herds in the simulation model was based on (1) the value of R_{ind}, (2) the prevalence within each value of R_{ind}, and (3) the expected number of infectious animals of an infectious herd within each prevalence range.

Characterization of herds in states

As mentioned before this study focuses on between-herd spread and control of Aujeszky's disease virus and therefore the herd was used as a modelling unit. R_{ind} was used in the characterization of a herd and R_{herd} was calculated for the total population. To incorporate heterogeneity among herds, they were subdivided into two different main herd types (breeding and fattening herds). In The Netherlands all pigs in a breeding herd have been vaccinated at once 3 times a year since September 1993 (Stegeman, 1995), while pigs in a fattening herd have been vaccinated once or twice per cycle. Field observations in breeding herds have shown that R_{ind} in herds vaccinated with the vaccine strain-783 o/w[1] or Begonia is significantly less than 1 (Van Nes, 1995). De Jong and Kimman (1994) have shown that R_{ind}=10 in unvaccinated Specific Pathogen Free (SPF) pigs at 26 weeks of age. Stegeman et al. (1995) showed an R_{ind} of 3.5 and 1.5 in fattening herds that had been vaccinated with strain-783 o/w once and twice respectively. Taking these experimental results into account, three different vaccination strategies per herd type were defined, as shown in Table 1.

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1 o/w stands for oil and water emulsion

Table 1. Definition of the different strategies and states

Breeding herds:

Strategy	Number of gE-prevalence classes	Number of states	Number of infectious states	Definition control strategy
1	3	14	11	no vaccination (R = 10)
2	3	10	7	vaccinating less than 3 times per year with strain-783 or Begonia (R = 1.5)
3	3	8	3	vaccinating 3 or 4 times per year with strain-783 or Begonia (R = 0.5)

Rearing and fattening herds:

Strategy	Number of gE-prevalence classes	Number of states	Number of infectious states	Definition control strategy
1	3	14	11	no vaccination (R = 10)
2	3	10	7	vaccinating once per cycle with strain-783 or Begonia (R = 3.5)
3	3	8	6	vaccinating twice per cycle with strain-783 or Begonia (R = 1.5)

Within each vaccination strategy, three different gE-prevalence ranges were defined. Within each prevalence range, herds can be infectious ($I^* > 0$) or not ($I^* = 0$). In the infectious herds one of the three situations (minor outbreak, epidemic, becoming endemic) may occur depending on the vaccination strategy (and the corresponding R_{ind}) applied by the herd owner. These situations each have a different number of expected infectious animals. The definition of the prevalence ranges within each R_{ind} and the calculation of the expected number of infectious animals per infectious herd were based on the analysis of a stochastic S(usceptible)I(nfectious)R(esistant)-model (Becker, 1989; De Jong and Diekmann, 1992) and supported by micro-simulation at animal level as described by Van Nes et al. (1996). However, not all situations are likely to occur at each prevalence range and some were therefore not taken into account. This resulted in a different number of states per prevalence range and per vaccination strategy in describing infectious herds, as is shown in Tables 2A and 2B for breeding and fattening herds respectively.

Tabel 2. Definition of the different states of (A) great-grandparent stock + multiplier and farrowing herds and (B) rearing and fattening herds

A. Great-grandparent stock + multiplier and farrowing herds

State	R	%P	I*
1	0.5	≤10	0
2	0.5	≤10	1
3	0.5	10-50	0
4	0.5	10-50	1
5	0.5	50-100	0
6	0.5	50-100	1
7	0.5	50-100	0
8	0.5	50-100	0
9	1.5	≤10	0
10	1.5	≤10	1
11	1.5	10-50	43
12	1.5	50-100	26
13	1.5	10-50	0
14	1.5	10-50	1
15	1.5	10-50	43
16	1.5	50-100	26
17	1.5	50-100	0
18	1.5	50-100	1
19	10	≤10	0
20	10	≤10	1
21	10	10-50	126
22	10	50-100	100
23	10	10-50	0
24	10	10-50	1
25	10	10-50	126
26	10	50-100	100
27	10	10-50	0
28	10	10-50	1
29	10	10-50	126
30	10	50-100	100
31	10	50-100	0
32	10	50-100	1

B. Rearing and fattening herds

State	R	%P	I*
1	1.5	≤10	0
2	1.5	≤10	1
3	1.5	50-100	53
4	1.5	50-100	14
5	1.5	10-50	0
6	1.5	10-50	1
7	1.5	50-100	53
8	1.5	50-100	14
9	3.5	≤10	0
10	3.5	≤10	1
11	3.5	10-50	84
12	3.5	50-100	42
13	3.5	10-50	0
14	3.5	10-50	1
15	3.5	50-100	42
16	3.5	50-100	0
17	3.5	50-100	1
18	3.5	50-100	42
19	10	≤10	0
20	10	≤10	1
21	10	50-100	350
22	10	50-100	67
23	10	10-50	0
24	10	10-50	1
25	10	50-100	350
26	10	50-100	67
27	10	10-50	0
28	10	50-100	1
29	10	50-100	140
30	10	50-100	67
31	10	50-100	0
32	10	50-100	1

R = Reproduction ratio

%P = Prevalence which is defined as the percentage gE-positive animals

I* = Expected number of infectious animals in equilibrium

To give an example, an infection in a fattening herd with vaccination strategy 2 can develop in a number of ways, as shown in Figure 1. The non-infectious herds with prevalence ranges of smaller than 10%, between 10% and 50% and greater than 50% are represented by states 9, 13 and 16 respectively. In the transition of the states from 9 to 10, 13 to 14 and 16 to 17 only minor outbreaks occur, while in transition from state 10 to 11 a major outbreak occurs. From the states 10, 11, 14 and 17 the infection can either die out after some time and the population then makes a transition to states 9, 13 or 16 or the infection can persist and the population will go to states 12, 15 or 18.

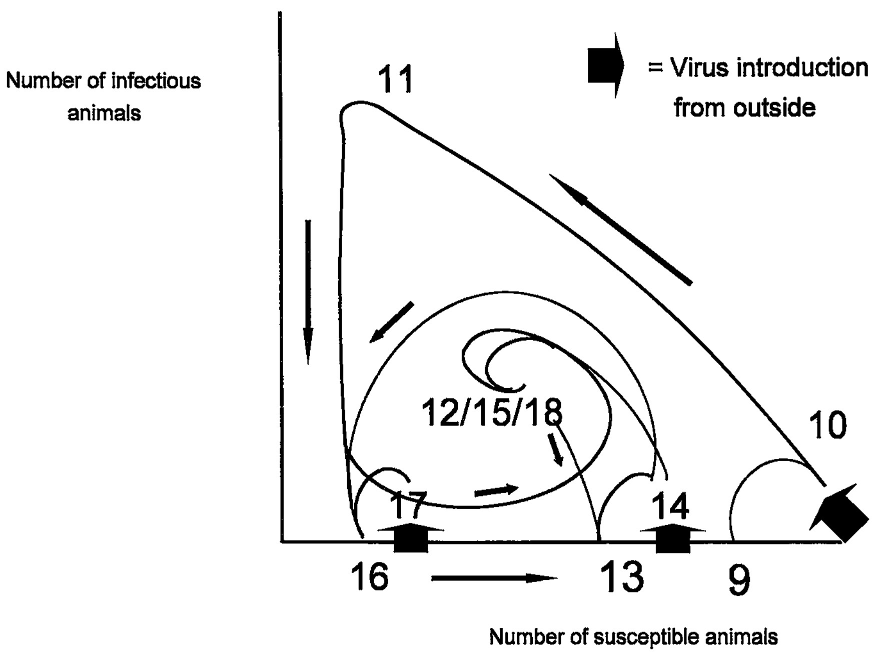

Figure 1. The possible course of an infection within a herd

Transition matrix

After the different states within each herd type were defined, a transition matrix (M), which included the probabilities of a herd going from one state in time period (t) to another in the next time period (t+1), was calculated. The transition matrix for breeding herds with respect to Aujeszky's disease virus when Strategy 2 (see Table 1) is applied is shown in Appendix A. This matrix is subdivided into 4 sub-matrices (A, B, C and D).

$$M = \begin{pmatrix} A & C \\ B & D \end{pmatrix} \tag{1}$$

In the submatrices the probabilities of the following transitions are presented:

A = herds going from non-infectious to non-infectious states

B = herds going from non-infectious to infectious states

C = herds going from infectious to non-infectious states

D = herds going from infectious to infectious states

To include the non-linearity of the transmission process, the transmission probabilities from non-infectious to either non-infectious or infectious (matrices A and B) were dependent on the state vector. The fraction of herds that becomes infectious equals 1 minus the number of herds that has not been infected by the virus emitted by infectious herds at the rate $(\gamma + \alpha) \times fi_t$ (James, 1977; Miller, 1979)

$$pi_t = 1 - e^{-(\gamma + \alpha) \times fi_t} \tag{2}$$

where pi_t is the probability of infection for a non-infectious herd in week t, fi_t the fraction of infectious herds in (t), γ is the rate of animal contacts and α is rate of other contacts. γ and α represent the average number of herds to which the virus is spread through animal and other contacts respectively by each infectious herd, irrespective of the infection status of that herd.

The rate of other contacts (α)

The impact of other contacts (through parameter α) in the calculation of the new infectious herds was based on data which were described by Stegeman et al. (1996). In that study the average number of virus introductions per year was below 1 in breeding herds which were vaccinated at 4-month intervals by the modified live virus strain 783 o/w. Differences were found in herds with and without sanitary facilities and the way replacement gilts were obtained (homebred versus purchased).

In our simulation model the rate of number of herds j which become infectious by other contacts per infectious herd k (α_{jk}) includes the spread of the infection by people, air, material etc. and is based on (1) the expected number of infectious animals in each herd in each infection state k (I_k^*) and (2) the average number of herds j to which the virus is spread per infectious animal in a herd with infection state k ($n_{int,jk}$).

$$\alpha_{jk} = I_k^* \times n_{int,jk} \tag{3}$$

The rate of animal contacts (γ)

Rate γ is assumed to be a function of (1) the average number of deliveries of each infectious herd per time unit (ϕ) and (2) the probability that at least one of the animals in the delivery is infectious (λ):

$$\gamma_{jk} = \phi_{v(j)v(k)} \times \lambda_{jk} \tag{4}$$

where

$\phi_{v(j)v(k)}$ = average number of deliveries from a herd of herd type k to a herd of herd type j per time unit

λ_{jk} = probability that at least one infectious animal (piglet/breeding sow) is delivered from herd k to herd j

where

$$\lambda_{jk} = 1 - \left(\frac{N_{H,k} - I_k^*}{N_{H,k}} \right)^{T_k(x_k) \times n_{del,v(j)v(k)}} \tag{5}$$

I_k^*	=	the expected number of infectious animals in each herd in each infection state k
$N_{H,k}$	=	number of animals per herd of infection state k
$n_{del,v(j)v(k)}$	=	the average number of animals per delivery from a herd of herd type k to a herd of herd type j
$T_k(x_k)$	=	average number of weeks that a herd in infection state k will be infectious

To specify these animal contacts in more detail, animal types per herd type were also defined. To account for different animal contacts the number of herd types was increased; besides subdivision into breeding and fattening herds, the breeding herds were subdivided further into three different herd types: great-grandparent stock+multiplier, rearing and farrowing herds, while rearing herds were modelled as fattening herds.

Table 3. The number of animals per delivery (n_{del})

Product	From	To	Number of animals per delivery $n_{del}(\phi)$
Breeding piglets	Great-grandparent stock / multiplier	Rearing	41.34
Gilts	Rearing	Great-grand-parent stock / multiplier	3.80
	Rearing	Farrowing	37.53
Piglets	Great-grandparent stock / multiplier	Fattening	55.76
	Farrowing	Fattening	53.07

Great-grandparent stock and multiplier herds produce replacement gilts for themselves and succeeding farrowing herds. These replacement gilts are reared in rearing herds. All three kinds of sow herds produce piglets for fattening herds. In practice, the precise number of herds per herd type and most of the relationships between and within herds are unknown. The numbers of great-grandparent stock + multiplier, rearing, farrowing and fattening herds in the Netherlands were estimated to be 846, 363, 8353 and 18114 respectively. These numbers as well as the number of animals per delivery (Table 3) were calculated from data from one of the largest breeding companies and the Central Statistical Office (CBS) in The Netherlands. The number of deliveries per week was assumed to be 1 and the definitions of the states within each of these herd types were assumed to be the same. To include the different herd types in the calculation of the number of new infectious herds in the next time period (week) the basic formula (2) was expanded as follows:

$$pi_{jk,t} = \left(1 - e^{-\left(\frac{\phi_{v(j)v(k)} \times \frac{Z_{v(j)v(k)}}{T_k(x_k)} \times \lambda_{jk} \times x_k(t)}{N_{v(j)}} + \frac{I_k^{*} \times n_{int,jk} \times x_k(t)}{N}\right)}\right) \quad \textbf{(6)}$$

Where:

$n_{int,jk}$	=	the average number of herds j to which the virus is spread per infectious animal in a herd with infection state k
$N_{v(j)}$	=	total number of herds in the herd type in which infection state is j
N	=	total number of herds in the population
$x_k(t)$	=	number of herds in infection state k
$Z_{v(j)v(k)}$	=	average number of herds in herd type j which are in contact with a herd in herd type k per time unit

The other symbols have been defined earlier.

Animal contacts were defined per herd type and therefore weighted by $N_{v(j)}$ while other contacts were defined over the total number of herds (Bouma et al., 1995; De Jong et al., 1995). Now, $pi_{t,jk}$ can be used to calculate a and b in transition matrix M (see appendix A for transition matrix M for great-grandparent stock, multiplier and farrowing herds).

$$a_{ij}^{'} = a_{ij} \times \left(1 - \left(\sum_{k=1}^{s} pi_{t,jk}\right)\right) \quad \textbf{(7)}$$

$$b_{ij}^{'} = b_{ij} \times \left(\sum_{k=1}^{s} pi_{t,jk}\right) \quad \textbf{(8)}$$

So

$$M' = \begin{pmatrix} A \times (1 - pi_t) & C \\ B \times pi_t & D \end{pmatrix} = \begin{pmatrix} A' & C \\ B' & D \end{pmatrix} \qquad \textbf{(9)}$$

where

s = number of non-infectious states

a and b are elements of submatrices A and B of transition matrix M

a' and b' are elements of submatrices A' and B' of the adapted transition matrix M' (submatrices C and D are the same in matrices M and M')

After calculating matrix M' the next generation vector (x_{t+1}) could be calculated.

$$x_{t+1} = M' \times x_t \qquad \textbf{(10)}$$

Calculation of R_{herd}

To determine whether or not the infection will spread from one herd to another, the basic reproduction ratio R_{ind} was used as input for the model (to characterize and classify the herds), but R_{herd} was calculated from the output. In this model, R_{herd} is defined as the total number of secondary infectious herds produced by one typical herd during the whole period of infection (De Jong and Diekmann, 1992). In the definition, "typical" is used because four herd types and 32 different infection grades within each herd type are considered. R_{herd} for the total population is equal to the eigenvalue of next-generation-matrix RM:

$$RM_{jk} = (w_{ji} \times b_{ik}) \times (pi_{jk} \times e_j) \qquad \textbf{(11)}$$

where:

w_{ji} = is an element of matrix w which was calculated as follows:

$$W = (I - D)^{-1} \qquad \textbf{(12)}$$

I = identity matrix

D = submatrix D

b_{ik} = element of submatrix B

e_j = eigenvector of submatrix A

pi_{jk} was calculated in the same way as in the simulation (see equation 6).

If $R_{herd} < 1$, the infection cannot spread and the population is effectively protected against infection.

BASIC RESULTS

No vaccination

Based on the model the R_{herd} in case of no vaccination (Strategy 1) was calculated to be 3.03, which means that infection will not disappear without vaccination. In the equilibrium situation, which is defined as being the situation where the variables do not change significantly (≤ 0.1%), about 42% of the total number of herds were infectious, and 38%, 15% and 47% were in the prevalence classes [≤ 10%], [> 10% and ≤ 50%], [> 50%] respectively. Most of the herds were in the prevalence class [> 50%], which means that most of the animals in the herds were gE-positive.

Vaccination

The equilibrium situation in the case of no vaccination was taken as the starting situation for vaccination strategies 2 and 3. The resulting changes in distributions over the different prevalence classes are shown in Table 4 for Strategies 2 and 3.

Table 4. Distribution of the herds over the gE-prevalence classes over time for Strategies 2 and 3

Week	Strategy					
	2			3		
	≤10	>10 and ≤ 50	>50	≤10	>10 and ≤ 50	>50
50	33.94	24.65	41.40	72.50	20.49	6.16
100	39.00	23.76	37.24	86.80	11.76	1.32
150	41.13	22.27	36.60	92.68	7.05	0.26
200	42.10	21.38	36.52	95.69	4.26	0.05
250	42.64	20.93	36.43	97.41	2.58	0.01
500	43.49	20.41	36.11	99.79	0.21	0.00
1000	43.62	20.35	36.03	100.00	0.00	0.00

As shown in this table, 95% of the herds are in the prevalence class [≤ 10%] after 200 weeks with vaccination Strategy 3, where distribution comes in an equilibrium again with Strategy 2. This means that the percentage of gE-positive animals in the herds decreases over time with Strategy 3 and reaches another endemic equilibrium with Strategy 2.

The related course of the percentages of infectious herds is shown in Figure 2 in which the distribution of the percentage of infectious herds over time for the different vaccination strategies is presented. As can be seen from this figure it will take about 100 weeks before the percentage of infectious herds is below 1% for Strategy 3, while the percentage of infectious herds goes from 41.6% to 37.3% for Strategy 2.

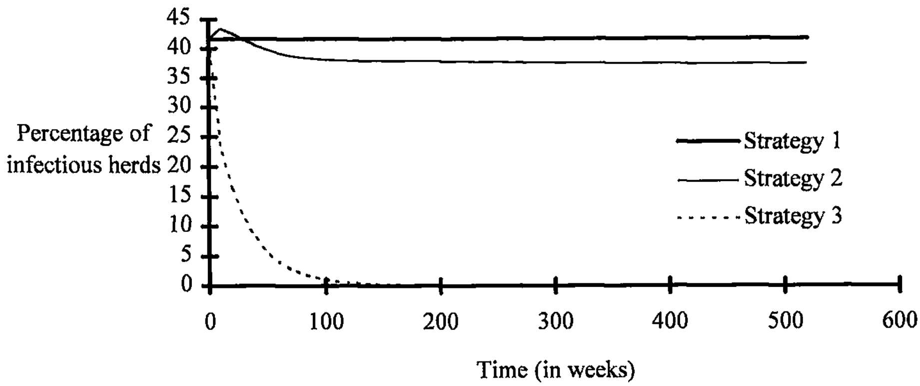

Figure 2. Percentage of infectious herds over time per strategy

The changes in the distribution of the prevalence range and in the percentage of infectious herds over time show that the infection will be eradicated by applying Strategy 3 and an equilibrium will be reached asymptotically by applying Strategy 2. This is in agreement with related R_{herd}-values, which were 2.80 and 0.51 for Strategies 2 and 3 respectively.

The number of new effective virus introductions per vaccination strategy and per time unit are shown in Figure 3.

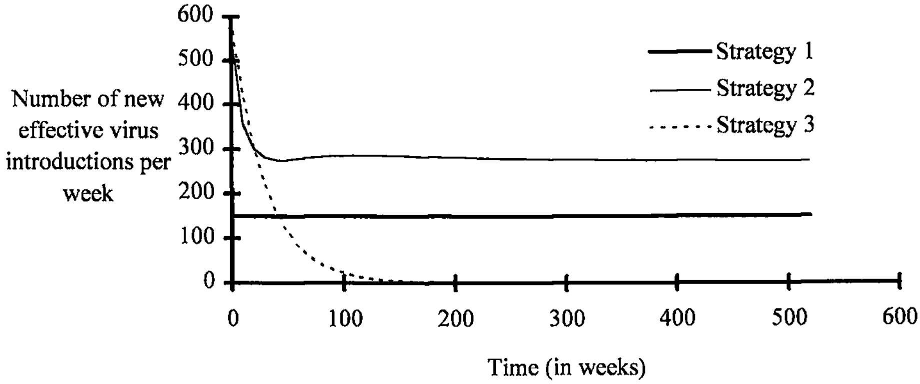

Figure 3. Number of effective virus introductions per week

In equilibrium the number of effective virus introductions was the highest for Strategy 2. Effective introduction can be defined as a situation in which a herd goes from a non-infectious state to an infectious one. Thus, it does not include all introductions. The virus introductions are caused by either animal contacts or other contacts. It turned out that 4%, 18% and 98% of all introductions were caused by other contacts for Strategies 1, 2 and 3 respectively. This means that the proportional percentage of introductions caused by other contacts increases if a more intensive vaccination strategy is applied.

Impact of other contacts

When the impact of other contacts was reduced, the R_{herd}-value for vaccination strategy 1 (no vaccination) decreased in a linear way (Figure 4) but the infection would not be eradicated, i.e. the R_{herd}-value remained greater than 1 (see also Van Nes et al., 1996).

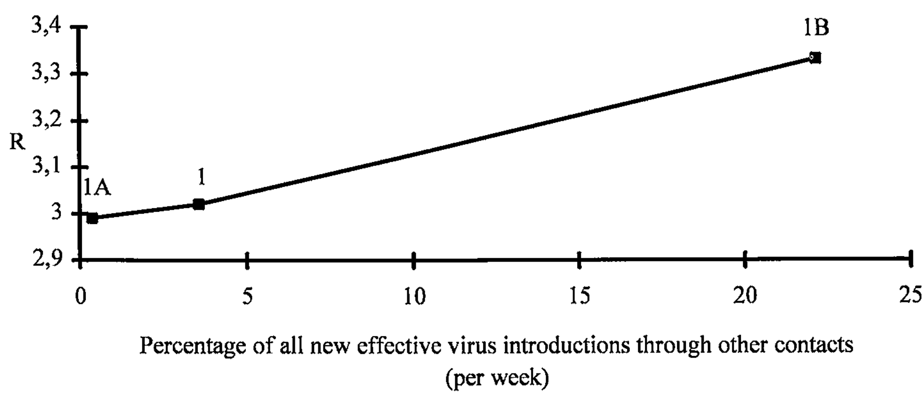

Figure 4. Influence of all new effective virus introductions caused by other contacts on the R-value (R_{herd})

The distribution over the different prevalence classes also changed. To illustrate this the equilibrium distributions of Strategies 1, 1A and 1B are shown in Table 5. In none of the cases vaccination had taken place; the only difference between strategies 1, 1A and 1B was the impact of the other contacts (see also Figure 4: 1: 3.6%, 1A: 0.4% 1B: 22.0%).

Table 5. Distribution of the total number of herds over the different gE-prevalence classes by changing impact of other contacts from 1 to 1A and 1B

Prevalence class	Percentage of herds		
	1	1A	1B
≤ 10	38	39	25
> 10 and ≤ 50	15	15	16
> 50	47	46	59

By reducing the impact of other contacts, the percentage of herds in prevalence class [≤ 10%] increased while especially the percentage of herds in prevalence class [> 50%] decreased.

DISCUSSION AND OUTLOOK

During the development of this simulation model, high priority was given to the possibilities of validating the parameters used. For example, the input on R_{ind}-values and prevalence ranges within each R_{ind}-value in the definition of the infection states were based on results of a number of experiments (De Jong and Kimman, 1994; Stegeman et al., 1995; Van Nes et al., 1996) and most of the parameters which were used in modelling the animal contacts were based on empirical data. Data on impact of other contacts, however, were hardly available. The results of the model show that R_{herd}-value as well as the distribution over the different prevalence classes are sensitive to this parameter. Therefore, it is important that these kinds of contacts get more priority in future veterinary research.

In the study described by Stegeman et al. (1996), the average gE-seroprevalence in breeding herds was 67.0 $\pm$ 23.0% while it was about 80% in fattening herds. In our study, the total number of herds was subdivided into gE-seroprevalence classes, which made it difficult to calculate a percentage for the total population or for the fattening and breeding herds separately. When the total number of herds was uniformly distributed over each gE-prevalence class, the percentage for fattening herds was approximately the same in this study compared with the results of Stegeman et al. (1996), while the percentage of breeding herds was far lower (about 20 %). This is mainly because more than half of the breeding herds in the study of Stegeman et al. (1996) were farrow-to-finish herds while these were assumed to be separate herds (fattening and finishing herds) in this chapter. Also the fact that the field experiment was carried out in the most densely populated livestock area of the Netherlands (i.e., in the southern part of the country), while the simulation study focused on the country as a whole, may be of influence. Research is under way to make the simulation model region specific.

The vaccination strategies applied did not change during the simulation. In reality pig farmers may change their strategy over time and they may use additional measures such as increased culling because of Aujeszky's disease virus. Further (modelling) research is desired to determine if, and if so when and how, additional culling becomes profitable.

The methods of extra culling and/or vaccination can be used in several scenarios to eradicate Aujeszky's disease virus from the population. For example, the virus can be eradicated from top to lower levels in the production pyramid. In this scenario great grandparent stock herds become free first and are followed by multiplier, farrowing and fattening herds respectively. With this scenario the influence of animal contacts on the percentage of infectious herds is decreased. Furthermore, it is also possible to evaluate differences in eradication strategy per region. A region with a low herd density has better perspectives to become free of the infection than a region with a high herd density. More modelling research is under way to determine the impact of this kind of scenarios on the transmission of Aujeszky's disease virus and on the profitability of each of these scenarios.

This study shows that from an epidemiological point of view vaccination strategy 3 (i.e. vaccinating sows with strain-783 o/w 3 to 4 times per year and fattening pigs twice per cycle) is the best strategy to eradicate Aujeszky's disease virus. This is in agreement with the results of the studies by Houben et al. (1993) and Stegeman (1996). However, this does not imply that this strategy is the most profitable one from an economic point of view. To get an answer to that issue the cost of vaccination and losses avoided (either direct through improved performances or indirect through averting export bans) should also be taken into account. These aspects are quantified in the following chapters.

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Appendix A Transition matrix (M) for *Great-grandparent stock* + *multiplier and farrowing* herds when using Strategy 2.

State	9	13	17	10	11	12	14	15	16	18
9	1	0.01	0	0.67	0	0	0	0	0	0
13	0	0.99	0.03	0	0	0	0.88	0	0	0
17	0	0	0.97	0	0	0.20	0	0	0.20	1
10	1	0	0	0	0	0	0	0	0	0
11	0	0	0	0.33	0.92	0	0	0	0	0
12	0	0	0	0	0.08	0.80	0	0	0	0
14	0	1	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0.12	0.92	0	0
16	0	0	0	0	0	0	0	0.08	0.80	0
18	0	0	1	0	0	0	0	0	0	0

CHAPTER 4

A SIMULATION MODEL TO EVALUATE THE SPREAD AND CONTROL OF AUJESZKY'S DISEASE VIRUS: II COMPARING STRATEGIES

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ABSTRACT

A computer simulation model was developed for Aujeszky's disease virus with which "what-if" scenarios can be carried out to explore the epidemiological and economic effects of various vaccination strategies and other important factors which influence the dynamics of an infection among a population of herds. Other factors that influence the dynamics of Aujeszky's disease virus and the resulting economic consequences are 1) the different herd types and the ways in which animals are exchanged between these herds and 2) the density of herds in different regions. To examine the impact of these factors the total number of herds in the Netherlands was subdivided into four herd types (great-grandparent stock + multiplier, rearing, farrowing and fattening herds) and four regions were considered (North, East, West-Middle, South).

First, the situation without vaccination was evaluated and afterwards the situation in which various vaccination strategies were applied. At equilibrium, when no vaccination was carried out the percentage of infectious herds was highest for rearing herds (76.3%) and lowest for great-grandparent stock+multiplier herds (20.0%). Differences in vaccination strategies had more impact on the herd type "fattening" than on "farrowing". Besides the difference in herd type, also herd density in a region is an important factor in the eradication process. Lastly, the importance of the percentage of non-vaccinated herds in controlling the infection was shown by "what-if" scenarios.

INTRODUCTION

Decision-makers seldom have complete knowledge of input-output relationships regarding eradication of a contagious disease agent. Appropriate decisions must consider both epidemiological and economic effects (Dijkhuizen, 1992). To support these decisions, Buijtels et al. (1996a) developed a computer simulation model for Aujeszky's disease with which "what-if" scenarios can be carried out to explore the epidemiological effects of various vaccination strategies and other important factors which influence the course of an infection.

Some vaccine strains lack the gene encoded glycoprotein E (gE; formerly, glycoprotein I), which has been noticed in every field virus strain so far (Van Oirschot et al., 1990). Pigs infected with Aujeszky's disease virus can be detected in populations that have been vaccinated with gE-deleted Aujeszky's disease virus strains by testing for antibodies to gE (Van Oirschot et al., 1988).

In the model, the structure of the production process and the herd density in the affected regions can be considered, together with the vaccination strategy applied. The infection can be eradicated from the top to the bottom level of the production pyramid. Regional eradication of the infection is also possible. A region with a low herd density has better perspectives to eradicate the infection than a region with a high herd density.

This chapter describes the effects of the different herd types in the production pyramid and of regionalization on the effectivity of Aujeszky's disease eradication in the Netherlands. The production process and different regions are defined first, after which the results are presented. The approach is general, however, and can be applied to other regions and countries as well.

MATERIAL AND METHODS

Production process

To account for different kinds of animal contacts all herds were assigned to different herd types according to the different types of animals (see Figure 1).

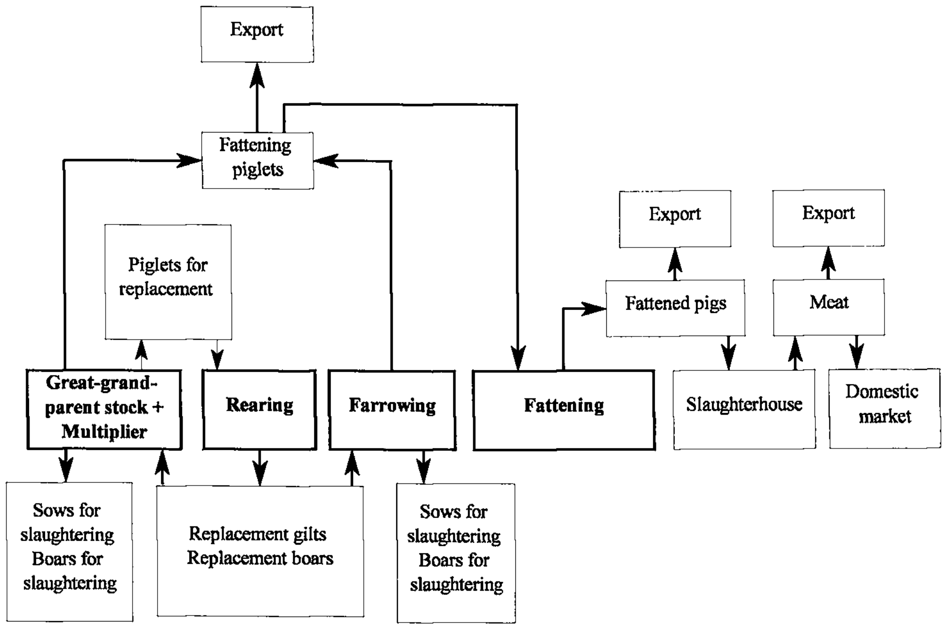


Figure 1. The production process

Herds can be subdivided into great-grandparent stock + multiplier, rearing, farrowing, and fattening herds. Great-grandparent stock + multiplier herds produce piglets for replacement which are reared in rearing herds. The resulting replacement gilts are delivered to the great-grandparent stock + multiplier and farrowing herds. All three kinds of sow herds (great-grandparent stock, multiplier, and farrowing herds) produce (at least part of) their piglets for fattening herds (see Figure 1). In practice, the precise number of herds per herd type and most of the relationships between them are not well known. The number of herds per herd type and the number of animals per delivery representing the situation in the Netherlands were derived from data from one of the largest breeding companies and the Central Statistical Office (CBS) in the Netherlands, and were checked for consistency. This calculation is summarized in Appendix A. As could be expected, the number of herds per herd type increases as the herd type gets lower in the production pyramid. The number of sows is the highest in the herd type great-grandparent stock + multiplier. This depends mainly on the annual replacement rate of breeding sows and the resulting number of replacement gilts which are needed in the different herd types. Besides the calculation for the entire country, the one for the four different regions in the Netherlands is also shown, and will be described in the next paragraph.

Regions

Besides the subdivision into herd types, the total number of pig herds in the Netherlands was subdivided into 4 more or less homogeneous regions considering herd and animal density: North, East, West-Middle and South (see Table 1 and also Stegeman et al., 1996).

Table 1. Breeding and fattening herds and herd density per region

Region	Percentage of herds		Percentage of animals		Average herd size		Number of herds per km²
	Breeding	Fattening	Breeding sows	Fattened pigs	Breeding sows	Fattened pigs	
North	4.75	3.62	3.96	3.29	129.04	298.02	0.2289
East	41.71	48.23	32.29	35.66	119.63	242.63	3.0392
West-Middle	10.85	11.87	5.63	6.78	80.23	187.35	0.6254
South	42.69	36.28	58.11	54.28	210.38	490.93	3.1289

Source: CBS, Maycounting 1993.

Herd density is almost the same in regions South and East, while it is far lower in the other two regions. This Table shows a remarkable difference between percentages of herds and animals per region. This is because of the differences in herd size per region: herds are on average larger in the southern region (See also Appendix A). This also results in a different number of breeding gilts and fattening pigs which are transported per herd to herds of another herd type (Table 2).

Table 2. Number of animals transported per sending herd per week[1]

Product	From	To	Region[2]			
			1	2	3	4
Breeding piglets	Great-grandparent stock / multiplier	Rearing	35.63	33.39	20.94	45
Gilts	Rearing	Great-grand-parent stock / multiplier	3.26	3.08	1.92	4.14
	Rearing	Farrowing	32.37	30.31	19.03	40.86
Piglets	Great-grandparent stock / multiplier	Fattening	48.73	44.74	28.54	71.35
	Farrowing	Fattening	49.72	44.37	27.36	65.74

[1] Exclusive the export part
[2] 1= North, 2= East, 3=West-Middle and 4=South

As shown in this table, most of the replacement gilts go to farrowing herds. Rearing herds have contacts with more farrowing herds than with great-grandparent stock + multiplier herds within and/or between regions. In this model it is assumed that replacement gilts are distributed only within a region.

The number of fattening piglets that is transported from a sow herd does not significantly differ within each region, whereas it does between regions. The regions North and East deliver 78% and 95% of their fattening piglets respectively to fattening herds within the same region and the rest goes to fattening herds in other regions. Sow herds in the other two regions (West-Middle and South) only deliver fattening piglets to fattening herds within the region.

Simulation model

For determining the effects of policy-making measures with respect to Aujeszky's disease control in pigs at regional level, the simulation model of Buijtels et al. (1996a) was used as a basis. In this model pig herds are characterized by 32 different infection states within each herd type. These states are based on (1) the value of the reproduction ratio R, which, in this case, is the number of pigs that would be infected by a single infectious pig in a completely gE-negative population, (2) the gE-prevalence in the herd, and (3) the number of infectious animals that is present in the herd. R is a yardstick measuring whether or not the infectious agent will spread: $R < 1$ means that the infection will not spread and $R > 1$ that it will. The R of an entire region can be calculated on a pig-per-pig (R_{ind}) and on a herd-per-herd basis (R_{herd}) (Van Nes et al. 1996a). The R_{ind}-values are based on field and laboratory experiments (De Jong and Kimman, 1994; Stegeman et al., 1995a; Van Nes et al., 1996b) and were used in the definition of the different vaccination strategies (Table 3), while the R_{herd}-values were calculated in this model.

Table 3. Definition of the vaccination strategies

Breeding herds:

Strategy	R_{ind}	Definition vaccination strategy
1	10	no vaccination
2	1.5	vaccinating less than 3 times per year with strain-783 or Begonia
3	0.5	vaccinating at least 3 times per year with strain-783 or Begonia

Fattening and rearing herds:

Strategy	R_{ind}	Definition vaccination strategy
1	10	no vaccination
2	3.5	vaccinating once per cycle with strain-783 or Begonia
3	1.5	vaccinating twice per cycle with strain-783 or Begonia

The probabilities of a herd going from one state to another are described in a transition matrix. To include the non-linearity of the transmission process the transmission probabilities from non-infectious to either non-infectious or infectious were modelled dependent on the current state vector by considering the consequences of the current state for animal and other contacts. Animal contacts are a function of (1) the average number of deliveries of each infectious herd per time unit, (2) the average number of animals per delivery and (3) the probability that at least one of the animals in the delivery is infectious. The other contacts, which include transmission of fomites, airborne transmission, indirect transmission through other species, and minor disease-specific routes such as venereal or iatrogenic transmission (Buijtels et al., 1996b), are a function of (1) the expected number of infectious animals in each herd and (2) the average number of herds contacted in that way. The transition matrix together with the calculation of the percentage of new infectious herds per time unit were used to calculate the state vector for each time period. A more detailed description of the model can be found in Buijtels et al. (1996a).

RESULTS

The results are subdivided into four parts. First the effects of herd type and region on the control of the infection are described individually for Strategy 1 (no vaccination). Subsequently, the effects of herd type and region for the two other vaccination strategies are described. Finally, the effect is shown of the situation when more herds are not vaccinated.

Effects of herd type in a non-vaccinated population

In the equilibrium situation, which can be defined as the situation where the outcome variables, i.e. the state vector in the model, do not change anymore, the percentage of infectious herds differed per herd type (Table 4) when none of the herds were vaccinated. The percentage of infectious herds was relatively high for rearing herds (76.3%) and differed for the sow herd types of the production pyramid (20.0% for great-grandparent stock+multiplier compared with 42.3% for farrowing herds). This difference can mainly be ascribed to the difference in the number of replacement gilts which are delivered from rearing herds to different kinds of sow herds (see Table 2). The percentage of infectious fattening herds was about the same as that of the farrowing herds and is lower than the percentage of infectious herds for rearing herds. This might be caused by differences in average herd size and the number of herds from which they receive their animals.

Table 4. Percentage of infectious herds per herd type in equilibrium and the equilibrium distribution over the different prevalence classes

Herd type	Percentage of infectious herds	Prevalence classes		
		≤ 10	> 10 and ≤ 50	>50
Great-grandparent stock + Multiplier	20.0	57.3	17.5	25.2
Rearing	76.3	8.5	8.4	83.1
Farrowing	42.3	20.1	28.0	52.0
Fattening	42.9	45.9	7.4	46.7

Also the equilibrium distribution over the different prevalence classes differed per herd type. Within the sow herd types, more than 50% of the herds in the herd types great-grandparent stock + multiplier and farrowing were in the prevalence classes [≤ 10%] and [> 50%] respectively. This was to be expected because the percentage of infectious herds was also lower in the herd type great-grandparent stock + multiplier. Furthermore, the high percentage of rearing herds in prevalence class [> 50%] was also to be expected considering the high percentage of infectious herds.

Effects of regions in a non-vaccinated population

The R_{herd}-values calculated from the model specifications for the different regions showed that the infection would not be eradicated in any of the regions if no vaccination was done (see Table 5). In equilibrium, the regions East and South had the highest percentage of infectious herds (44.5% and 43.2% respectively). The distribution over the different prevalence classes also differed per region. More than 45% of the herds in the regions North and West-Middle were in prevalence class [≤ 10%] while more than 45% of herds in the regions East and South were in prevalence class [> 50%].

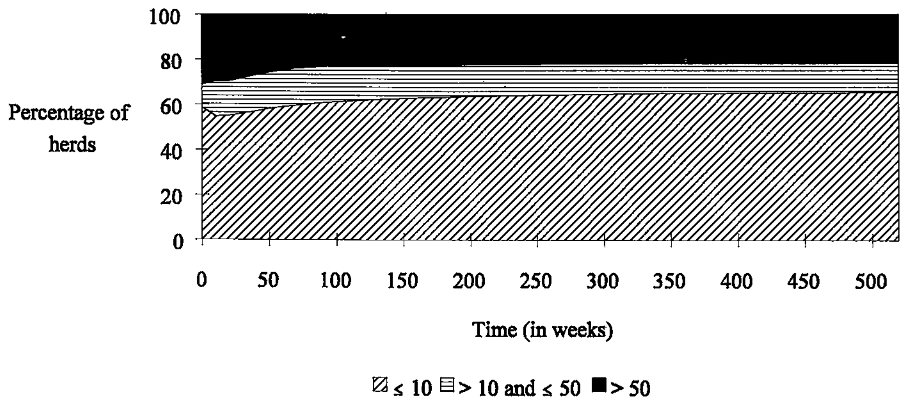
Table 5. Distribution of the total number of herds per region over the different prevalence classes

	R_{herd}	% of infectious herds	Prevalence classes		
			≤ 10	> 10 and ≤ 50	> 50
North	2.1	32.3	49.1	14.0	36.9
East	3.0	44.5	36.2	13.7	50.1
West-Middle	2.4	28.0	58.7	9.5	31.8
South	3.2	43.2	42.5	9.8	47.7

Effects of regions and herd type in a vaccinated population

The effect of applying different vaccination strategies on the distribution over the different prevalence classes over time can be examined per herd type and region (Figures 2 and 3 for farrowing and fattening herds respectively).

A.



B.

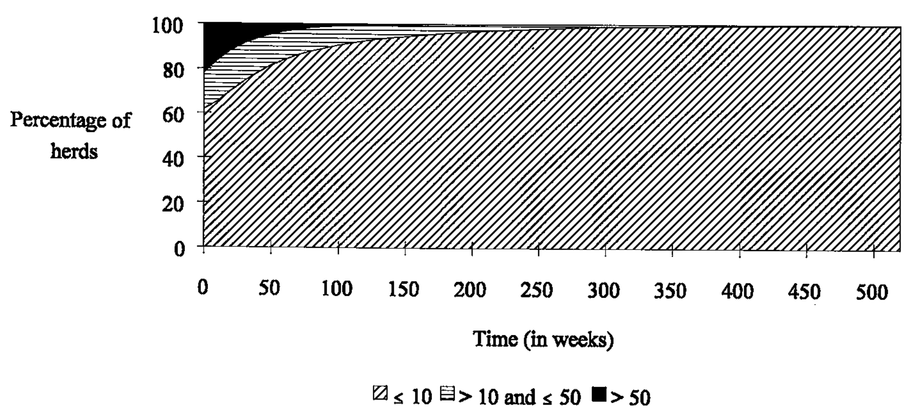
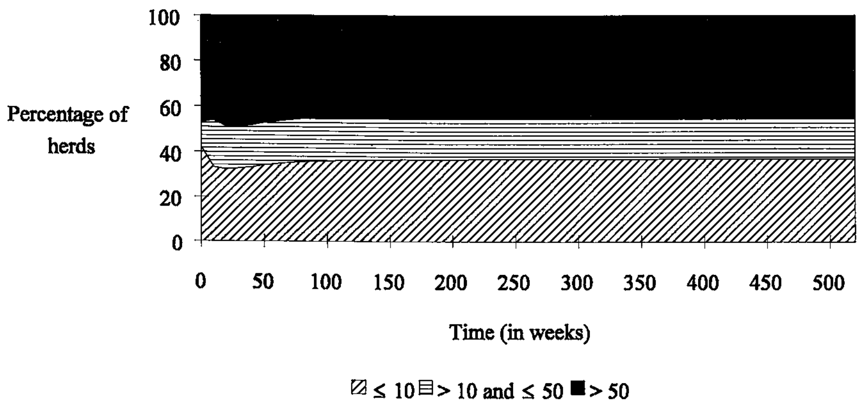


Figure 2. Distribution of farrowing herds over the gE-prevalence classes over time when applying Strategy 2 (A) or 3 (B)

A.



B.

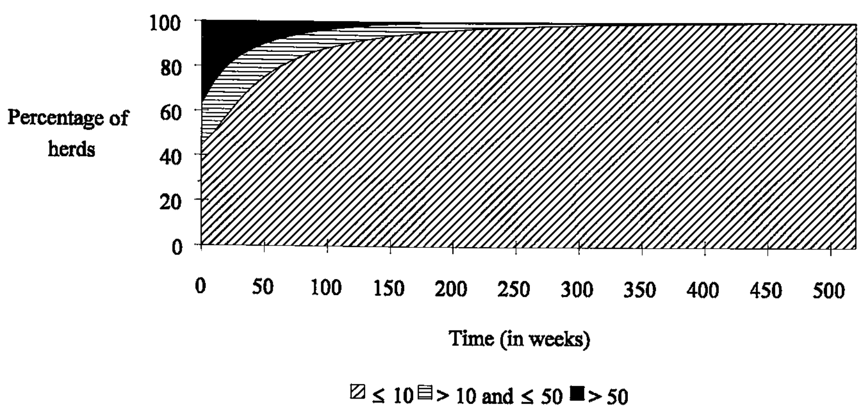
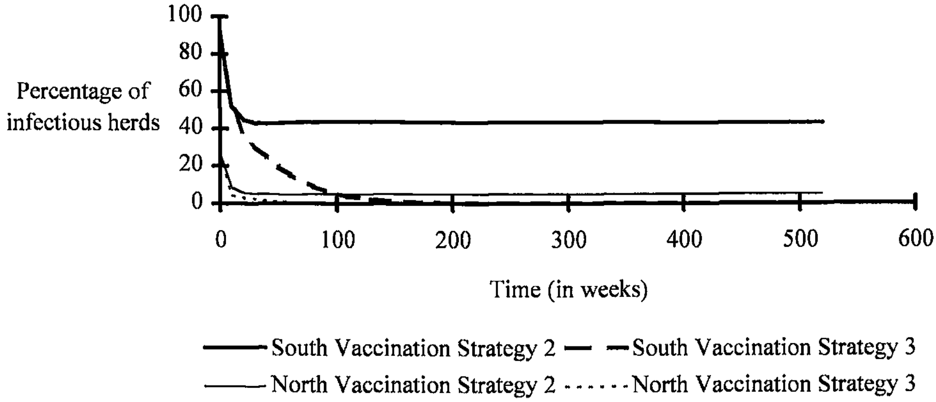


Figure 3. Distribution of fattening herds over the gE-prevalence classes over time when applying Strategies 2 (A) or 3 (B)

As shown in these figures, the percentage of herds in prevalence class [≤ 10%] increased over time in both herd types, which means that the number of gE-positive animals in these herds decreased over time. However, the Aujeszky's disease virus would eventually only be eradicated under Strategy 3, which can also be concluded from the reproduction ratios, which were 2.80 and 0.51 for vaccination strategies 2 and 3 respectively. There was a greater difference in the related development of the percentage of infectious herds over time, as shown in Figure 4.

Figure 4A shows the percentages of infectious farrowing herds in regions South and North, when for all herds either Strategy 2 or 3 is applied. Initially 26.7 and 93.4% of the farrowing herds in the regions North and South were infectious. These percentages come from the equilibrium distribution, when no vaccination was done. When for all herds Strategy 3 was applied, it took less than 200 weeks for the farrowing herds in both regions to become non-infectious, whereas 5.0% and 43.2% of the farrowing herds remained infectious in the regions North and South respectively, if Strategy 2 was applied. For fattening herds in both regions it also took less than 200 weeks to become non-infectious, if vaccination Strategy 3 was applied for all herds. Remarkable was the increase in the percentage of infectious fattening herds in both regions if Strategy 2 was applied. This was mainly because of the increase in the number of new effective virus introductions, which occurred each week. Both figures show that the differences in percentage of infectious herds between the two regions became smaller, if a more intensive vaccination strategy (Strategy 3) was applied.

A.



B.

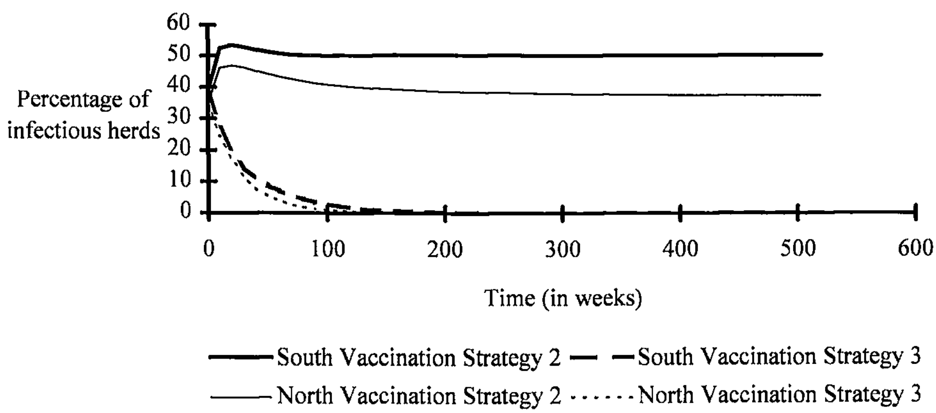


Figure 4. Percentages of infectious farrowing (A) and fattening (B) herds over time when applying Strategies 2 or 3 in the regions South and North

Scenario

The model can also be used to increase the insight into the spread and control of Aujeszky's disease virus by carrying out "what-if" scenarios. As an example the effects are described of a proportion of non-vaccinated herds when for other herds the more intensive vaccination strategy (Strategy 3) was applied. The question was what would happen if 3%, 6% or 9% of all herds (and per herd type) were not vaccinated while for others the most intensive vaccination strategy was applied. The non-vaccinated situation was used as the starting situation. Furthermore, it was assumed that the non-vaccinated herds were equally distributed over the regions and "mixed freely" with all other herds.

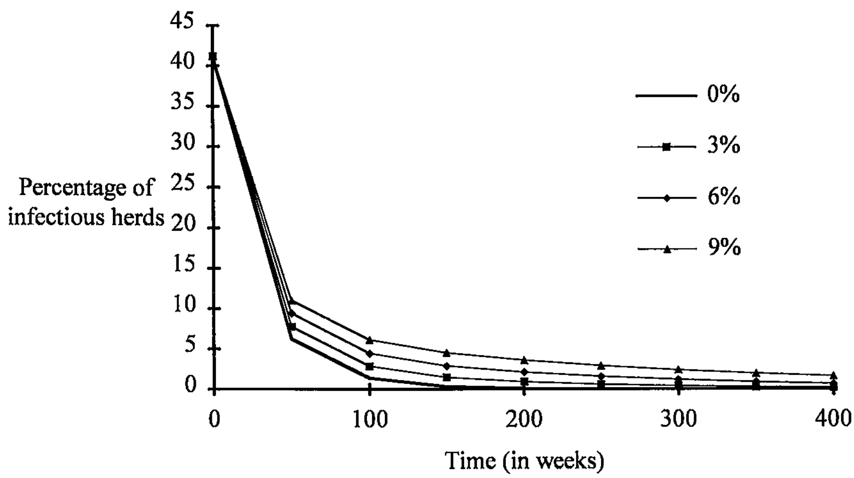


Figure 5. Percentage of infectious herds over time when different percentages of herds are not vaccinated

Figure 5 shows the percentage of infectious herds over time. It can be seen that it would take 3-4 years more than if all herds were vaccinated before the level of less than 1% infectious herds was reached, if the percentage of non-vaccinated herds increased from only 0 to 3%. This increase in length of time until eradication was greater if the percentage of non-vaccinated herds increased to 6 and 9%, as could be expected. Yet, Aujeszky's disease virus would be eradicated in all situations, as R_{herd} was 0.51, 0.65, 0.76, 0.87 respectively when 0%, 3%, 6% and 9% of the herds were not vaccinated.

The distribution over the prevalence classes also changed, as shown in Table 6. It took less than 150 weeks to reach the situation where less than 1% of the herds were in prevalence class [> 50%], if all herds were vaccinated intensely, whereas it took more than 400 weeks, if 9% of the herds were not vaccinated. This increase in time was not linear per percent of increase of non-vaccinated herds, which means that non-vaccination would also influence other factors, which would in turn, cause more herds to remain in prevalence class [> 50%]. The weekly number of new effective virus introductions and the percentage of these new introductions which were caused by other contacts might be factors to be studied to deeper understanding of the infection spread. Both factors are shown in Table 7.

Table 6. Development of the distribution over the different prevalence classes over time when different percentages of herds are not vaccinated

Time (in weeks)	0%			3%			6%			9%		
	≤ 10%	> 10% and ≤ 50%	> 50%	≤ 10%	> 10% and ≤ 50%	> 50%	≤ 10%	> 10% and ≤ 50%	> 50%	≤ 10%	> 10% and ≤ 50%	> 50%
50	74.6	17.9	7.5	73.2	17.8	9.0	71.7	17.7	10.6	70.2	17.6	12.1
100	88.0	10.1	1.9	85.8	10.7	3.5	83.6	11.2	5.2	81.3	11.6	7.1
150	93.4	6.1	0.5	91.1	7.1	1.8	88.7	8.0	3.3	86.2	8.7	5.1
200	96.1	3.8	0.1	94.1	4.9	1.0	91.8	5.9	2.3	89.2	6.8	4.0
250	97.7	2.3	0.0	96.0	3.3	0.7	93.9	4.4	1.7	91.3	5.5	3.2
300	98.6	1.4	0.0	97.3	2.3	0.4	95.4	3.3	1.3	93.0	4.4	2.6
350	99.2	0.8	0.0	98.1	1.6	0.3	96.5	2.5	1.0	94.3	3.6	2.1
400	99.5	0.5	0.0	98.7	1.1	0.2	97.4	1.9	0.7	95.3	2.9	1.7

Table 7. Development of the number of new effective introductions and the percentage of new effective virus introductions over time caused by other than animal contacts when different percentages of herds are not vaccinated

Time (in weeks)	0%		3%		6%		9%	
	1	2	1	2	1	2	1	2
1	524.4	0.1	530.1	0.1	534.8	0.1	538.7	0.2
50	125.9	0.1	167.6	0.2	209.8	0.3	273.1	0.3
100	29.1	0.1	74.4	0.2	116.5	0.3	155.8	0.4
150	6.2	0.1	40.9	0.3	77.9	0.4	115.6	0.4
200	1.3	0.1	24.7	0.3	54.8	0.4	89.0	0.4
250	0.3	0.1	15.4	0.3	39.1	0.4	69.5	0.5
300	0.1	0.1	9.8	0.4	28.1	0.4	54.7	0.5
350	0.0	0.1	6.2	0.4	20.2	0.5	43.4	0.5
400	0.0	0.1	3.9	0.4	14.5	0.5	34.6	0.5

1 = number of effective virus introductions
2 = percentage of effective virus introductions caused by the other than animal contacts

This table shows that the number of new effective virus introductions increased if for more herds per herd type not any vaccination was applied. This increase was and still remains largest over time if 9% of the herds were not vaccinated. This also holds for the percentage of new effective virus introductions which are caused by other than animal contacts. Despite the fact that these kinds of contacts do not play an important role, they should get more attention in the final phase of eradication.

DISCUSSION AND CONCLUSIONS

In the model described above, herds were subdivided into 4 different herd types. In practice, several herd types can be in the same herd (e.g. the herd types farrowing and fattening are in farrow-to-finish herds) or one herd can be divided into two herds (e.g. rearing of breeding gilts or boars can take place in separate herds). This may have an effect on the results of the simulations. For example it is possible that the agent will remain longer in farrow-to-finish herds compared with separate farrowing and finishing herds. This was also reported in other research (Siegel et al., 1993; Leontides et al., 1995; Stegeman et al., 1995b).

The number of deliveries from one region to another used in this chapter concerned net deliveries. In practice, there will be more deliveries. In the regions with the lowest herd densities, this may have resulted in an increase in the number of new virus introductions, as the percentage of infectious herds was lower in these regions, particularly, if less intensive vaccination strategies were pursued (see Figure 4B)

Figures 2, 3 and 4 show that herd type "fattening" is important in the national eradication process of Aujeszky's disease virus. However, most of the new virus introductions, with the less intensive vaccination strategies, are likely to result from animal contacts, as shown in Buijtels et al. (1996a). Thus, it is important that sow herds remain free of Aujeszky's disease, as they supply piglets to fattening herds. To support this a national Aujeszky's disease virus free certification program has been introduced (Stegeman, 1995). If there are no signs of Aujeszky's disease virus during an 8-month serological survey, a herd is declared free of Aujeszky's disease virus. In the near future only transport of Aujeszky's disease-free breeding stock will be allowed.

Herd density plays an important role if less intensive vaccination strategies are applied, as is shown in Figures 4A and 4B. These figures also show that, from an epidemiological point of view, herd density is not an important factor if the most intensive vaccination strategy to get free of the Aujeszky's disease agent is applied. However, from an economic point of view it may be important to take herd density into account, as the less intensive vaccination strategy for one of the herd types (e.g. fattening herds) may economically be better in some of the regions.

The proportion of non-vaccinated herds seems to be important in the control of Aujeszky's disease virus. Importance will even increase when these herds are clustered together in the region or when there are animal contacts with many different herds.

This model is part of a larger model, and is meant to support policy-making in controlling Aujeszky's disease. As has become clear from the results, the model calculates the percentage of infectious herds. This parameter could be used to calculate the changes in the production of piglets, fattened pigs and pig carcasses per time unit. These changes in production together with changes in trade (e.g. export bans) could be used to calculate the changes in prices of the products in each time unit. Finally, the changes in production and prices should be integrated to compare different strategies in the eradication of Aujeszky's disease. Further research in this respect is under way.

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Appendix A Summary production process

	Region				Total
	North	South	East	West	country
Great-grandparent stock + Multiplier					
Number of herds	80	165	240	100	585
Average sows present	320	446	359	289	366
Farrowing index	2.1	2.1	2.1	2.1	2.1
number of piglets weaned per litter	11	10.8	11	11.1	10.92
% replacement breeding sows (in % per year)	69	73	70.6	72	71.74
% replacement breeding boars (in % per year)	50	50	50	50	50
Rearing					
Number of herds	120	200	320	150	790
Average number of gilts delivered per herd per week	16	28	20	14	20
Farrowing					
Number of herds	455	4042	3978	1025	9500
Average sows present	125	169	123	81	138
Farrowing index	2.1	2.1	2.1	2.1	2.1
number of piglets weaned per litter	9.8	9.6	9.8	9.9	9.73
Number of replacement gilts delivered per herd per year	0	0	0	0	0
Number of fattening piglets delivered per herd per year	2261	2957	2178	1478	2438
% replacement breeding sows (in % per year)	47.00	51.00	48.70	50.00	49.74
Fattening					
Number of herds	828	8299	11032	2715	22874
Number of pig places	300	490	240	185	326.35
Number of fattened pigs delivered per herd per year	862	1401	690	530	936

CHAPTER 5

THE TRADE ARGUMENT FOR ERADICATING AUJESZKY'S DISEASE: EFFECTS OF EXPORT RESTRICTIONS ON THE NETHERLANDS PIG INDUSTRY

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ABSTRACT

Market outcomes and pig producers' returns are simulated under different assumptions about the closure of export markets for live piglets and live animals. If the Netherlands fails to eradicate Aujeszky's disease before its trading partners in these markets, live piglet exports would be banned, reducing industry revenue and export earnings by about 9% and 10% respectively in the medium term. If exports of live fattened pigs are also banned, the reductions are 26 and 32% respectively. The piglet-producing sector would be more severely affected than the fattening sector.

INTRODUCTION

Aujeszky's disease is a contagious viral disease that affects the central nervous system of pigs. Although similar viral strains can affect other animals, including cattle and sheep, no cases of Aujeszky-like infections have been reported in humans. In very young animals without immunity, mortality can be 100%. In older swine, symptoms are milder, depending on age and immune status, with about 2% mortality in mature animals. Vaccination can reduce the disease effects and ultimately lead to eradication since it increases the quantity of the virus needed to cause infection and reduces the spread of the disease (Gustafson, 1986; Kimman, 1995).

Under EU rules, countries or regions that are Aujeszky-free can ban imports of breeding animals carrying antibodies of the disease; movements to Aujeszky-free areas from other areas of both breeding and rearing pigs are subject to strict conditions and controls which differ depending on whether or not the area of origin has an EU-approved eradication program (EC, 1993). Germany already has an EU-approved eradication program and so a temporary closure of the German borders for piglets belongs to one of the possibilities. In more detail this would mean that about 10% of the total export of piglets from the Netherlands is banned and these products will go either to the domestic market or to the other export markets. However, as the EU-measures are well within current GATT rules, which recognize the concept of disease-free areas and the right of trading countries to protect such areas, providing it is done according to relevant international standards and scientific recommendations (GATT, 1994), it might also be possible that as soon as Germany achieves the Aujeszky-free status it bans import of all live animals. This would mean also about 60% of the total export of fattened pigs is also banned.

The optimal control/eradication strategy has been the subject of some debate (see, for example, Stegeman, 1995; Buijtels et al., 1996). McInerney (1995) compared four alternative response strategies for UK conditions: do nothing, reduce the incidence and maintain the disease at low levels by vaccination, suppress to low levels through vaccination then eradicate by slaughter of the remaining positive animals, and one-step eradication via a test-and-slaughter policy. Using cost-benefit criteria, it was shown that the optimal strategy depends on factors such as pig density, prevalence levels and marketing considerations.

The purpose of this chapter is to describe a model of the Dutch markets for piglets, fattened pigs and carcasses, allowing for interaction between two markets (domestic and export) and taking account of flows of imports and exports in and out of the system at each stage of the marketing chain. The model is estimated econometrically and first used as a framework for estimating the effects on demand (and therefore on price) of a number of pig diseases. After the estimated effects and demand elasticities are described, the model is used for simulating the effects on prices and trade flows because of Aujeszky's disease virus, under different assumptions about how export buyers/Dutch industry react to these outbreaks.

MATERIAL AND METHODS

Data description

Monthly data on important quantities, prices and infections in the pig production sector were gathered from the Product Boards for Livestock, Meat and Eggs (PVE) from January 1988 to December 1994. The data contain:

- Dutch monthly prices of piglets and fattened pigs;
- German and Belgium prices of piglets and fattened pigs;
- monthly quantities of piglets exported (not specified to countries) and fattened pigs exported (QHE) (not specified to countries);
- number of carcasses demanded in the Netherlands and exported;
- the occurrence of the different infections at the domestic and export markets during the period of interest. These infections are:
    - Swine Vesicular Disease (SVD) in Dutch herds (SVDNL);
    - the export ban because of SVD in Dutch herds (SVDEXP);
    - Classical Swine Fever in Dutch herds (CSFNL);
    - Classical Swine Fever in the most important export countries (Belgium, Germany and Italy) (CSF);
    - Porcine Respiratory Reproductive Syndrome in Dutch herds (PRRS).

With the assumptions that (1) every sold fattened pig was a piglet 3 months previously, (2) the total amount of animals which are slaughtered each week is equal to the amount of fattened pigs slaughtered each week (3) the mortality rate during the fattening stage is 2%, the amount of piglets available for fattening or export in the Netherlands can also be calculated.

Table 1. Means and standard deviations of monthly observations of the variables, estimation period 1988-94

Variable	Units	Mean	Standard deviation	Minimum	Maximum
SPI piglet imports	'000 head	2.94	8.60	0.0	49.32
SPN Dutch supply of piglets	'000 head	2031.58	143.41	1661.59	2308.19
DPN Dutch demand of piglets	'000 head	1871.16	113.50	1574.29	2172.67
DPE piglet exports	'000 head	163.36	65.52	19.00	360.27
SHI fattened pig imports	'000 head	11.17	8.69	1.42	57.85
SHN Dutch supply of fattened pigs	'000 head	1815.86	120.20	1522.99	2088.14
DHCN Dutch demand of pigmeat	'000 carcasses	812.67	112.94	467.40	1063.16
DHE export of live fattened pigs	'000 head	196.81	50.55	94.89	338.64
DHCN export of pigmeat	'000 carcasses	817.56	99.88	589.55	1211.67
PPN Dutch price of piglets	Dfl/piglet	102.71	26.84	58.95	158.14
PPI/PPE1 import/export price of piglets (Belgium)	Dfl/piglet	106.01	23.18	63.20	153.63
PPE2 export price of piglets (Spain)	Dfl/piglet	115.54	26.55	61.53	179.40
PHN Dutch price of fattened pigs	Dfl/carcass	276.79	42.16	208.71	372.62
PHI import price of fattened pigs (Belgium)	Dfl/carcass	324.03	42.43	252.16	405.90
PHE export price of fattened pigs (Germany)	Dfl/carcass	298.65	44.59	222.79	385.00

Table 1 shows the variable definitions, their units of measurement and sample first and second moments. Dutch price data were deflated by the relevant consumer price index, whereas the prices of the other countries were converted from ECU to Dutch guilders, and deflated by the consumer price index. Piglet prices for two destinations, Belgium and Spain, were used as these are both important, and geographically separated, export destinations. Prices of fattened pigs were derived from the price per 100 kg liveweight, assuming a slaughter weight of 83 kg.

Over half the final product of the Dutch pig industry is exported. During the four years 1991-94, annual exports of live fattened pigs and of pigmeat remained fairly steady at about 2.5 million fattened pigs and 900-950 tons of pigmeat respectively. Piglet exports, however, increased by 129% between 1991 and 1992, reaching 2.636 million in 1992. This level was maintained in 1993-94. Table 2 shows the main trade flows as annual averages during 1993-94. Germany is by far the most important export destination for live fattened pigs and pigmeat, whereas Spain and Italy together took 64% of piglet exports.

Table 2. Annual overage trade flows in 1993-94

	Imports piglets	Imports fattened pigs	Exports piglets	Exports live fattened pigs	Exports carcasses
Total ('000s)	5.55	161.3	2487.5	2524.0	11448.2[1]
Destination of exports			Percentage of total exports		
Belgium/Lux'bourg			22.6	8.2	4.6
France			4.0	11.1	9.9
Germany			8.6	57.9	46.0
Italy			27.5	19.5	25.1
Spain			36.6	1.4	1.6
Other Countries			0.6	1.9	12.8[2]

Source: Central Bureau of Statistics, The Hague.
1 Equivalent to 950.2 thousand tons of pigmeat.
2 Includes 10.6% to the UK.

In the simulation we assume that prevalence of Aujeszky's disease in the Netherlands remains unchanged at the 1994-95 level. Our model is used to simulate the effects on the Dutch industry of increasing levels of trade restrictions as successive trading partners achieve Aujeszky-free status and close their borders against imports from the Netherlands, beginning with Germany (Level 1). It is plausible to assume that in a second phase (Level 2) France and Belgium also eradicate the disease, but before the southern European importing countries. However, closure of French and Belgian frontiers (in addition to those of Denmark and Germany which are already closed in fact or by assumption), would pose a problem for the transport of Dutch animals. Only relatively expensive transport by sea would be available. Therefore, complete closure of all export markets (Level 3) could correspond to the unlikely case whereby all importing countries achieve Aujeszky-free status before the Netherlands, or the slightly more plausible situation in which all countries with common boundaries do so, thereby effectively blocking trade routes further south.

The demand for each of the mentioned quantities can be explained by equation 1.

$$D = f\,(P,\ P^0,\ Z,\ u) \tag{1}$$

where D is the quantity demanded, P is the own price, P^0 are other relevant prices, Z are other observable determinants of demand, Z are other exogenous factors (including disease outbreaks, feed price, seasonal effects, time trends) and u is the disturbance term.

Each demand functions cannot be considered in isolation when the relationship between quantity and price is studied. Therefore demand and supply functions are estimated together in a model where the supply of products is equal to the demand of products when no stocking is assumed. Such models are known as simultaneous equation models (Maddala, 1989).

The model

The structure of the Netherlands piglet market is described by the following set of monthly domestic and aggregate foreign trade relationships:

$$SPN_t = f_1(BS_{t-2},\ Z_{1t}) \tag{2}$$

$$SPI_t = f_2(PPN_t, PPI_t, Z_{2t}) \tag{3}$$

$$DPN_t = f_3(PPN_t, PHN_t, Z_{3t}) \tag{4}$$

$$DPE_t = f_4(PPN_t, PPE_t, Z_{4t}) \tag{5}$$

$$\begin{aligned} SPN_t &= DPN_t + DPE_t - SPI_t \\ &= f_5(PPN_t, PHN_t, PPI_t, PPE_t, Z_{2t}, Z_{3t}, Z_{4t}) \end{aligned} \tag{6}$$

where SPN is supply of piglets from within the Netherlands, BS is number of breeding sows, SPI is supply of piglets imported into the Dutch market, DPN is demand for piglets from fatteners within the Netherlands, DPE is export demand for piglets; PPN is price of piglets on the Dutch market, PHN is price of fattened pigs on the Dutch market, PPI is price of piglets in a representative import source, PPE is price of piglets in a representative export destination, Z_i are other exogenous factors (including disease outbreaks, feed price, seasonal effects, time trends).

Equation (6) is the equilibrium condition for the piglet market, which implicitly defines the Dutch piglet price: in each period, piglet price on the Dutch market adjusts to equate total demand, net of imported supplies, to the domestic supply of piglets, which is assumed independent of current (monthly) price. The function f_5 is defined by f_i, i=1,...,4.

The structure of the market of fattened pigs is as follows:

$$SHN_t = (1 - m)\, DPN_{t-3} \tag{7}$$

$$SHI_t = f_6(PHN_t, PHI_t, Z_{5t}) \tag{8}$$

$$DHCN_t = f_7(PHN_t, Z_{6t}) \tag{9}$$

$$DHE_t = f_8(PHN_t, PHE_t, Z_{7t}) \tag{10}$$

$$DHCE_t = f_9(PHN_t, PHE_t, Z_{8t}) \tag{11}$$

$$\begin{aligned} SHN_t &= DHCN_t + DHE_t + DHCE_t - SHI_t \\ &= f_{10}(PHN_t, PHI_t, PHE_t, Z_{5t}, Z_{6t}, Z_{7t}, Z_{8t}) \end{aligned} \tag{12}$$

where SHN is supply of fattened pigs from within the Netherlands, SHI is fattened pigs imported into the Dutch market, DHCN is demand for fattened pig carcasses by Dutch processors and meat distributors, DHE is export of live fattened pigs, DHCE is export demand for fattened pig carcasses slaughtered in the Netherlands; PHI is price of fattened pigs in a representative import source, PHE is price of fattened pigs in a representative export destination, Z_i are other exogenous factors (including disease outbreaks, seasonal effects, price of competing meats, lagged endogenous variables, time trends).

Monthly fattened pig supply is determined by the demand for piglets by Dutch fatteners 15 weeks (which is assumed to be three months) earlier, adjusted by the mortality rate *m*, and is therefore independent of current (monthly) price of fattened pigs (equation (7)). Equation (12) is the equilibrium condition for the market fattened pigs; each period, the

Dutch price of fattened pigs adjusts to equate domestic supply to total demand (including live animals for export and animals for slaughter), net of imported fattened pigs.

When expressed as a monthly model, there is a recursive relationship between the piglet and fattened pig markets. Current price of fattened pigs affects the piglet price via its effect on the domestic demand for piglets to be fattened; in this demand equation, it acts as an indicator of the profitability of fattening piglets for the market of fattened pigs. However, the outcomes in the piglet market do not affect current endogenous variables in the market of fattened, since piglets bought by Dutch fatteners do not appear as finished fattened pigs until about three months later, independently of the current (monthly) price of fattened pigs.

The link between the two markets is modelled as if all piglets pass to fatteners via a market decision. This is only an approximation to the Dutch situation, where about 27% of piglets remain for fattening with the producer who bred them (Backus et al., 1994). Our model implicitly assumes that the decision to retain piglets for fattening depends on their marginal opportunity cost.

The endogenous variables in this system are SPN, SPI, DPN, DPE, PPN, SHN, SHI, DHCN, DHE, DHCE, PHN. All other variables are treated as exogenous, except the prices on export and import markets, which are tested for endogeneity. When the system is simulated to obtain short-run effects, SPN is assumed to be exogenously determined according to a combination of technical and institutional factors. For the medium-run simulations, this assumption is retained as long as piglet price is greater than the marginal cost of producing piglets. When price falls below this level, piglet producers are assumed to adjust their supply in response to price. In neither case is it necessary to estimate equation (2) econometrically. In the simulations, domestic supply of fattened pigs is given by equation (7) (which is derived from (3)) in the short term; in the medium-run simulations, it is assumed that, when price of fattened pigs fails to cover marginal cost, supply contracts according to a more price-responsive supply function. These assumptions result in kinked supply curves for both piglets and fattened pigs.

Thus, the equations to be estimated econometrically are equations (3), (4), (5) from the piglet market, and equations (8), (9), (10) and (11) from the market of fattened pigs. In order to simulate the short-run responses of piglet and fattened pig prices, given current piglet supply SPN, the two-equation system consisting of equations (6) and (12) is inverted to yield solutions for PP and PH, given SPN and the other exogenous variables. The allocation of total net supplies between different demand and import components, given market clearing prices, is calculated using equations (4), (5), (9), (10) and (11) (export carcasses). In order to facilitate solution of the model, all functions f_i, i=1,...,10 are assumed to be linear.

RESULTS

Estimated Demand relationships

The seven equations to be estimated econometrically are all over-identified. These equations were estimated jointly by Iterative Three Stage Least Squares, using all the predetermined (exogenous and lagged endogenous) variables as instruments. Prices in export and import markets were tested for exogeneity by the Hausman test (Hausman, 1978), applied to equations (6) and (12), inverted so as to express the Dutch price for piglets and fattened pigs respectively as functions of the other relevant variables. Only the Belgian piglet price was found to be endogenous. The endogeneity of this variable was allowed for in both estimation and simulation.

The estimates of the parameters (except those for constants and monthly dummies) are reported in Appendix A. Variables were retained in the model only if their coefficients were significant at 30% or better. The signs and magnitudes of the coefficients are all satisfactory, as are for the most part the t-ratios. Although a large part of the variation remains unexplained, this is not surprising in a monthly model. The disease dummies tell an interesting story: exports of both piglets and live fattened pigs are affected by the live export ban (SVDEXP) operated by the Netherlands during September and November 1992 and March 1993 due to outbreaks of swine vesicular disease. Over and above the effect of this export ban, exports of live fattened pig reacted negatively to Dutch outbreaks of SVD, classical swine fever (CSF) (March and May 1990, and second quarter 1993) and porcine respiratory reproductive syndrome (PRRS) (first half of 1991) whereas piglet exports are affected only by PRRS. By contrast, piglet exports receive a boost during outbreaks of CSF elsewhere in Europe, and this positive effect extends also to exports of pig carcasses. Although meat exports are depressed by the presence of SVD in the Netherlands, the imposed export ban on live animals (SVDEXP) had a weakly significant *positive* effect on meat exports resulting in an increase of about 5%, suggesting the displacement of some demand from live exports to exported carcasses.

Contrary to other findings (for example, Holt and Johnson, 1988; Hallam and Zanoli, 1993), feed price was not found to be significant in the derived demand for piglets for fattening (equation (3)) and hence was also absent from the supply equation (7) of fattened pigs. Moreover, Dutch demand for pig carcasses was unresponsive to prices of other meats (chicken and beef) (equation (9)).

Four equations (piglet imports and exports, imports and exports of fattened pig) showed significant first-order serial correlation and were adjusted using a simple two-step procedure involving estimates of the autocorrelation parameter derived from the Durbin-Watson statistic (Koutsoyiannis, 1977).

An implication of linear demand and supply functions, as opposed to various alternative non-linear specifications (including constant-elasticity functions) is that these functions can meet the price and quantity axes. For example, for sufficiently high (low) prices on the Dutch market, export demand (import supply) may become zero. Given the complications posed by these properties of the model when simulating, the system was tested for non-linearity in prices by including quadratic and/or square-root terms in prices on the right-hand side of the main equations of the system. However, these terms were all insignificant. Since pork is a strongly differentiated food item, albeit one with close substitutes, it is not unreasonable to suppose that demand elasticities decline as total marketed quantity increases, as is implied by linear functions.

Table 3. Estimated demand elasticities[1]

Variable	Elasticity with respect to				
	PPN	PHN	PPI/PPE1	PPE2	PHI/PHE
SPI	8.37 (3.03)		7.48 (3.29)		
DPN	-0.169 (0.03)	0.143 (0.06)			
DPE	-1.457 (0.48)		1.282 (0.45)	0.711 (0.34)	
SHI		1.882 (1.03)			-1.966 (1.17)
DHCN		-0.341 (0.06)			
DHE		-1.839 (0.62)[2]			1.824 (0.61)[2]
DHCE		-0.498 (0.19)			0.282 (0.18)

1 Calculated at the sample means (standard errors in parentheses).
2 Cumulative effect after two periods.

Table 3 presents estimates of the price elasticities calculated at sample means. Their signs and magnitudes conform with prior expectations. Demand for finished fattened pigs, whether for slaughter or export, is more price-elastic than derived demand for piglets. The high price elasticities for imports are due to the small numbers imported and the opportunistic nature of this essentially localised cross-border trade. In most equations, price elasticities calculated at the sample mean with respect to the relevant Dutch price and the competing trade price are close in absolute value, indicating that traders react to relative prices only. These restrictions, when imposed on the parameters of the model, were accepted by both F- and likelihood ratio tests, with p values of 0.05 and 0.04 respectively.

Ex post simulation

The estimated model can be inverted to simulate the endogenous variables in the two markets over the estimation period. Table 4 presents statistics comparing the simulated values of some key endogenous variables with their observed values.

Table 4. Performance statistics of the ex post simulation

	Price piglets	Price fattened pigs	Export piglets	Export fattened pigs	Export pigmeat
Mean percent error (%)	-0.32	-0.06	4.80	2.36	0.56
RMS percent error (%)	20.02	7.98	54.67	26.19	8.37
Correlation coefficient	0.812	0.888	0.790	0.621	0.699
Inequality coefficient	0.00175	0.00028	0.00147	0.00106	0.00011
bias%	0.0	0.0	0.0	0.0	0.0
variance%	13.8	5.5	2.9	0.1	1.1
covariance%	86.2	94.5	96.9	99.9	98.2

These statistics are calculated as:

$$\textit{Mean percent error} = 100\frac{1}{T}\sum_{t}^{T}(Y_t^s - Y_t^a)/Y_t^a$$

$$\textit{RMS percent error} = 100\sqrt{\frac{1}{T}\sum_{t}^{T}[(Y_t^s - Y_t^a)/Y_t^a]^2}$$

$$\textit{Theil's inequality coefficient}: U = \frac{\sqrt{\frac{1}{T}\sum_{t}^{T}(Y_t^s - Y_t^a)^2}}{\sqrt{\frac{1}{T}\sum_{t}^{T}(Y_t^s)^2} + \sqrt{\frac{1}{T}\sum_{t}^{T}(Y_t^a)^2}}$$

where Y_t^s is the simulated value, Y_t^a is the actual value, and T is the number of periods simulated (see Pindyck and Rubinfeld, 1981). Pearson's product moment correlation coefficient lies between -1 and 1; a value of 1 indicates no simulation error. Theil's inequality coefficient lies between 0 and 1; U=0 denotes no simulation error.

Average errors are small. However, both simulated price series fluctuate more than observed prices; this is particularly true for the simulated piglet price during 1990 and 1991. This feature accounts for the large percentage root mean square error, and the size of the variance component in the inequality coefficient. More than half of the percentage RMSE for piglet exports is due to just three outlying observations.

Graphical evidence is given in Appendix B in which the estimated and observed prices of piglets and fattened pigs and the estimated and observed numbers of piglets exported, fattened pigs exported and pig carcasses are shown. Overall, the model reproduces the medium-term trends of the variables well, although it does not always simulate accurately the more extreme month-to-month variation in series around these trends. This is not surprising, given the share of monthly variation unexplained by the regression model.

Simulations

When using the estimated model for simulation, the following adjustments are made:

(1) endogenous variables are constrained to take non-negative values.

(2) mortality during finishing of fattened pigs is set at 2%.

(3) all exogenous variables are set equal to their average 1994 values, both for the base run (calibrated on 1994) and when simulating trade restriction scenarios.

(4) for the simulations of trade restrictions in the short term, the domestic supply of piglets is set equal to its level in the base run and the domestic supply of fattened pigs is as given by equation (7). This reflects the assumption that, in the short run, there will be no culling of breeding sows or reduction in fatteners' capacity, regardless of price movements.

(5) for the medium-term simulations, it is assumed that when price falls below marginal cost in either market, the capacity of the corresponding sector begins to contract. Thus, below these price thresholds, the vertical supply function in the piglet market and the relatively inelastic supply function in the market of fattened pig are replaced by more elastic supply functions that allow for the withdrawal of capacity and the disappearance of producers from the industry. The construction of these supply functions is explained in the Appendix C.

In each market, therefore, the medium-term supply function is kinked. The right-hand segment of the curve (vertical for piglets, highly price-inelastic for fattened pigs) reflects output decisions, assuming that 1994 capacity is maintained. Along the left-hand segment of the function, small price changes result in relatively large quantity changes as higher-cost producers withdraw from production. These supply curves describe rational producer responses to price reductions lasting into the medium term in an industry whose fixed costs correspond to factors specific to the industry (housing, breeding stock).

Three different scenarios (A, B, C) are defined on three different levels. In Scenario A the export of only live piglets is banned whereas live animals and live animals plus carcass exports are restraint in Scenario's B and C respectively (see Table 5).

Table 5. Simulation Scenarios

Trade restrictions affect: / Aujeszky-free status attained by:		A. Live piglets only	B. Live piglets and fattened pigs	C.Live animals and carcasses
Level 1	Germany	1A	1B	1C
Level 2	Germany, France, Belgium	2A	2B	2C
Level 3	All importing countries	3A	3B	3C

Although, given current EU legislation and GATT criteria, restrictions against pigmeat imports (Scenario C) could not be legally upheld on the grounds of protecting the domestic herd against Aujeszky's disease, it is interesting nevertheless to investigate what the impact of such measures would be, should they be adopted for some other animal health or food safety reason. The corresponding runs demonstrate the ability of the model to simulate trade restrictions at all levels of the production chain. The results for scenario C are shown in Appendix D.

In order to simulate the scenarios in Table 5, the following adjustments are made to the model:

(6) For Level 1 scenarios (only Germany's borders closed), the Belgian piglet price falls in line with piglet price in the Netherlands. The price transmission relationship used is based on a regression, with an estimated transmission coefficient of over 80%.

(7) For all scenarios, the parameters of equation (5) (piglet exports) are scaled down in accordance with the average 1993-94 export share of the market or markets that are assumed to be closed (see Table 2). For scenarios B and C equation (10) (exports of fattened pigs) is also changed in the same way. These parameter changes also affect equations (6) and (12) (when the export of fattened pigs are also restricted), and thus the solutions for prices on the Dutch markets reflect the removal of a segment of export demand. For the scenarios in column C of Table 5, the parameters of equation (11) (export carcasses) are also scaled down consistently with the average 1993-94 export share of the market or markets that are assumed to be closed.

This procedure implies that, without market closures, the relative share of each importing country in the total exported would remain the same at all price levels, and thus that, for each type of export, price elasticities of demand are equal between export destinations.

(8) For B scenarios, it is assumed that there is some displacement of demand from live exports to pigmeat exports. This effect is based on the coefficient of SVDEXP in equation (11), indicating that when live exports were suspended during certain months of 1992-93, export demand for pigmeat increased by 55.2 thousand carcasses (equivalent to about 28% of average exports of live fattened pigs). To reflect this displacement effect in the simulation, the intercept of equation (11) is increased by an amount representing 28% of the export of live fattened pigs (1993-94 monthly averages) foregone by the country or countries whose markets are closed. It is assumed that there is no displacement effect in the short term and for scenario A. Also, for scenario C there can be no displacement effect since, at each level, a country's export markets for both live animals and pigmeat are closed simultaneously.

Table 6. Percentage changes compared with base run "1994"

	Short term						Medium term					
	1A	1B	2A	2B	3A	3B	1A	1B	2A	2B	3A	3B
PPN	-4.9	-9.3	-14.7	-25.3	-75.4	-100.0	-4.9	-14.3	-14.7	-34.2	-45.1	-46.1
PHN	-1.1	-11.4	-3.2	-21.4	-19.1	-54.3	-1.1	-10.9	-3.2	-17.9	-10.4	-22.6
SPN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.1	-8.7
DPE	-7.1	-3.2	-23.5	-15.0	-100.0	-100.0	-7.1	+1.2	-23.5	-7.9	-100.0	-100.0
SHN	+0.6	-0.1	+1.8	+1.6	+9.7	+9.7	+0.6	-0.3	+1.8	+0.3	+5.3	-0.7
DHE	+1.8	-50.3	+5.1	-69.5	+30.3	-100.0	+1.8	-50.6	+5.1	-70.7	+16.5	-100.0
DHCE	+0.5	+8.6	+1.4	+14.1	+8.13	+29.7	+0.5	+8.4	+1.4	+12.6	+4.4	+16.0
DHCN	+0.3	+3.3	+1.0	+6.3	+5.6	+16.2	+0.3	+3.2	+1.0	+5.3	+3.1	+6.6

Following a trade ban, capacity cannot adjust for at least 5-6 months for piglet producers and 3 months for fattened pig farmers, due to the biological lags in the production process. For a trade ban lasting longer than these biologically determined periods, producers are able to react to operating losses. However, because of their reluctance to reduce the size of the breeding sow herd or leave fixed capacity unused in response to price changes of temporary duration, adjustment may be delayed longer than the biologically determined minimum period. If producers know that the Netherlands will reach Aujeszky-free status in the foreseeable future, after which the trade ban will be lifted, it is probable that producers will absorb losses on fixed capital and will reduce capacity only when variable costs are no longer covered. Thus, given our medium-term time horizon, structural change begins when the highest-cost producers can no longer cover variable costs and cease production. The capacity of the industry then contracts. Thus, the starting point of the medium term assumed here is defined by the industry's ability and willingness to react structurally to lower prices.

When the trade ban affects piglets only (A scenarios), piglet price bears the direct effect. However, prices of fattened pigs also fall due to the increased supply of fattened pigs. The fall in piglet exports in scenarios 1A and 2A is less than the base-run share of exports taken by the markets which have closed, due to an offsetting price-induced increase in demand in those markets remaining open. For scenarios 1A and 2A, the medium-term effects are not different from those in the short term. This is because the price falls in each market are not sufficient to stimulate any structural adjustment. However, with both 1B and 2B there is some structural adjustment in the fattening sector in the medium term (see Table 6).

With the exception of scenario 1B, in which the direct impact on the market of fattened pigs is greater than in the piglet market, the short-term effect on piglet prices is greater than that for fattened pigs. In the medium term, the fall in the price of fattened pigs relative to piglet price is even smaller, which is explained by two factors. First, because fixed costs of production are a much smaller proportion of the price of fattened pigs than the piglet price (34.3% compared to 53.8%), capacity adjustment is triggered by a smaller percentage price fall in the sector of fattened pigs than in the piglet sector. This difference between the two sectors in their propensity for structural adjustment has the effect of shifting a significant part of the price impact back up the chain to the piglet sector. Second, the assumption on the demand side that some export demand for live animals is displaced to export demand for carcass meat, helps to sustain the price of fattened pigs. It should be noted that, in the C scenarios, when only the first of these two factors is in operation, the medium-term impact of the trade bans considered is still much greater on piglet price than on price of fattened pigs (see Appendix D).

In the medium term, when only the German markets for live animals are closed (Level 1), piglet imports fall by 80% (1A) and 100% (1B), while domestic piglet output remains unaltered. However, the destination of these piglets changes. The withdrawal of German export demand is offset by increased demand in other markets at both levels in the chain, with the relative size of the increase depending on the demand elasticities in the different markets. In scenario 1B, part of the fall in demand of fattened pigs due to withdrawal of German buyers is offset by increased demand for exports of fattened pigs to other countries in response to the lower price of fattened pigs, and part is transferred (by assumption) to export demand for slaughtered carcasses, which increases in any case due to the lower price of fattened pigs. Domestic demand for slaughtered fattened pigs (for final consumption or processing) also increases. Therefore the throughput of the industry hardly changes.

By contrast, when all export markets for piglets only (3A) or for all live animals (3B) are closed, and medium-term adjustments take place, prices fall far enough to trigger capacity adjustments in both sectors. Despite decreases of 3% (3A) and nearly 9% (3B) in piglet production, exports of slaughtered carcasses increase by 38.1 thousand per month and 138.1 thousand per month respectively. In the second case, this increase offsets more than half the fall in demand of fattened pigs due to the ban on live exports. Domestic offtake of slaughtered carcasses also increases. Note that the increase in slaughterhouse throughput implied by the various medium-term scenarios simulated ranges from 0.6% (scenario 1A) to 6.6% (scenario 3B).

In the intermediate scenarios (level 2), the outcome depends strongly on whether only piglets, or all live animals, are affected by trade restrictions. In the first case (2A), piglet price and exports suffer, whereas the fattened pig sector increases its throughput with only a 3.2% price reduction. However, when live fattened pigs exports are also banned (2B), the reduction in exports is less marked for piglets than for fattened pigs. The fall in prices of fattened pigs due to the closure of three important markets for live fattened pigs exports is passed back up the chain, putting downward pressure on piglet prices; this stimulates price-responsive piglet demand from southern Europe. The increase in demand from this region cancels part of effect of the closure of northern European markets, and prevents piglet price falling further.

Appendix D shows the effects of bans on both live animals and pigmeat exports (C scenarios). The industry's throughput falls by about 19% in the medium term even when only Germany's markets are closed. In the extreme case where all Dutch export markets are closed for both live and slaughtered animals, the throughput of the industry would decline by over 52% and prices of fattened pigs would fall by over 40%. The model predicts that domestic offtake would rise by some 12%. This increase has implications for the domestic processing industry and would have significant repercussions on consumer demand for other meat and non-meat protein foods. The partial equilibrium framework adopted here makes it impossible to explore these effects.

Table 7 summarizes the impact on industry revenues, producer surplus and export earnings resulting from different degrees of closure of export markets for piglets and all live animals. When only the German market for piglets is closed, the industry's revenue falls by 1.2%. Fattened pig farmers actually gain due to the lower price they pay for piglets. Both sectors lose when all live animal exports to Germany are banned and industry revenue falls by 11.7% in the short run; this effect hardly changes in the medium term, when structural changes and demand displacement effects have time to operate. However, the loss is more evenly distributed between the two sectors than in the short run. When all countries are closed to piglet exports from the Netherlands, the net loss in revenue is over 8% even after medium-term adjustment. Not surprisingly, it is the piglet producers who bear the brunt of the market closures; their revenue is nearly 47% lower after all medium-term adjustments have occurred whereas fatteners make significant gains. When all markets for all live animals are closed, both sectors lose and yet even here, pig producers suffer a far larger fall in revenue and producer surplus.

Export earnings fall in all scenarios relative to the base run. The total loss is less in the medium run than in the short run for scenarios 1B, 2B, 3A and 3B, since in the short run there is no demand displacement from live animal exports to slaughtered carcass exports and no structural adjustments to moderate price impacts. Although the number of exported carcasses increases in all scenarios, export revenues from pigmeat decline due to the lower prices of fattened pigs. It is assumed here that the fall in Dutch prices is fully passed on to importing countries, and not partly absorbed by Dutch slaughterhouses or exporting firms.

Producer surplus is revenue minus variable costs, where variable costs are measured as the area under the supply functions. Producer surplus is the amount available to cover all fixed costs including management income and return on capital, as well as any profit. In the short run, producer surplus is measured relative to the short-run supply functions (vertical for piglets, relatively price-inelastic for fattened pigs) where all or most costs are assumed fixed. In calculating producer surplus, two different views can be taken concerning fattened pig producers' outlay on piglets. Expenditure on the piglets that have been fattened to produce the fattened pigs currently sold is a fixed (historical) cost. Expenditure on the replacement of these fattened pigs by new piglets is a variable cost, and should be recognized as such even in the short run. These two views give rise to two alternative measures of the short-run change in producer surplus in the fattened pig sector: the first (shown in Table 7) considers piglet cost as a fixed item in the short run. The second allows for the fact that the replacement cost of piglets has fallen, and that producers benefit from this even in the short run (not shown). According to the second measure, the total surplus loss is smaller and the relative surplus for piglet producers is greater than with the first measure. Moreover, fattened pig farmers enjoy an increase in producer surplus in the A scenarios.

In the medium term, when only piglet exports are restricted, at whatever level, fattened pig farmers gain in terms of revenue, net of piglet cost, and producer surplus. As more countries join the trade ban, whether it affects piglets only or all live animals, an increasing share of the loss falls on piglet-producing sector.

Table 7. Percentage changes in revenues and producer surplus (PS) compared with 1994 base run

		Short term						Medium term					
	Scenario	1A	1B	2A	2B	3A	3B	1A	1B	2A	2B	3A	3B
Piglet revenue		-4.9	-9.3	-14.7	-25.3	-75.4	-100.0	-4.9	-14.3	-14.7	-34.2	-46.8	-50.8
Fattened pig revenue		-0.6	-11.4	-1.5	-20.1	-11.2	-49.9	-0.6	-11.1	-1.5	-17.6	-5.6	-23.2
Fatteners' outlay on piglets		-3.7	-8.5	-13.2	-24.6	-73.3	-100.0	-3.7	-13.5	-13.2	-34.0	-42.1	-46.5
Fattened pig revenue net of piglet cost		+1.3	-13.2	+5.4	-17.5	+25.4	-20.3	+1.3	-9.7	+5.4	-8.0	+16.0	-9.4
Net industry revenue[1]		-1.2	-11.7	-2.5	-20.6	-14.0	-51.5	-1.2	-11.5	-2.5	-18.2	-8.6	-25.6
Export revenue	total	-1.0	-13.8	-3.0	-23.8	-14.1	-54.9	-1.0	-13.6	-3.0	-21.8	-9.6	-31.5
	piglets	-11.7	-12.2	-34.7	-36.5	-100.0	-100.0	-11.7	-13.3	-34.7	-39.4	-100.0	-100.0
	live fattened pigs	+0.7	-56.0	+1.7	-76.0	+5.4	-100.0	+0.7	-56.0	+1.7	-76.0	+4.4	-100.0
	fattened pig carcasses	-0.7	-3.8	-1.9	-10.3	-12.5	-40.8	-0.7	-3.4	-1.9	-7.6	-6.4	-10.2
Change in producer surplus[2]	total	-14.9	-91.3	-43.5	-179.6	-240.0	-523.6	-7.2	-61.2	-20.5	-104.5	-64.4	-132.7
mln guilders/month	piglets	-11.0	-20.7	-32.8	-56.3	-167.9	-222.6	-11.0	-31.8	-32.8	-76.2	-100.3	-102.5
at 1994 prices	fattened pigs	-3.9	-70.6	-10.7	-123.3	-72.1	-301.0	+3.8	-29.4	+12.3	-28.3	+35.9	-30.2
Distribution of total PS loss	piglets	-74	-23	-75	-31	-70	-43	-153	-52	-160	-73	-156	-77
per cent	fattened pigs	-26	-77	-25	-69	-30	-57	+53	-48	+60	-27	+56	-23

1 Revenue of piglet producers plus revenue of fattened pig producers net of piglet cost.

2 Producer surplus in the base run differs between the short-run and medium-run scenarios, due to the different positions assumed for the supply curve. Therefore, changes in PS in the short run and the medium are relative to a different base value.

No allowance is made in these estimates for any decline in feed prices that may be triggered by falling pig and fattened pig prices. Given the competitive structure of the feed compounding industry in northwestern Europe, scope for sympathetic feed price reductions is assumed to be small.

Sensitivity analyses of several key assumptions were carried out. (1) If the average variable cost of the highest-cost output is assumed to be more than 20% higher than the industry's average variable cost, this has the effect of reducing the price-sensitivity of the left-hand segment of the medium-term supply function and, given the assumed linearity of the function, it implies greater divergence of the most efficient producers' marginal and average variable cost below the industry's average variable cost. When the price-sensitivity of the lower segment of the supply functions is reduced in this way, it results in smaller quantity changes and larger price reductions for most medium-run scenarios. Moreover, the higher average variable cost of the marginal producer is assumed to be above the industry average cost, the more likely it is that capacity contractions are triggered in both sectors for relatively small price falls. The effects of these changes on the economic results given Table 7 are relatively modest, given that price and quantity changes are mutually offsetting. However, if a greater dispersion of cost conditions is assumed in the piglet sector than in the fattening sector, piglet supply contracts earlier than in the simulations presented above, and the distribution of the total burden between the two sectors is less unequal.

(2) Sensitivity analyses were performed in which prices on export markets rose by 10% above their 1994 levels, to reflect the stronger demand for non-Dutch supplies on the part of Aujeszky-free importers. This had the effect of making exports somewhat more buoyant in Level 1 scenarios, with a correspondingly smaller fall in piglet price (with smaller fall in revenue of fattened pigs) but these effects dwindled in Level 2 scenarios; the impact was very small in 3A and, of course, non-existent in 3B, where all export markets are closed.

DISCUSSION AND CONCLUSION

The simulation results presented in this chapter illustrate the effects that can be expected if export demands are imposed on exports from the piglet- and fattened pig-producing sectors of the Netherlands. The simulation model is partly based on econometrically-estimated relationships. However, when the simulation scenarios involve extrapolation well outside the range of empirically observed behaviour, artificially constructed supply relationships, based on theoretical reasoning and assumptions about industry marginal cost, replaced those based on empirical observation. For this reason, the results presented for Levels 2 and 3 scenarios should be taken as indicative only. By contrast, the results for Level 1 scenarios (only German markets closed) may be given greater credence. A limitation of the approach is the assumption that no new markets are opened up, either within or outside Europe, even when prices fall significantly.

If all export markets were closed to exports of live animals from the Netherlands, piglet output would contract by 8-9% due to the withdrawal of production capacity because of piglet producers' inability to cover operating costs, while producer surplus (revenue minus variable costs) in the piglet sector would fall by some 100 million guilders per month (in 1994 guilders). Piglet producers who remained in the industry would be unlikely to cover their fixed costs, leading after some time to rising levels of debt and bankruptcy. Fattened pig farmers would experience a small decline in output, a reduction in revenue (net of piglet cost) of over 9% and a loss of producer surplus of 30 million guilders per month (in 1994 guilders). Total export revenue (piglets and fattened pigs) would fall by over 31%.

In the less extreme and more plausible case that only Germany achieves Aujeszky-free status before the Netherlands, export revenue would fall by 1% if only piglet exports are restricted and by over 13% if restrictions extend to all live animal imports into Germany. The corresponding falls in producer surplus for the industry as a whole are 7 million and 61 million guilders per month respectively.

The importance to the Dutch pig industry of live animal exports to other European countries is such that failure to eradicate Aujeszky's disease from the national pig herd until after trade partners have achieved Aujeszky-free status would seriously damage the profitability of the industry in the medium term. Under reasonable assumptions about the cost structure and the distribution of cost efficiency with the industry, our simulations demonstrate that if all export markets for live animals are closed to Dutch exports, structural change would occur, and capacity would be lost to the industry that, particularly with respect to breeding sows, would take some time to replace.

In the search for an optimal control/eradication strategy, it is important for policy makers to consider sector-level and trade implications alongside detailed cost-benefit studies at the level of the individual price-taking producer level. Only when the endogeneity of market prices and trade responses is taken into account can a realistic assessment of the benefits of eradication be reached.

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Appendix A Econometric estimates of demand equation parameters (t-ratios in parentheses)

Equation	PP	PH	PPI/PPE1	PPE2	PHI/PHE	t	Diseases[1]	$\bar{R}^2$ / D.W.[2]	ρ
2. SPI	0.239 (2.76)		-0.210[3] (-2.28)				CSF -6.23(-3.18) PRRSNL 10.98(2.95)	0.213 1.62	0.674
3. DPN	-3.073 (-6.24)	0.966 (2.56)						0.282 1.98	
4. DPE	-2.317 (-3.03)		1.993[3] (2.87)	1.005[4] (2.07)		0.653 (2.07)	SVDEXP -114.04(-4.30) PRRSNL -69.24(-2.63) CSF 53.14 (3.37)	0.441 2.04	0.332
7. SHI		0.076 (1.83)			-0.068[5] (-1.69)	0.228 (3.94)		0.678 1.66	0.652
8. DHCN		- 0.922 (-6.24)						0.470 1.84	
9. DHE		-1.965 (-4.38)			2.280[6] (5.26)		SVDNL -18.62(-1.36) SVDEXP -87.85(-4.05) CSFNL -61.83(-4.04) PRRSNL -28.20(-1.44)	0.286 1.78	0.328
10. DHCE		-1.470 (-2.66)			0.773[6] (1.58)		SVDNL -66.63(-3.53) SVDEXP 55.04 (1.61) CSF 39.47 (2.24)	0.677 1.93	

1 Disease dummies are: SVD: swine vesicular disease; CSF: classical swine fever; PRRS: porcine respiratory reproductive syndrome. The subscript NL indicates an outbreak in the Netherlands. The subscript EXP indicates that an export ban on Dutch live exports was in operation. No subscript indicates a disease outbreak on the territory of one or more trading partners. *t* is a linear time trend.

2 In equations with first-order serial correlation (ρ≠0), the $\bar{R}^2$ and Durbin-Watson statistics for these equations relate to the transformed values of the regressand;

3 PPI/PPE1= Price of piglets in Belgium (endogenous);

4 PPE2= Price of piglets in Spain (exogenous);

5 PHI= Price of fattened pigs in Belgium (exogenous);

6 PHE= Price of fattened pigs in Germany (exogenous). Endogeneity/exogeneity of prices in exporting and importing countries based on Hausman tests.

Equations 2,3,4,8 and 10 contain some monthly and other dummies. Lagged PH and PPE were also significant in equation 9.

Appendix B Estimated and obeserved prices and numbers

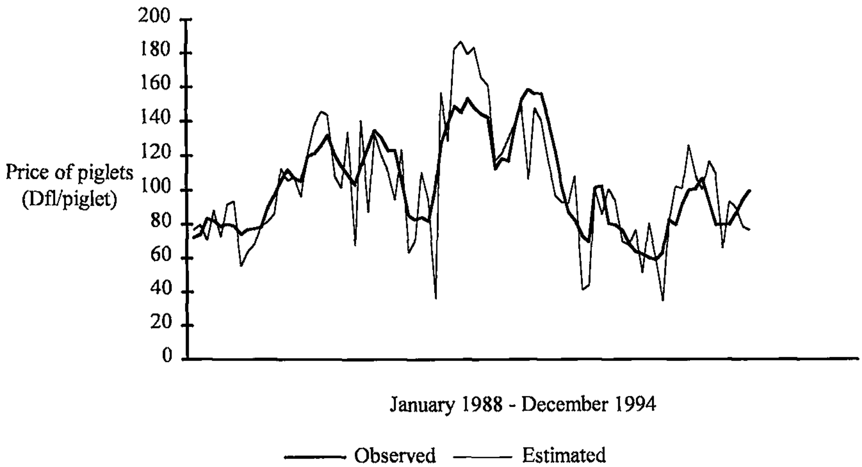

Figure A1. Price of piglets

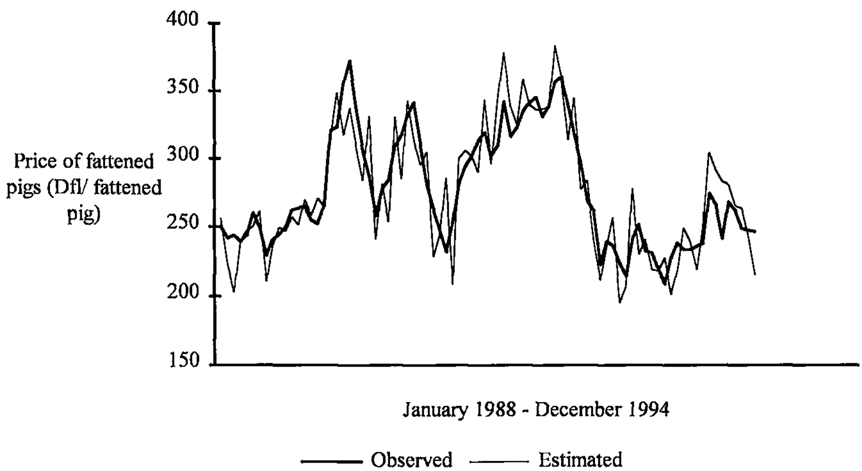

Figure A2. Price of fattened pigs

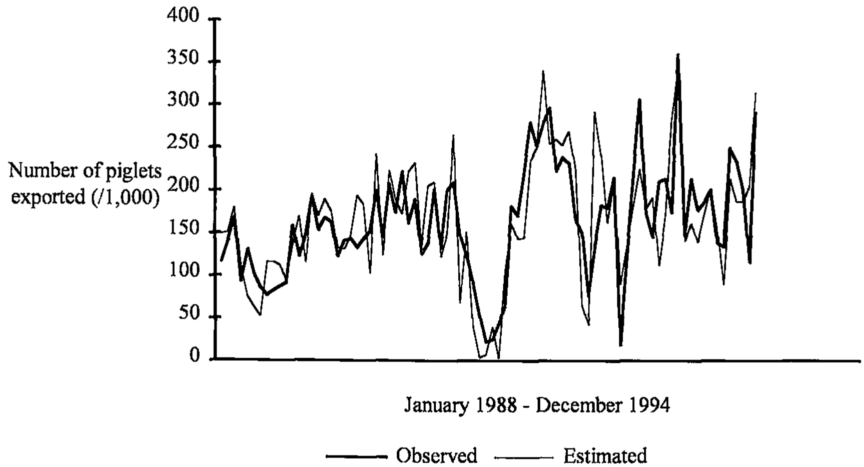

Figure A3. Number of piglets exported

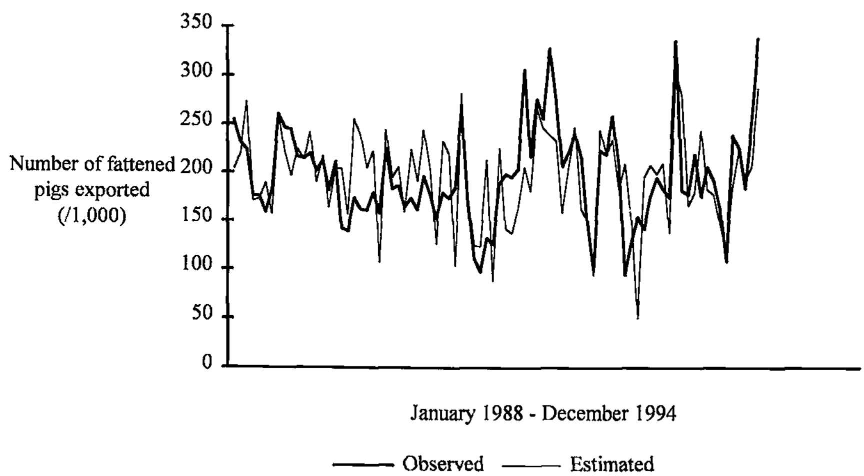

Figure A4. Number of fattened pigs exported

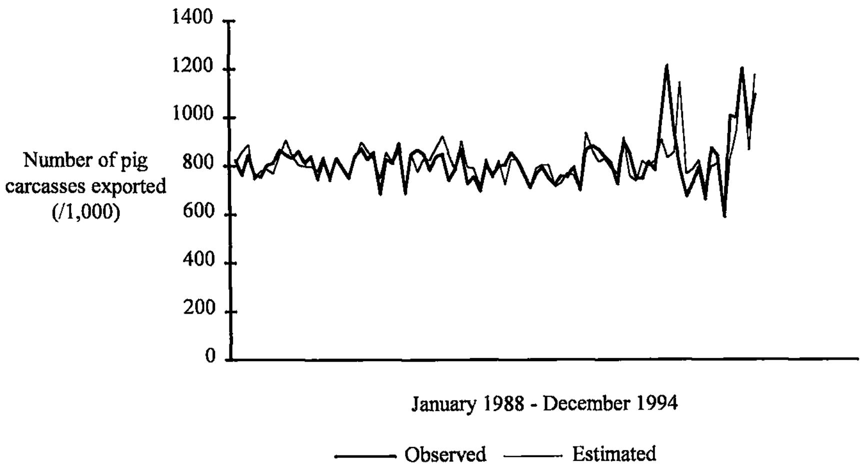

Figure A5. Number of pig carcasses exported

Appendix C Construction and simulation of supply response functions

Because the model was estimated over a period during which demand was relatively stable and Dutch pig producers were not under price pressure, it was not possible to estimate the medium-term reaction of producers to large price decreases. The supply functions used in the simulations consist of two segments: a relatively inelastic right-hand segment corresponding to observed behaviour in recent years, and a more price-elastic lower left-hand segment, corresponding to unobserved price levels, which has been constructed as explained below.

Piglet supply depends on long-term price expectations, herd dynamics and exogenous capacity constraints such as manure restrictions. During the period 1988-94, piglet supply fluctuated around a stationary mean of 2.04 million per month, with a coefficient of variation of about 7%. This is taken to be the optimal supply over the observed range of prices, given the current manure restrictions which prevent further significant expansion of capacity. Therefore, the right-hand segment of the piglet supply function over the range of prices in the sample was assumed to be vertical at this output level and was not estimated econometrically.

Fattened pig farmers' short-term supply response at historically observed prices is calculated from the econometrically-estimated domestic demand function for piglets, based on monthly price movements; it is rather inelastic with respect to price of fattened pigs, due to short-term capacity constraints. It is reasonable to assume that constraints on further expansion would persist in the medium term due to manure regulations.

It is, however, unrealistic to suppose that the observed insensitivity of supply to price changes in both sectors would continue in the medium term if prices fell to the low levels implied by the short-term supply functions. Therefore, in the medium-term simulations, when price falls below threshold levels PPN^* and PHN^* in the relevant market, the industry is assumed to contract along a supply function that is much more elastic than the behaviour observed at higher price levels.

The price thresholds PPN^* and PHN^* are the industry-level average variable cost of marginal producers of piglets and fattened pigs respectively. PHN^* is composed of piglet cost (PPN) plus other variable costs per fattened pig for the marginal producer. Data is available on average variable costs to the industry in 1994. It is assumed that the average variable cost of the highest-cost units of output is 20% higher than the average variable cost for the industry as a whole (PHN_{94}^*=$AVCH_{94}$).

Using the fact that price equals marginal cost in a competitive industry where individual producers maximise profit, linear implicit supply functions are constructed through the points (PPN^*_{94},SPN_{94}) and (PHN^*_{94},SHN_{94}^*) (where SHN_{94}^* is the output level corresponding to PHN^* using equation (7)), subject to the constraints that $PPN^*_{94}=1.2*AVCP_{94}=MCP_{94}$, $PHN^*_{94}=1.2*AVCH_{94}=MCH_{94}$ and $AVC_{94}=\frac{1}{Q}\int_0^{Q_{94}} MC.dQ$ for each market. This gives the following implicit supply functions:

Piglets: $PPN = 33.618 + 0.00824\ SPN$ **(A1)**

Fattened pigs: $PHN = 67.345 + PPN + 0.04288\ SHN$ **(A2)**

The intercept of the piglet supply function (=33.618) is interpreted as the average (and marginal) cost per piglet of the lowest-cost output, which is 20% below the industry's average variable cost. Also for the supply function of fattened pigs, the intercept (=PPN+67.345) is marginal cost per head of the most efficient production. Since both segments of the supply function of fattened pigs shift with the piglet price, it follows that, in each simulation run, the position of the kink in the supply curve, which is given by the point of intersection of equation (A2) with equation (7), may differ from that of the base run. The elasticity of supply at the level of supply corresponding to 50% of 1994 output on these segments of the medium-term supply functions is 5. These orders of magnitude indicate that, although the assumed linear supply functions are undoubtedly simplified representations of the path along which the industry would contract, their implications are nevertheless realistic.

During the medium-term simulations, if the simulated piglet price (PPN^s) falls below the threshold PPN^*, the supply function (A1) is triggered and SPN becomes endogenous in the model. Similarly, if $PHN^s < PHN^* = PPN^s + (PHN_{94}^* - PPN_{94})$, the estimated supply function of fattened pigs (7) is replaced by the more price responsive function (A2). Since PPN^s is endogenous, this means that both segments of the supply function fattened pigs are different from one simulation to another, and the point at which the kink occurs is endogenous. The model is solved iteratively, with simulated prices being checked against the price thresholds PPN^* and PHN^* at each iteration. The convergence properties of the model are stable, and the model converges after several iterations.

Appendix D Percentage changes compared with base scenario "1994"

	Short term			Medium term		
	1C	2C	3C	1C	2C	3C
PPN	-41.9	-89.9	-100.0	-47.0	-49.3	-54.9
PHN	-78.4	-100.0	-100.0	-28.6	-32.5	-41.9
SPN	0.0	0.0	0.0	-13.5	-25.8	-56.3
DPE	+38.6	+36.5	-100.0	+44.3	+4.1	-100.0
SHN	-3.7	-12.4	+9.0	-19.0	-28.8	-52.5
DHE	-5.5	-41.0	-100.0	-38.8	-65.5	-100.0
DHCE	-27.9	-43.7	-100.0	-39.4	-55.0	-100.0
DHCN	+23.1	+29.4	n.d.[1]	+8.4	+9.5	+12.3

1 Not defined. Within the model, the increase in domestic demand for carcasses when price of fattened pigs falls to zero is +29.4%. With all export markets closed, the increase in supplies available to the domestic market is in excess of +100%.

CHAPTER 6

COST-BENEFIT ANALYSIS TO SUPPORT POLICY-MAKING IN THE CONTROL OF AUJESZKY'S DISEASE VIRUS

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ABSTRACT

In this chapter four control strategies to eradicate Aujeszky's disease virus in the Netherlands were compared epidemiologically and economically. Calculations showed that infection in the Dutch swine population will not disappear without vaccination, nor with a vaccination strategy where sows are vaccinated less than 3 times per year and fattening pigs once per cycle. The infection will only be eradicated, if sows are vaccinated at least 3 times per year and fattening and rearing piglets at least once per cycle.

Vaccination decreases production losses. The decrease is largest if the vaccination strategy changes from "no vaccination" to the less intensive vaccination strategy but extra vaccinations in more intensive vaccination strategies do have influence. The production losses are mainly caused by dead animals (especially gilts) and abortions. Growth delay in gilts and piglets have less influence.

Especially the sales distribution on piglet markets (import, export and on the domestic market) is influenced by vaccination, but the revenues decreased less than 4.3%, except for the numbers of piglets and live animals which were imported into the Netherlands, which decreased by more than 15% and about 9% respectively. The accompanying revenues from piglets and fattened pigs are the highest if "no vaccination" is done. Compared with the revenues in this strategy, this difference is most striking on the piglet market, where the decrease was about 3.6%. The decrease on the market of fattened pigs was about 0.55%.

According to the resulting net present values no-"vaccination" is in principle the preferred option, at least when taking into account the vaccination costs and the direct production losses. An export ban of at least two years on live animals to Germany, makes the most intensive vaccination strategy economically the best strategy. A prolonged export ban would make this strategy even more favourable.

INTRODUCTION

Aujeszky's disease is an infection which mainly occurs in the pig production sector (Gustafson, 1986). Economic losses from Aujeszky's disease virus infection can come from mortality in piglets, abortions and other reproductive failures in sows. Besides these so-called "direct economic losses", losses may also be caused by export bans, which are denoted as "indirect economic losses". In the Netherlands breeding sows and gilts are mainly sold on the domestic market, whereas piglets, fattened pigs and pig carcasses are sold on the domestic market and export markets, such as Germany, France and Italy. In finding the economically best vaccination strategy, the costs and benefits of strategies to eradicate Aujeszky's disease are of interest. In the literature, partial budgeting and cost-benefit analysis are commonly used for comparing different control/prevention strategies (Ngategize and Kaneene, 1985; Levy and Sarnat, 1986; Dietrich et al., 1987; Van der Kamp et al., 1990). Specific problems in calculating the costs and benefits are, among other things, the determination of the types and categories of costs and benefits to include in the analysis and the setting of the appropriate prices (Little and Mirrlees, 1974; Gittinger, 1981).

In general, there are two methods for measuring costs and benefits, in economic terms, namely integral and differential calculations. The former calculates total costs and benefits, the latter only the changes in costs and benefits (Van der Schroeff, 1970). In the case of policy decisions on animal health control, most of the aspects after applying different strategies are incremental and therefore differential calculation is the more appropriate technique. This method was used, for example, in studies by Hugoson and Wold-Troell (1983), McInerney and Turner (1989), Berentsen et al. (1990), Van der Kamp et al. (1990) and Houben et al. (1993). In these studies, only changes resulting from a certain control program were measured and evaluated.

In this chapter four vaccination strategies to eradicate Aujeszky's disease virus in the Netherlands are compared epidemiologically and economically. First, the epidemiological effects of Aujeszky's disease per vaccination strategy and the model in which the prices of piglets and fattened pigs are calculated, are described. Subsequently, the direct and indirect costs are defined together with distribution of the revenues over the different markets. By using these costs and revenues the four different vaccination strategies are compared and evaluated.

MATERIAL AND METHODS

Simulation model

For determining the effects of different vaccination strategies on Aujeszky's disease in pigs at regional level, the simulation model of Buijtels et al. (1996b) was used as a basis. In this model pig herds are characterized by 32 different infection states within each herd type. These states are based on (1) the value of Reproduction ration which is, in this case, the number of secondary pigs caused by one infectious pig (R_{ind}) (De Jong and Diekmann, 1992), (2) the prevalence of Aujeszky's disease virus within each value of R_{ind} and (3) the expected number of infectious animals per herd within each prevalence range. The R_{ind} values are based on field and laboratory experiments (De Jong and Kimman, 1994; Stegeman et al., 1995; Van Nes et al., 1996) and used in the definition of the different vaccination strategies as shown in Table 1. Strategy 1 is the basic - non-vaccination - strategy with which the other 3 strategies are compared. Strategy 3 and 3' are included to show the effects of a more intensive vaccination in fattening herds.

Table 1. Definition of the vaccination strategies

Strategy	Herd type	Definition vaccination strategy
1	B	No vaccination
	R+F	No vaccination
2	B	Vaccinating less than 3 times per year with strain-783 or Begonia
	R+F	Vaccinating once per cycle with strain-783 or Begonia
3	B	Vaccinating 3 or 4 times per year with strain-783 or Begonia
	R+F	Vaccinating twice per cycle with strain-783 or Begonia
3'	B	Vaccinating 3 or 4 times per year with strain-783 or Begonia
	R	Vaccinating twice per cycle with strain-783 or Begonia
	F	Vaccinating once per cycle with strain-783 or Begonia

B is breeding herds, R is rearing herds and F is fattening herds.

The probability of a herd going from one state to another is described in a transition matrix. To include the non-linearity of the transmission process, the transmission probabilities from non-infectious to either non-infectious or infectious are defined such that they depend on the state vector itself and the animal and other contacts. Animal contacts are a function of (1) the average number of deliveries of each infectious herd per time unit, (2) the average number of animals per delivery and (3) the probability that at least one of the animals in the delivery is infectious. The other contacts, which include transmission by fomites, airborne transmission, indirect transmission through other species, and minor disease-specific routes, such as venereal or iatrogenic transmission (Buijtels et al., 1996a) are a function of (1) the expected number of infectious animals in each herd and (2) the average number of herds to which the virus is delivered per infectious herd. The transition matrix together with the calculation of the percentage of new infectious herds per time unit are used to calculate the state vector for each time period. A more detailed description of the model can be found in Buijtels et al. (1996b).

Epidemiological calculations of this simulation model indicated that infection in the Dutch swine population will not disappear without vaccination, nor with vaccination Strategy

2, in which sows are vaccinated less than 3 times per year and rearing and fattening pigs once per cycle. The infection will only be eradicated, when sows are vaccinated at least 3 times per year and fattening and rearing pigs at least once per cycle (Strategies 3 and 3'). These results are described more extensively in Buijtels et al. (1996b and 1996c).

In the model the following direct effects of Aujeszky's disease on the production process are defined:

- number of abortions sows;
- number of gilts and fattening pigs with growth delay;
- mortality of piglets, gilts, sows and boars.

The extent to which these losses occur depends on (1) the number of infectious animals (I^*) per herd in the different infection states, (2) the probability that an infectious animal is clinical or subclinical and (3) the probability that a production loss will occur per clinical or subclinical animal. I^* is shown per infection state in Buijtels et al. (1996b), while the other two parameters are defined per production loss and per vaccination strategy in Table 2.

Table 2. Parameters used in the calculation of the production loss categories per strategy

Production loss category	Vaccination strategy				
	1	2	3	3'	all
Breeding herds	B[1]	B[1]	B[1]	B[1]	C[2]
Number of abortions in sows	0.15	0.02	0.0005	0.0005	0.05
Number of piglets with growth delay	0.15	0.02	0.0005	0.0005	0.05
Number of dead piglets	0.15	0.02	0.0005	0.0005	0.02
Rearing herds					
Number of gilts with growth delay	0.25	0.04	0.001	0.001	0.05
Number of dead gilts	0.25	0.04	0.001	0.001	0.01
Finishing herds					
Number of fattening pigs with growth delay	0.25	0.04	0.001	0.04	0.05
Number of dead fattening pigs	0.25	0.04	0.001	0.04	0.02

[1] B: probability that an infectious animal is clinical or subclinical
[2] C: probability that a production loss will arise per animal that is clinical or subclinical

The probability that an infectious animal is clinical or subclinical decreases, if the vaccination strategy is more intensive and the probability that a production loss will occur per animal that is clinical or subclinical are assumed to be the same for all vaccination strategies and stationary over time. These assumptions are based on available data (Houben et al., 1993; Stegeman et al., 1995) and expert opinions.

Table 3. Total number of cases per production loss category and per strategy after a period of 10 years

	Strategy			
Production loss category	1	2	3	3'
Number of gilts with growth delay	920,645	91,409	47	34
Number of dead gilts	3,288	326	0	0
Number of abortions in sows	2,391,363	20,013	1	1
Number of piglets with growth delay	6,805,679	56,960	2	3
Number of dead piglets	388,896	3,255	0	0
Number of fattening pigs with growth delay	20,395,340	2,210,707	551	417,995
Number of dead fattening pigs	1,165,448	126,326	31	23,885

The resulting total number of cases per production loss category in the Netherlands for each vaccination strategy is shown in Table 3. This table indicates that Aujeszky's disease virus does not cause many production losses, at least when taking into account that more than 25 million piglets and 22 million fattened pigs are produced in the Netherlands each year (CBS, 1995). Vaccination decreases the number of cases per production loss category. The decrease is largest if the strategy changes from "no vaccination" to the less intensive vaccination (Strategy 1 vs 2) but extra vaccinations in the more intensive strategies (Strategy 3 vs 3') do have influence. Furthermore, this table illustrates that the numbers of cases in breeding and rearing herds are not affected by the vaccination strategy in fattening herds. This is mainly because the number of new introductions caused by other than animal contacts is limited.

Definitions of the costs

Direct costs

Costs are subdivided into two categories: direct and indirect costs. Direct costs include both the costs of vaccination and the costs of the production losses. The yearly costs of vaccination (VC) per herd and per vaccination strategy are calculated as follows:

$$VC = N_{vis} \times C_{vis} + N \times N_{vacc} \times C_{vacc} \quad (1)$$

where N_{vis} is the number of visits of the veterinarian for eradication of Aujeszky's disease virus, C_{vis} are the fixed costs per visit, N is the number of animals per herd, C_{vacc} are the costs per vaccination (vaccine costs and costs of labour of the farmer) and N_{vacc} is the number of yearly vaccinations per animal[1]. The calculation of the costs per production loss is based on Rougoor et al. (1996) and is shown in Appendix A.

Besides the cost of vaccination and production losses, there are also effects if the supply of products increases and if different vaccination strategies are applied in eradicating the infection. These effects are included in the comparison of strategies by using Strategy 1 as the base.

Indirect costs

Indirect costs are costs that arise from reactions of other countries to Aujeszky's disease infection in the Netherlands. For example, Dutch export to Germany, which is by far the most important export destination for live fattened pigs and pig carcasses, suffered already from stricter import criteria and/or a considerable price differential for non-certified products. Under the EU rules, countries or regions that are Aujeszky-free can ban imports of breeding animals carrying antibodies of the disease; movements to Aujeszky-free areas from other areas of both breeding and rearing pigs are subject to strict conditions and controls,

[1] For fattening and rearing herds this parameter is calculated as the number of cycles per year times the number of vaccinations per cycle

which differ depending on whether or not the area of origin has an EU-approved eradication program (EC, 1993). Germany has already an EU-approved eradication program and thus a (temporary) closure of the German borders for piglets is possible. This means that about 10% of the total export of piglets from the Netherlands could be banned. If so, these piglets will go to either the domestic market or other export markets. However, if the EU-measures are well within current GATT rules, it might also be possible that, as soon as Germany achieves the Aujeszky-free status, it will ban all live animals. The GATT rules recognize the concept of disease-free areas and the right of trading countries to protect such areas, providing it is done according to relevant international standards and scientific recommendations (GATT, 1994). This would mean that then about 60% of the total export of fattened pigs would also be banned.

Calculation of prices

The calculation of the prices of piglets and fattened pigs is based on the model which is described in detail in Buijtels and Burrell (1996). The simulation model in this chapter is based on an econometrically-estimated, partial-equilibrium model of the Dutch piglets and fattened pigs markets, which recognizes technical and price linkages between these two markets. Imports and exports of live animals occur at both levels (piglets as well as fattened pigs) in the vertical production chain, and the distribution of carcasses over domestic and export markets is also modelled. The changes in prices, market outcomes and pig producers' returns are simulated and assumptions about closure of export markets for live piglets and fattened pigs can be changed. Once these price changes are determined, they are multiplied by the appropriate quantities.

RESULTS

Introduction

This section is subdivided into four parts. First, the direct costs and revenues are described per vaccination strategy over a time horizon of 10 years. Then the strategies are compared and evaluated by using these costs and revenues. Lastly the effects of an export ban on live animals to Germany at different points in time are described. The revenues represent the total sales of piglets, fattened pigs and pig carcasses.

Direct costs

The various direct costs per vaccination strategy are shown in Table 4, and were calculated in real prices, where a discounting factor of 4% per year was used. The costs are highest per dead animal (especially for gilts) and per abortion, while growth delay is of minor influence. The same ranking applies to the total costs in the population, except for the mortality in breeding sows, because this does not occur as often as the other mortalities (see Table 4).

The costs of production losses are highest for Strategy 1 and lowest for Strategy 3', as could be expected. If the costs of vaccination are also included, however, the direct costs are lowest for Strategy 2 and highest for Strategy 1, despite the fact that in Strategy 3 the infection was eradicated after 7 years, and thus the vaccination could then be stopped.

Table 4. Average and total costs (in Dfl) per production loss per vaccination strategy after a period of 10 years

Production loss category	Average costs per unit (in Dfl.)[1]	Strategy			
		1	2	3	3'
Number of gilts with growth delay	1.10[2]	792,109	85,297	51	37
Number of dead gilts	313.86[3]	862,297	84,591	50	37
Number of abortions in sows	296.49	607,483,932	4,826,786	247	263
Number of piglets with growth delay	0.13[2]	878,980	5,629	0	0
Number of dead piglets	52.44[3]	17,810,386	137,494	7	7
Number of fattening pigs with growth delay	0.75[2]	8,886,093	988,613	316	221,645
Number of dead fattening pigs	100.59[3]	100,257,759	10,387,231	3,074	2,209,926
Total production losses		736,971,555	16,515,641	3,746	2,431,915
Vaccination costs	1.60	0	279,785,352	427,701,137	321,932,455
Total		736,971,555	296,300,993	427,704,883	324,364,370

1 the average costs per unit are based on a price of piglets of Dfl 100 per piglet and Dfl 320 per 100 kg. of slaughter weight for fattened pigs
2 per day
3 per animal

Revenues

The resulting products of the production process (piglets, fattened pigs and carcasses) are distributed over the domestic and export markets. The influence of vaccination strategies on revenues from different products is shown in Table 5. In this table the absolute revenues from products are given for Strategy 1, while revenues for other strategies are given relative to this strategy.

Vaccination has mainly an influence on piglet markets but the decreases of the various quantities given in Table 5 were all less than 4.3%, except for the numbers of piglets and fattened pigs which were imported into the Netherlands. These decreased by more than 15% and about 9% respectively. Difference in intensity of vaccination hardly influences the revenues from the products. This is because of the fact that Aujeszky's disease virus does not cause many cases per production loss category (see Table 4), especially not in vaccinated herds. Because of these losses, however, the supply on the total market of piglets as well as fattened pigs is decreased, which has a more than complementary positive effect on the price of piglets and fattened pigs, because the revenues from piglets and fattened pigs are highest in Strategy 1. If Strategy 1 is compared with the other strategies, this positive effect is strongest on the piglet market, where the decrease in revenues was about 3.6%. On the market of fattened pigs this was about 0.55%.

Table 5. Distribution of products over different markets (in Dfl/1,000) for the different vaccination strategies after 10 years

	Absolute	Percentage of change		
	Strategy 1	2	3	3'
QPN	20,484,845	-4.18	-4.22	-4.22
QPE	1,588,292	2.80	2.82	2.82
QPI	108,816	-16.29	-16.43	-16.43
QHE	4,199,560	1.32	1.33	1.34
QHMN	17,651,292	-0.85	-0.85	-0.85
QHME	19,402,150	-0.68	-0.69	-0.69
QHI	67,191	-8.98	-9.06	-9.06
Revenue piglets	21,964,321	-3.62	-3.65	-3.65
Revenue fattened pigs	41,185,810	-0.53	-0.54	-0.54
Total revenues	63,150,132	-1.61	-1.62	-1.62

QPN is demand for piglets from fatteners within the Netherlands, QPE is export demand for piglets, QPI is piglets imported into the Dutch market, QHE is export of live fattened pigs, QHCN is demand for carcasses of fattened pigs by Dutch processors and meat distributors, QHCE is export demand for carcasses of fattened pigs slaughtered in the Netherlands and QHI is fattened pigs imported into the Dutch market.

Comparison of the different strategies

After the costs and the revenues have been calculated per vaccination strategy, the strategies can be compared. In Table 6 the different direct costs and revenues are summarized per strategy and the present values (PV) are presented given there is no export ban. According to these present values "no vaccination" is economically speaking the best solution. If eradication of Aujeszky's disease virus is required, however, Strategy 3' is economically the best solution. Because of the advantage that vaccination is no longer needed after the infection is eradicated from the population, Strategy 3 will economically be preferred, if the period of comparison has prolonged from 10 to, say, 12 years.

Table 6. Calculation of the present value per vaccination strategy (in Dfl./1,000) after 10 year given there is no export ban

	Strategy			
	1	2	3	3'
Vaccination costs	0	279,785	427,701	321,932
Production losses	736,972	16,516	4	2,432
Total direct costs	736,972	296,301	427,705	324,364
Total revenues	63,150,132	62,135,781	62,126,589	62,126,510
Present value	62,413,160	61,839,480	61,698,884	61,802,145

Table 7. Differences in distribution of different products (in Dfl) with or without export bans on piglets or live animals at different moments for vaccination strategy 1.

	absolute	Export ban on piglets relative to no export ban			Export ban on live animals relative to no export ban		
	no export ban	t=8	t=9	t=10	t=8	t=9	t=10
QPN	20.48	-0.56	-0.36	-0.17	-1.05	-0.68	-0.33
QPE	1.59	-1.90	-1.24	-0.61	-1.74	-1.14	-0.56
QPI	0.11	-2.20	-1.43	-0.69	-25.29	-16.47	-8.05
QHE	4.20	0.19	0.12	0.05	-12.87	-8.31	-4.02
QHCN	17.65	-0.10	-0.06	-0.03	-1.32	-0.86	-0.42
QHCE	19.40	-0.09	-0.05	-0.02	-0.21	-0.13	-0.06
QHI	0.07	-1.06	-0.66	-0.28	-22.44	-14.39	-6.93
Piglet revenues	21.96	-0.65	-0.42	-0.20	-0.98	-0.63	-0.31
Fattened pig revenues	41.19	-0.06	-0.04	-0.02	-1.94	-1.25	-0.61
Total revenues	63.15	-0.27	-0.17	-0.08	-1.61	-1.04	-0.50

[1] divided by 1,000,000,000

Effects of an export ban

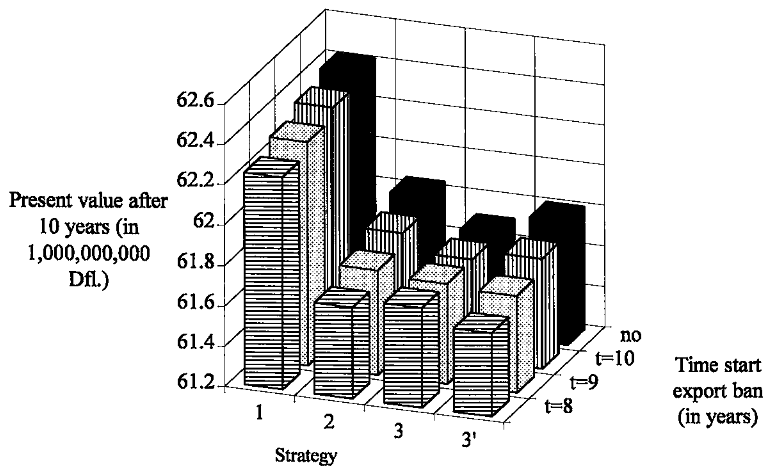
If the export of piglets or live animals to Germany is prohibited at the start of year 8 (t=8), 9 or 10 after the beginning of the vaccination strategy, the distribution of the different products over the markets and the accompanying revenues change as shown in Table 7. The changes are only shown for Strategy 1, as there is hardly any difference between strategies.

An export ban on piglets has only minor effects on the distribution of the products, as all changes were less than 2.5%, while an export ban on all live animals has a more dramatic effect. As far as the export of fattened pigs is concerned, the difference is not as great as expected, because about 60% of the export was banned by Germany. Other countries take over a large part of this export. Moreover, imports of both fattened pigs and piglets into the Netherlands are terminated, which means that the total numbers of piglets and fattened pigs on the domestic market are decreased.

After an export ban of at least two years total revenue was decreased by less than 0.5% and more than 0.5% respectively if export of piglets and live animals to Germany stopped. The decrease after the export ban on piglets is mainly caused by the piglet market while the market of fattened pigs is more influenced if export of live animals is ceased. This could be expected, because in this situation more export of fattened pigs than of piglets is banned.

The costs are only different because of effects of changes in prices on the costs of production losses. Therefore, the changes in revenues especially influence the present value. Figure 1 shows the present values after 10 years per vaccination strategy if export bans on (A) piglets and (B) live animals (piglets and fattened pigs) are imposed at different points in time. As shown in this figure, an export ban on piglets only will not economically justify vaccination. An export ban on live animals of at least 2 years makes Strategy 3 economically the best strategy. A prolonged export ban makes this strategy even more favourable.

A. Piglets



B. Live animals

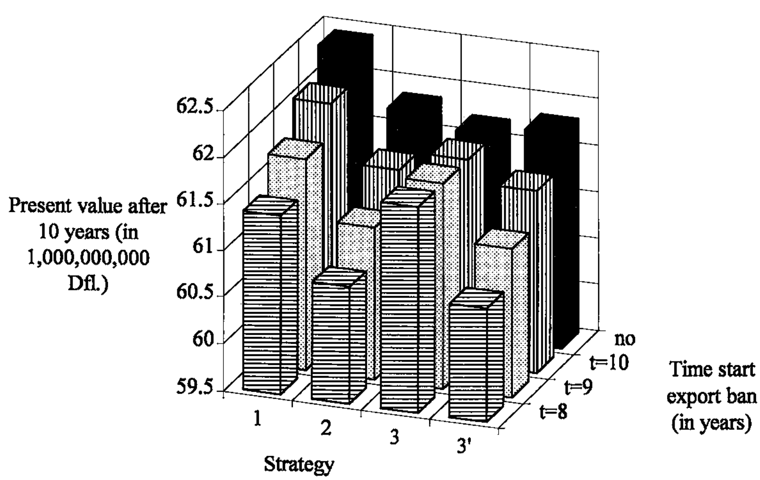


Figure 1. Present values after 10 years per vaccination strategy when export bans of (A) piglets and (B) live animals occur at different points in time

DISCUSSION AND CONCLUSION

In this chapter four different vaccination strategies were economically evaluated after having been compared in an epidemiological way in Buijtels et al. (1996b, 1996c). It was shown that export is an important economic feature in choosing the best strategy. Without any export bans on live animals, it would, economically speaking, be better not to vaccinate.

An export ban on live animals to Germany for at least two years moved the economically preferred choice from "no vaccination" to the most intensive vaccination strategy under consideration. Hence, insight into market behaviour and resulting effects is far more important than insight into direct production losses from this type of infection. This was also indicated in a study by McInerney (1995), in which four alternative response strategies were compared: do nothing, reduce the incidence and maintain the disease at low levels by vaccination, suppress to low levels through vaccination, then eradicate by slaughtering remaining positive animals, and one-step eradication via a test-and-slaughter policy. Unfortunately, no direct answer to the choice of a strategy was given, as the comparison was only indicative rather than exact and definitive. It was shown, however, that the optimal strategy depends on factors such as pig density, prevalence levels and marketing considerations when cost-benefit criteria are used.

Vaccination was the only eradication method which was taken into account in this comparison, because the Netherlands is a densely populated area regarding pigs. For example, total depopulation/repopulation is not a technically possible nor an economically feasible option. This does not mean, however that it would not be feasible to remove the last percentages of gE-positive animals from the total population. At the end of a vaccination strategy, a combination of vaccination and depopulation/repopulation may be an economically attractive solution. More research is under way to investigate at which prevalence this is the case per vaccination strategy.

The major determinant of the economic profitability of a vaccination strategy is the occurrence of export bans. Besides direct effects of export bans these also affect distribution of and revenues from complementary products and so these should also be taken into account to estimate the effects of Aujeszky's disease at national level. A good example that this may be of influence is BSE. The export ban on British cattle seems to be of influence on the EU cattle market and, for example, the EU pig market. The prices of cattle have decreased, and those of pigs increased, mainly because of the change in demand on the market.

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Appendix A Calculation of costs per production loss

Costs per day of growth delay

The costs per day of growth delay (CGD) are calculated as:

$$CGD = \frac{VCGP}{GP} \qquad \textbf{(A1)}$$

Where GP is the length of the growing period and VCGP are the variable costs during the growing period. This last variable is calculated as:

$$VCGP = SLW \times MP - (PGP + FC + DC) \qquad \textbf{(A2)}$$

where SLW is the weight at slaughtering (in Kg), MP is price of meat (in Dfl/kg), PGP is price of the animal at the start of the growing period, FC are the feed costs and DC are the delivery costs.

Costs per dead animal

The costs of a dead animal are subdivided into (1) the costs until the moment of death (CD) and (2) the revenue foregone for housing and labour during the not completed growing period (RHL).
CD and RHL are calculated as:

$$CD = PGP + PNGP \times (SLW \times MP - PGP) \qquad \textbf{(A3)}$$

$$RHL = (1 - PNGP) \times (LC + HC) \qquad \textbf{(A4)}$$

where PNGP is part of the growing period which is completed, LC is costs of labour and HC is costs of housing.

Costs per abortion in sows

The costs per abortion are calculated as (1) the revenue forgone (RF) minus (2) the costs which were avoided (CA). These two entries are influenced by (a) the day on which abortion occurs, which is, in this model on day 60 of gestation, (b) the difference in farrowing rate (DFI) before and after abortion and (c) the number of piglets weaned per sow per year (PSJ).
DFI is calculated as:

$$DFI = FI - (FI \times \frac{365}{365 + BTB}) \qquad \textbf{(A5)}$$

where FI is the farrowing rate and BTB is the time between matings before and after abortion.

RF and CA are calculated as:

$$RF = DFI \times \frac{PSJ}{FI} \times PP \qquad \textbf{(A6)}$$

$$CA = DFI \times \frac{PSJ}{FI} \times (FC + EXC + OC) \qquad \textbf{(A7)}$$

where PP is the price of piglets, EXC is extra costs per sow and OC is other costs per piglet

CHAPTER 7

GENERAL DISCUSSION

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INTRODUCTION

The aim of this study was to develop a computer simulation environment in which "what-if" scenarios can be performed to explore the epidemiological and economic effects of Aujeszky's disease control. First a basic economic framework was developed for this type of analysis. This framework was subdivided into four different units: changes in infection (ΔI), changes in quantities (ΔQ), changes in prices (ΔP) and an integrated economic model (IEM). These units each have their own input and output, depending on the control strategy under consideration (Chapter 2).

To provide epidemiological information on the control of Aujeszky's disease virus, a simulation model was developed (Chapter 3) and the outcome, including the effects of herd type and regionalization, was presented (Chapter 4). For the quality of the decision making process it is important that the effect of potential intervention measures is quantified and the effect of chosen intervention is monitored in the field (see paragraph validation of the model).

To calculate the changes in prices as a result of the changes in product supply because of changes in infection and possible export bans, a price equilibrium model was developed and effects of export bans of different sizes were presented (Chapter 5). Lastly, a cost-benefit analysis of various control strategies was carried out (Chapter 6).

Each chapter includes a description and discussion of the objectives, methods and results of each particular part of the study. In this general discussion, the main experiences and some related aspects of the epidemiological model and the price equilibrium model are discussed. Subsequently, further eradication of Aujeszky's disease virus in the Netherlands is discussed including the possible use of the model in future research.

EPIDEMIOLOGICAL SIMULATION

Comparison of an ex-ante and a more ex-post approach

The current model is an extension of an earlier model, named AUDIT (Houben et al., 1993), which was constructed in a pilot study of about 5 months and aimed at supporting decision makers on whether or not to start a national eradication program in the Netherlands. At that time almost no (empirical) data on the spread of the disease was available, and most of the inputs were based on expert estimates. But, in such an early stage important decisions had to be made and hence there was a considerable potential role for a decision support model. Because more data became available and a more extensive model could be built, it was of interest to see whether (by hindsight) the early prototype model AUDIT was able to adequately predict reduction in the spread of Aujeszky's disease virus under various control strategies.

In both studies, a state transition approach (Hillier and Lieberman, 1990) was used to describe the course of infection. This was preferred to the Monte Carlo simulation using random elements because (1) the use of a model with random elements makes the model more complex and time-consuming, (2) the required minimum number of iterations is high, especially when more random factors are included and (3) additional information obtained in that way is not necessarily needed in the support of the decision-making process. The amount of detail in the current epidemiological model with respect to the state definitions was increased from 20 infection states in AUDIT to 32. The subdivision of states in AUDIT was based on infection and protection classes, whereas in the current model the reproduction ratio among individual animals (R_{ind}), the possible prevalence classes per R_{ind} and the expected number of infectious animals (I^*) were used. In this way the possibility of validation by field experiments was increased.

Potential reactivation was not included in the current simulation model, whereas it was in AUDIT. Van Oirschot and Gielkens (1984) and Cowen et al. (1990) found that reactivation of latent Aujeszky's disease virus was possible by administering high doses of corticosteroids. In that respect culling of latently infected pigs would decrease this likelihood and consequently increase the chances of eradication of Aujeszky's disease virus. Stegeman (1995) reported that there were no field data that indicated the necessity of culling gE-seropositive pigs to achieve eradication. Also during successful eradication programs in Denmark and Great Britain reactivation of Aujeszky's disease was rarely considered the origin of an outbreak (Andersen et al., 1989; Taylor, 1989), and also in AUDIT (Houben et al., 1993) reactivation turned out to be of minor importance. Therefore, reactivation was not included in the current model.

Both models produce the same type of results, although the results of the current model are much more detailed. Both models indicate that animal contacts have a great impact, which is discussed in more detail in the next section. In the current model, the contacts of the total production pyramid within and between regions are included whereas herds were subdivided into only finishing and breeding herds in AUDIT. The current approach offers the possibility of policy-making at regional level and decisions on the eradication of Aujeszky's disease virus from top to bottom in the production pyramid can now be supported.

Both models were used to compare and evaluate similar types of vaccination strategies. On the whole the results of both models were in line with each other. There were some differences, however. In the current model, it took more time before the infection was eradicated if sows were vaccinated 3 or 4 times per year and fattening and rearing piglets twice per cycle (Strategy 3). Besides that the virus was not eradicated in AUDIT if the most intensive vaccination strategy (Strategy 3) was applied in breeding and rearing herds and finishing herds were vaccinated only once (Strategy 2). The incorporation of the production pyramid and the direct link between the parameters used in the model and empirical evidence from experiments and field observations are factors that help explain these differences. Most of these factors were suggested in the pilot study and thus the pilot study can be considered appropriate in the (early) support of policy-makers.

The impact of animal contacts

More than 95% of the new effective virus introductions, defined as introductions that make herds going from a non-infectious state to an infectious state, are caused by animal contacts (Chapters 3 and 4). To enhance insight into the impact of such contacts in the course of the infection, the total herd population was subdivided into various herd types (great-grandparents stock+multiplier, rearing, farrowing and fattening). However, it was hard to obtain precise field data on the number of herds per herd type and the number and size of deliveries between herds of different herd types, as no distinct definitions of herd types were available in the various recording and database systems. Initially, only great-grandparents stock+multiplier, farrowing and fattening herds were defined, but results of experiments and early simulations showed that it was also important to distinguish between rearing herds. Combining great-grandparents stock and multiplier herds did not have a great impact on the results. The sensitivity analysis (Chapter 4) indicated that the percentage of infectious herds and the percentage of herds in prevalence class [> 50%] were highest in the herd type "rearing".

The impact of animal contacts and the differences in impact of the different herd types underline the importance of knowing more precisely the number of animal contacts between herds. In the current model the mass action principle (Bouma et al., 1995; De Jong et al., 1995) was used, which means that a herd of one herd type does not have contact with one or more specific herds of another herd type, but all herds within a herd type have the same probability of coming into contact. This is a simplification of reality and needs attention in further development of the model. Diekmann et al. (1996) introduced a contact structure, which is characterized by the following two properties: (1) each individual contacts exactly k other individuals and (2) these k acquaintances are a random sample of the population. These properties were already used in our model to calculate the reproduction ratio R between herds (R_{herd}), but not in the simulation part. Moreover, the number of acquaintances was the same for every herd and thus more research is needed for further development and inclusion of this contact structure and to make the number of acquaintances variable.

An option to improve the accuracy of the input parameters on animal contacts and thus of the epidemiological and economic simulation is to include data from the national Identification and Recording (I&R) system for pigs using a central and electronic database, which has been operational in the Netherlands since early 1996. The main objective of that system is to obtain reliable and up-to-date information on movements, possible locations and possible contacts of animals (Saatkamp, 1996).

Validation of the model

Validation is an important, but often ignored step in model building. It is important that a model mirrors the real system sufficiently enough to fulfil the purposes for which it has been developed (Dijkhuizen, 1992). The current model was validated both internally and externally. Internal validation of the model, in particular its equations, was carried out continuously during the development stage. As this project is part of a larger research program about Aujeszky's disease virus, more data became available from experiments (Bouma et al., 1995, 1996; De Jong and Kimman, 1994; De Jong et al., 1995) and field research (Stegeman et al. 1995, 1996 ; Van Nes et al., 1996). In the field the prevalence of gE antibodies in sow herds and the introduction rate of Aujeszky's disease virus for finishing herds are monitored. Especially, the latter measure is a sensitive indicator in the progress of the eradication campaign.

External model validation was performed in two ways. First, a number of sensitivity analyses were carried out to discover which variables and assumptions had a great impact on the results of the model (see Chapter 4). In this way the quantitative insight into the quality of the model and further understanding of the decision problem were enhanced, both through the analyses themselves and through the outcome provided. Second, the available yearly information about area-wide vaccination (programs) was collected for comparison.

Unfortunately, national/regional data on the prevalence of sows and fattening pigs in the Netherlands has only been available since 1994. More information is available, however, from a regional experiment on a vaccination program (about 320 herds in a region of 96 km^2) in southern Netherlands, which has been described by Stegeman et al. (1995, 1996) and Van Nes et al. (1996). In this program breeding pigs were vaccinated at 4-month intervals, replacement pigs received three vaccinations before service, and finishing pigs were vaccinated twice with the strain 783, dissolved in an oil-in-water emulsion. The gE-seroprevalence in breeding pigs decreased from 69% to 33% in 2 years and to less than 10%

in 5 years, while it decreased from 49% to 5% and to about 0% in 2 and 5 years respectively in finishing herds. This reduction in gE-seroprevalence was significantly more pronounced than in herds in which animals were vaccinated with gE-deleted vaccines to prevent clinical effects of Aujeszky's disease virus in an uncontrolled schedule. Despite the fact that these results are at animal level, one may conclude that the rapid decline in prevalence is in agreement with the results of the simulation model in which all herds (breeding, rearing as well as finishing herds) were in prevalence class [≤ 10%] within less than 5 years (see Chapter 3), while 38%, 15% and 47% of the herds were in prevalence classes [≤ 10%], [> 10% and ≤ 50%] and [> 50%] respectively at the beginning of the first year of the eradication program.

THE PRICE EQUILIBRIUM MODEL

To include the possible indirect effects through export restrictions in the economic comparison between various vaccination programs, a price-equilibrium model was developed (Chapter 5). The aim of this model was to estimate the changes in prices after the supply of products is changed or (part of) the export of at least one of the products is banned. The so-called realistic price expectation model (FMDSTRAT) of Berentsen et al. (1992) was used as the basis for simulation. Both models produce the same type of results although FMDSTRAT is primarily focused on potential export bans resulting from a Foot-and-Mouth disease outbreak in cattle and pigs. In the next paragraphs both models are compared.

FMDSTRAT is product oriented, which means that the effects of an export ban are calculated per single product and then summed over all products. This means that no cross effects between products were included in FMDSTRAT. In the parameter estimation of the current model, a significant positive effect of the price of hogs on the domestic demand of piglets was found, which means that a cross effect between fattened pigs/carcasses and piglets exists. This is certainly of importance to be included as shown by the results of the export ban on only piglets to Germany (Chapter 5); the revenues from piglets decreased where the revenues from fattened pigs increased.

Meat and breeding cattle (domestic as well as export) are the products in the calculation of FMDSTRAT whereas piglets, fattened pigs and pigmeat are the most important products in the current model. The elasticities of demand in FMDSTRAT are only determined for the different (export) countries and based on literature and/or experts. The Dutch elasticity of demand in FMDSTRAT is lower than the calculated domestic elasticities of demand for piglets as well as pig carcasses (-0.5 compared with -0.15 and -0.34 for piglets and pig carcasses respectively) in the current model. This means that according to reality the prices will decrease more in the current model when an export ban is imposed.

In FMDSTRAT the elasticities of demand for the Dutch product in the export countries are assumed to be the same as the elasticities of demand for the same product in that country. Comparison of these elasticities with the calculated elasticities in the current model shows that this assumption does not hold. This will definitely have an effect on the distribution of the products before and after an export ban of part of the export markets and therefore also on the economic results.

QUESTIONS FOR FUTURE RESEARCH

Last stage of eradication

An important research question in the final stage of the (Dutch) Aujeszky's disease eradication program is to determine the prevalence at which it is economically preferable to check the total sow population by blood sampling and cull the gE-positive sows. To answer this question the costs of an extra period of vaccination have to be compared with the costs of blood sampling of all the animals at the breeding and rearing herds on the one hand, and the earlier removal of the gE-positive sows on the other.

As an example a farrow-to-finish herd of 150 sows and a production of 3300 fattened pigs per year are assumed. In this herd, sows are vaccinated three times per year and fattening pigs 1.5 times per cycle on average. The yearly costs of vaccination (including the costs of 5 visits of the veterinarian) are Dfl 8817, the prevalence is assumed to be halved each year through vaccination, which is in line with the current Dutch eradication program.

The age structure in the herd and the retention pay offs (RPO) per sow (defined as the additional value of keeping a sow over immediate replacement) were taken from Huirne et al. (1993). The RPO-values indicate the losses when sows are removed prematurely. Furthermore, the gE-positive sows are assumed to be proportionally distributed over all parities, which gives a weighted RPO of Dfl 120. With these assumptions the costs of premature removal in an Aujeszky's disease eradication program were calculated.

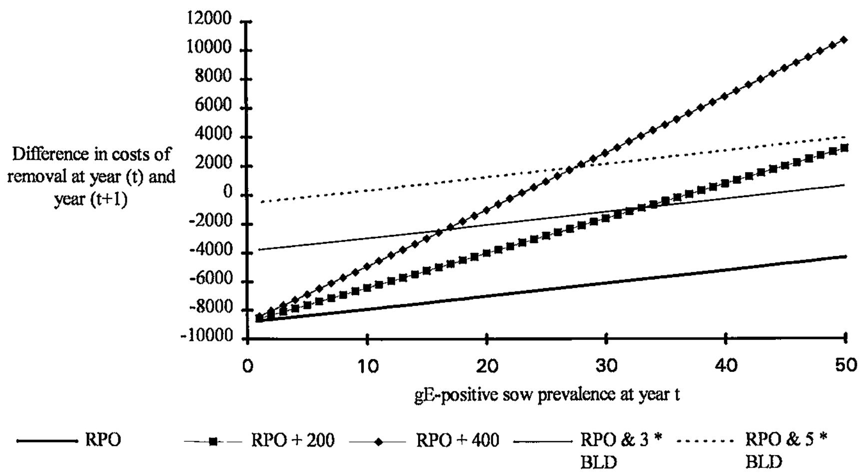

Figure 1. Differences in costs of removal at year (t) and year (t+1) for different prevalences of gE-positive sows

In Figure 1 the differences in cost of removal at time t and the costs of removal one year later (t+1) are shown. It is indicated that in the basic situation (i.e., RPO) it is economically preferred to check and remove all gE-positive sows. However, it is possible that (1) the price of the gE-positive sows at slaughtering decreases because of increased supply, (2) the price of replacement gilts increases because of increase in demand and (3) all animals have to be checked more than once, as new gE-positive or false gE-negative sows may be found after all sows are sampled once. To show the consequences of this, the RPO was increased by Dfl 200 (RPO+200) and Dfl 400 (RPO+400) or all sows were sampled 3 (RPO + 3*BLD) or 5 (RPO + 5*BLD) times more often as in the basic situation. The result of this was that when the herd had a prevalence higher than 36% and 22%, it would economically be preferred to vaccinate for one extra year and sample and remove the gE-positive sows afterwards when the RPO was increased by 200 and 400 respectively. In case of the increase of the number of blood samplings per sow by 3 and 5 times, it is economically preferred to vaccinate for one extra year and sample and remove the gE-positive sows afterwards when the prevalence is higher than 42% and 6% respectively. Not included in the calculations is a difference in risk of outbreaks among the scenarios. This risk may be higher when stopping the vaccination at a higher prevalence of gE-positive animals, and hence could decrease the break-even level for the sample and remove strategy.

The gE-positive sows can also be in only the higher parities and the yearly decrease in prevalence can also be less than half (especially at the lower prevalences). Both possibilities result in an increase of the prevalence at which it is economically preferred to remove the gE-positive sows.

For the current Dutch situation it can be concluded that it is economically preferred to start sampling the sows and remove the gE-positive ones as soon as possible, provided that the additional risk of new introductions of the virus is sufficiently limited. This conclusion is independent of whether or not the costs of vaccinating the fattening pigs are included as the problem might be to persuade the sow farmers to remove their gE-positive sows.

Re-infection after eradication

Another research question arises after the virus is eradicated from the Dutch population. As long as herds in other countries the Dutch producers have contacts with are not free from the virus, Dutch herds still run the risk of getting re-infected. Then the question arises whether Dutch producers have to continue vaccinating for some time or quit vaccination and run the risk of getting re-infected. The decision support system EpiMAN has several tools available to assist in the investigation, surveillance and control of at-risk properties. EpiMAN, which has been developed in New Zealand for the control of Foot-and-Mouth disease outbreaks, consists of a database management system, a geographic information system, simulation models and expert systems and is now being converted to the Dutch situation (Jalvingh et al., 1995). In the future, it can be used in the Netherlands to support the operational management during an outbreak, but also for tactical/strategic management. The support of the operational management focuses on setting the correct priorities for rapid identification and elimination of all virus sources, where series of what-if scenarios to investigate the likely consequences of major control policy options are related with the tactical/strategic management. Both kinds of support require insight into the risk factors involved in the introduction of an infection. Research is under way to quantify these risk factors and their economic consequences.

Randomization of the risk factors involved in the development of the infection (e.g., animal and other contacts) can enhance insight into the importance of these factors and can also provide additional information on variances of outcome parameters. This is especially important when simulating re-infections in a disease-free population (as is also done in EpiMAN). These variances can be calculated per control strategy and compared by calculating, for example, the Expected Monetary Value (EMV) and the cumulative density functions (CDFs) taking into account non-neutral risk attitudes, as was carried out by Dijkhuizen et al. (1994) and Saatkamp et al. (1996) respectively.

Application of the modelling approach to other diseases

The approaches which were applied in simulating Aujeszky's disease virus and in calculating changes in prices can also be used for other infections. IBR in cattle is an example of this and a first version of such a model showed promising results (Vonk Noordegraaf et al., 1996). In this model, herds were subdivided into infection states according to the same criteria as used in the current model. However, as, for example, reactivation seemed to be important in IBR, the simulation model of the virus had to be adapted to the particular characteristics of infection. In the model, herds were subdivided into 3 herd types depending on the number of animal deliveries from outside the herd.

Results in that study showed that other than animal contacts and reactivation have the greatest impact on the number of new introductions, as respectively 42.2% and 44.2% of the new introductions were caused by these factors. Furthermore the yearly number of vaccinations, the direct production losses from IBR and the possible export constraints have a great impact on the preferred vaccination strategy. In the preferred option all animals are vaccinated except those animals in certified negative herds and where no animals from outside are entered. Moreover, declared IBR-free youngstock is excluded from vaccination. This option was adopted by the steering committee that is responsible for the proposed eradication campaign of IBR in The Netherlands, due to start January 1, 1998.

MAIN CONCLUSIONS

- State-transition simulation proves to be an appropriate method to evaluate transmission of Aujeszky's disease virus. The epidemiological information obtained can well be used in economic evaluation of different control strategies.
- Aujeszky's disease is only eradicated in the Netherlands if the most intensive vaccination strategy (≥3 times per year) is applied for breeding sows, and fattening pigs are vaccinated at least once per cycle.
- If applying the most intensive vaccination strategy, it takes about 200 weeks for an average herd to become non-infectious.
- The relative impact of other than animal contacts on the number of new virus introductions increases from 4% to 98%, if the vaccination strategy is changed from "no vaccination" to the most intensive vaccination program.
- Subdivision of the total population into herd types and regions is important to enhance insight into transmission of infection in the pig population and to support decision making at regional level.
- Price equilibrium models can well estimate the short-term changes in prices as well as those in the medium term. To accomplish this, it is of importance that sufficient historical data about quantities, prices and the infections occurred are available to estimate the required parameters accurately. A monthly data-set of about 10 years turned out to be sufficient.
- Direct production losses from Aujeszky's disease virus are less than 6% of the vaccination costs when vaccination is carried out. More than 80% of these losses are caused by growth delay of fattening pigs.
- The most intensive vaccination strategy (i.e., sows are vaccinated 3 or 4 times per year and fattening and rearing pigs twice per cycle) is economically preferred if an export ban on part of the live animals is expected during at least 2 years within 10 years after the start of the vaccination program. If this is not to be expected then "no vaccination" turns out to be the best strategy. The risk of an export ban on live animals should justify the eradication of the virus from the population.

- For the current situation in the Netherlands it is economically preferred to start blood sampling all sows and remove the gE-positive animals instead of continuing vaccination, provided that the additional risk of new introductions of the virus is sufficiently limited.

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SUMMARY

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Aujeszky's disease is a contagious viral disease that affects the central nervous system of pigs. Several eradication programs or measures are available, each of them providing different results. Determining the preferred strategy is to a large extent a matter of economic consideration.

Under the EU rules, countries or regions that are Aujeszky-free can ban imports of breeding animals carrying antibodies of the disease; movements to Aujeszky-free areas from other areas of both breeding and rearing pigs are subject to strict conditions and controls, which differ depending on whether or not the area of origin has an EU-approved eradication program. If important import destinations achieve disease-free status, exporting countries that have failed to eradicate the disease will be severely penalized. Therefore, sterner demands are to be expected considering control and eradication of Aujeszky's disease in the Netherlands in the future. To meet these demands, the objective of this study was to develop a computer simulation environment in which "what-if" scenarios can be performed to explore the epidemiological and economic effects of different Aujeszky's disease control programs. The model can be used to support the choice of the optimal eradication program under various conditions, in particular from an epidemiological and economic point of view.

First, a flexible economic framework to evaluate Aujeszky's disease eradication programs was developed, and illustrated with an example (Chapter 2). The framework has four elements: changes in percentage of infectious herds, changes in product quantities, changes in product prices and economic integration. Each of these elements is defined as a separate module in the simulation model and has its own input and output data, depending on the control strategy under consideration. With these elements all epidemiological and economic aspects of the disease can be monitored over time.

In an illustrative example, probability distributions of the number of infectious herds corresponding to each control strategy were compared and the optimal strategy was chosen, according to the risk attitude of the decision maker. The framework can be considered a standardized approach in comparing and selecting animal health control strategies by integrating technical and economic data and principles.

To obtain epidemiological information with respect to the control of Aujeszky's disease virus, an epidemiological state-transition simulation model was constructed to evaluate the

spread of the virus (Chapter 3). In the model, the population of herds in the Netherlands is subdivided into four herd types: great-grandparent stock+multiplier, rearing, farrowing and fattening. Every time step, each herd is in one of 32 states per herd type. The states are based on (1) the reproduction ratio R_{ind}, which is the number of individuals infected by one infectious individual, (2) the prevalence for each value of R_{ind} and (3) the expected number of infectious animals in an infectious herd within each prevalence range of the herds. The different values of R_{ind} are based as much as possible on field data and experiments, where different vaccination strategies were applied.

The transition matrix with the probabilities of every possible transition from one state to another was calculated on a weekly base. With this matrix the distribution of herds over states from week to week was derived. To include the non-linearity of the transmission process, the transmission probabilities from non-infectious to either non-infectious or infectious were developed such that they depend on the state vector itself. The fraction of herds that becomes infectious equals one minus the fraction of herds that has not been infected by the virus emitted by infectious herds.

Calculations revealed that infection in the Dutch pig population would not disappear without vaccination, nor with a vaccination scheme in which sows were vaccinated less than 3 times per year and fattening pigs once per cycle (Chapter 4). The infection, however, would be eradicated within 2 to 3 years, if sows were vaccinated 3 or 4 times per year and fattening pigs twice per cycle. The outcome turned out to be sensitive to the impact of other than animal contacts on the number of new effective virus introductions per time unit.

The structure of the production pyramid and herd density in the affected regions were other important factors which influenced the course of infection. To examine the impact of these factors the total number of herds in the Netherlands were further subdivided into four regions (North, East, West-Middle, South).

Outcomes showed that the percentage of infectious herds in equilibrium was highest for rearing herds (76.3%) and lowest for great-grandparent stock+multiplier herds (20.0%) if no vaccination was done. The herd type "fattening" had more impact on the effectivity of the different vaccination strategies than the herd type "farrowing". This difference is becoming less if more intensive vaccination strategies are applied. Besides the difference in herd type, also herd density and the percentage of non-vaccinated herds were an important factor in the eradication process.

After simulating these epidemiological characteristics of Aujeszky's disease virus, market outcomes and pig producers' returns were simulated under different scenarios with respect to closure of export markets for live piglets and fattened pigs (Chapter 5). If the Netherlands fails to eradicate Aujeszky's disease before its trading partners in these markets, live piglet exports would be banned, reducing industry revenue and export earnings by about 9% and 10% respectively in the medium term. If exports of live fattened pigs are also banned, the reductions are 26 and 32% respectively. The piglet-producing sector would be more severely affected than the fattening sector. The model also showed that, if export markets for carcasses were also to close for an unspecified food safety reason, capacity of the industry would fall over 50%.

Lastly four control strategies to eradicate Aujeszky's disease virus in the Netherlands were compared epidemiologically and economically (Chapter 6). Vaccination decreased the number of cases per production loss. The decrease was largest if vaccination strategy changed from "no vaccination" to the less intensive vaccination. Extra vaccinations under more intensive vaccination strategies, however, still had impact. The attendant costs were highest per dead animal (especially for gilts) and per abortion. Growth delay of gilts and piglets turned out to be of minor importance.

The sales distribution on the piglet markets (import, export and on the domestic markets) was particularly influenced by vaccination, but the decreases in revenues were only less than 4.3%. The only exception was the number of piglets and live animals that were imported into the Netherlands, which decreased by more than 15% and about 9% respectively. The accompanying revenues from piglets and fattened pigs were highest if "no vaccination" was done. Compared with the revenue in this strategy, this difference is greatest on the piglet market, as the decrease in revenue was about 3.6%, while the decrease was about 0.55% on the market of fattened pigs.

According to the resulting present values over a period of 10 years, "no vaccination" is economically the best solution only if no trade restrictions are to be expected. Economically speaking, however, the most intensive vaccination strategy should be applied, if an export ban of two years on live animals to, for instance, Germany is expected within 10 years after the

start of the vaccination strategy. A prolonged export ban makes this strategy even more favourable. From an economic point of view intermediate vaccination strategies are never preferred.

The main conclusions of this thesis are:

- State-transition simulation proves to be an appropriate method to evaluate transmission of Aujeszky's disease virus. The epidemiological information obtained can well be used in economic evaluation of different control strategies.
- Aujeszky's disease is only eradicated in the Netherlands if the most intensive vaccination strategy (≥3 times per year) is applied for breeding sows, and fattening pigs are vaccinated at least once per cycle.
- If applying the most intensive vaccination strategy, it takes about 200 weeks for an average herd to become non-infectious.
- The relative impact of other than animal contacts on the number of new virus introductions increases from 4% to 98%, if the vaccination strategy is changed from "no vaccination" to the most intensive vaccination program.
- Subdivision of the total population into herd types and regions is important to enhance insight into transmission of infection in the pig population and to support decision making at regional level.
- Price equilibrium models can well estimate the short-term changes in prices as well as those in the medium term. To accomplish this, it is of importance that sufficient historical data about quantities, prices and the infections occurred are available to estimate the required parameters accurately. A monthly data-set of about 10 years turned out to be sufficient.
- Direct production losses from Aujeszky's disease virus are less than 6% of the vaccination costs when vaccination is carried out. More than 80% of these losses are caused by growth delay of fattening pigs.

- The most intensive vaccination strategy (i.e., sows are vaccinated 3 or 4 times per year and fattening and rearing pigs twice per cycle) is economically preferred if an export ban on part of the live animals is expected during at least 2 years within 10 years after the start of the vaccination program. If this is not to be expected then "no vaccination" turns out to be the best strategy. The risk of an export ban on live animals should justify the eradication of the virus from the population.
- For the current situation in the Netherlands it is economically preferred to start blood sampling all sows and remove the gE-positive animals instead of continuing vaccination, provided that the additional risk of new introductions of the virus is sufficiently limited.

SAMENVATTING

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De ziekte van Aujeszky is een besmettelijke virale ziekte die het centrale zenuwstelsel van varkens aantast. Verscheidene uitroeiingsprogramma's zijn beschikbaar, die elk andere epidemiologische en economische resultaten opleveren. In het bepalen van de beste strategie speelt de economische uitkomst een belangrijke rol.

Onder EU regels kunnen landen of regio's die Aujeszky-vrij zijn importen van fokmateriaal, die antigenen van de ziekte bij zich dragen, verbieden. Vervoer van (op-) fokmateriaal van Aujeszky-vrije gebieden naar andere gebieden gebeurt onder strikte condities en regels die afhangen van het al dan niet beschikken van een EU-goedgekeurd bestrijdingsprogramma van het land van herkomst. Wanneer belangrijke importbestemmingen de Aujeszky-vrij status bereiken worden exportlanden, waar de ziekte nog heerst, hard gestraft. Vandaar dat in de toekomst meer beperkende maatregelen worden verwacht indien de ziekte van Aujeszky in Nederland niet zou worden uitgeroeid. Om hierop te kunnen anticiperen is in het kader van de doelstelling van dit onderzoek een computersimulatiemodel ontwikkeld waarmee "wat-als" scenario's kunnen worden uitgevoerd om de epidemiologische en economische effecten van verschillende uitroeiingsprogramma's voor de ziekte van Aujeszky te bepalen en te vergelijken. Hiermee kan de keuze van het epidemiologisch en economische optimale uitroeiingsprogramma worden ondersteund onder variërende omstandigheden.

Allereerst is een flexibel economisch raamwerk ontwikkeld waarmee uitroeiingsprogramma's voor de ziekte van Aujeszky kunnen worden geëvalueerd. Dit raamwerk is geïllustreerd met een voorbeeld (Hoofdstuk 2). Het raamwerk bestaat uit vier onderdelen: veranderingen in het percentage infectieuze bedrijven, veranderingen in de produkthoeveelheden, veranderingen in produktprijzen en de economische integratie. Elk onderdeel is specifiek gedefinieerd en heeft zijn eigen in- en outputgegevens, welke afhangen van de betreffende controlestrategie. Met deze elementen kan de ziekte in de tijd worden gevolgd.

In een illustratief voorbeeld worden verdelingen van het aantal infectieuze bedrijven, behorende bij elke controlestrategie, vergeleken en de optimale strategie wordt gekozen al naar gelang de risico-attitude van de beleidsmaker. Het raamwerk kan worden beschouwd als een gestandaardiseerde aanpak voor het vergelijken en selecteren van controlestrategieën in de diergezondheid via het integreren van technische en economische principes en gegevens.

Op basis van de epidemiologische simulatie van de ziekte van Aujeszky is aanvullend een simulatiemodel ontwikkeld en uitgewerkt (Hoofdstuk 3). In dit model is de bedrijfspopulatie opgesplitst in vier bedrijfstypen: kern-+subfok-, opfok-, vermeerderings- en vleesvarkenshouderijbedrijven. Per bedrijfstype is elk bedrijf in één van de 32 statussen ingedeeld. Deze statussen zijn gebaseerd op (1) de reproduktie ratio R_{ind} welk gedefinieerd is als het aantal varkens dat binnen een bedrijf door één infectieus varken worden geïnfecteerd, (2) de prevalentieklasse per waarde van R_{ind} en (3) het verwachte aantal infectieuze dieren op een infectieus bedrijf binnen elke prevalentieklasse. De verschillende waarden van R_{ind} zijn zoveel mogelijk gebaseerd op experimenten en praktijkdata waarin de verschillende vaccinatiestrategieën werden gebruikt.

De transitiematrix met de overgangskansen van één status naar een andere wordt op weekbasis berekend. Met deze matrix wordt de verdeling van bedrijven over de statussen verkregen. Om de non-lineariteit van het transmissieproces te simuleren, hangen de overgangskansen van niet-infectieus naar ofwel niet-infectieus dan wel infectieus af van de vector waarmee de verdeling over de statussen wordt weergegeven. De fractie bedrijven dat infectieus wordt is gelijk aan één min de fractie bedrijven dat niet geïnfecteerd raakt door het virus.

Berekeningen tonen aan dat de infectie zonder vaccinatie niet uit de Nederlandse varkenspopulatie verdwijnt, ook niet bij een vaccinatieschema waarin zeugen minder dan 3 keer per jaar werden gevaccineerd en vleesvarkens 1 keer per cyclus (Hoofdstuk 4). De infectie wordt echter binnen 2 of 3 jaar uitgeroeid wanneer zeugen 3 of meer keren worden gevaccineerd en vleesvarkens 2 keer per cyclus. De resultaten bleken gevoelig voor de omvang van andere dan diercontacten en het aantal nieuwe effectieve introducties van virus per tijdseenheid.

De structuur van de produktiepiramide en de bedrijfsdichtheid in de betrokken regio's zijn andere belangrijke factoren die de ontwikkeling van de ziekte beïnvloeden. Om de omvang hiervan te onderzoeken is het totaal aantal bedrijven niet alleen opgesplitst in bedrijfstypen maar ook in regio's (Noord, Oost, West-Midden, Zuid).

De resultaten geven aan dat het percentage infectieuze bedrijven in de evenwichtssituatie van het simulatiemodel het hoogst is bij opfokbedrijven (76.3%) en het laagst bij kern-+subfokbedrijven (20.0%) wanneer geen vaccinatie heeft plaatsgevonden. Het bedrijfstype "vleesvarkenshouderij" heeft meer effect op de effectiviteit van de vaccinatiestrategieën dan vermeerderingsbedrijven. Dit verschil wordt kleiner naarmate intensievere vaccinatiestrategieën worden gebruikt. Naast het verschil in bedrijfstype en bedrijfsdichtheid speelt het percentage niet-vaccinerende bedrijven ook een belangrijke rol in het uitroeiingsproces.

Nadat de epidemiologische informatie was verkregen, werden marktresultaten en produktieopbrengsten gesimuleerd bij verschillende scenario's aangaande het sluiten van exportmarkten van biggen en vleesvarkens (Hoofdstuk 5). Indien Nederland niet eerder de ziekte van Aujeszky uitroeit dan haar handelspartners, zullen de industrie en exportopbrengsten op de middellange termijn met respectievelijk 9% en 10% kunnen dalen door een exportverbod van biggen. Wanneer de export van vleesvarkens ook verboden wordt, zijn deze dalingen respectievelijk 26 en 32%. De zeugenhouders zullen hierbij zwaarder worden getroffen dan de vleesvarkenshouders. Het model geeft aan dat de capaciteit van de varkensindustrie met meer dan 50% zal dalen wanneer de exportmarkten van varkenskarkassen ook zouden sluiten.

Tenslotte zijn vier controlestrategieën om het virus van de ziekte van Aujeszky uit Nederland te verwijderen, epidemiologisch en economisch vergeleken (Hoofdstuk 6). Vaccinatie verlaagt de produktieverliezen. Deze verlaging is het grootst bij de overgang van niet vaccineren naar de minst intensieve vaccinatiestrategie, maar de extra vaccinaties in de intensievere vaccinatiestrategieën zijn nog steeds van invloed. De bijbehorende kosten zijn het hoogst per gestorven dier (met name voor opfokzeugen) en per abortus. Groeivertraging van opfokzeugen en biggen zijn minder van belang.

Met name de omzetverdeling op de biggenmarkt (import, export en op de binnenlandse markt) wordt beïnvloed door vaccinatie terwijl de verlagingen in opbrengsten minder dan 4.3% zijn behalve voor het aantal geïmporteerde biggen en levende dieren dat met respectievelijk meer dan 15% en 9% afnam. De bijbehorende totale opbrengsten voor biggen en vleesvarkens is het hoogst wanneer geen vaccinatie wordt toegepast. Vergeleken met de opbrengsten in deze strategie is het verschil het hoogst in de biggenmarkt waar de verlaging ongeveer 3.6% is, terwijl deze ongeveer 0.55% is in de vleesvarkensmarkt.

Volgens de berekende contante netto opbrengsten over een periode van 10 jaar, is niet vaccineren economisch gezien de beste oplossing wanneer geen exportbelemmeringen worden verwacht. Echter, aan de meest intensieve vaccinatiestrategie wordt economisch gezien de voorkeur gegevens wanneer binnen een periode van 10 jaar na aanvang van de vaccinatiestrategie een exportverbod van levende dieren van tenminste twee jaar naar bijvoorbeeld Duitsland wordt verwacht. Een verlenging van de duur van de vaccinatiestrategie versterkt alleen de keuze van deze strategie. Tussenliggende vaccinatiestrategieën dienen economisch gezien nooit gekozen te worden.

De belangrijkste conclusies van dit proefschrift zijn:

- Computersimulatie is een geschikte methode om de transmissie van het virus van de ziekte van Aujeszky te bestuderen. De verkregen epidemiologische informatie kan goed worden gebruikt in de economische evaluatie van de verschillende vaccinatestrategieën.
- De ziekte van Aujeszky wordt alleen uitgeroeid wanneer de meest intensieve vaccinatiestrategie (≥3 keer per jaar) is toegepast bij fokzeugen, en vleesvarkens tenminste 1 keer per cyclus worden gevaccineerd.
- Wanneer de meest intensieve vaccinatiestrategie wordt toegepast duurt het voor een gemiddeld bedrijf ongeveer 200 weken om in zijn geheel niet infectieus te worden.
- De relatieve invloed van andere dan diercontacten op het aantal nieuwe virus introducties stijgt van 4% tot 98% wanneer wordt overgegaan van geen vaccinatie naar het meest intensieve vaccinatieprogramma.
- Opsplitsing van de totale populatie in bedrijfstypen en regio's is van belang bij de vergroting van het inzicht in de transmissie van het virus door de varkenspopulatie en om het beleid op regionaal niveau te ondersteunen.

- Prijsevenwichtmodellen kunnen zowel de veranderingen in prijzen op korte termijn als op de middellange termijn goed schatten. Wel is het hiervoor belangrijk dat voldoende historische data over hoeveelheden, prijzen en de voorgekomen ziektes aanwezig zijn om de benodigde parameters nauwkeurig te kunnen schatten. Een maandelijkse data set van een periode van ongeveer 10 jaar bleek voldoende.
- Directe produktieverliezen door de ziekte van Aujeszky zijn minder dan 6% van de vaccinatiekosten wanneer er wordt gevaccineerd. Meer dan 80% van deze verliezen wordt veroorzaakt door groeivertraging van vleesvarkens.
- De meest intensieve vaccinatiestrategie waarin zeugen 3 of 4 keer per jaar worden gevaccineerd en opfok- en vleesvarkens 2 keer per cyclus heeft economisch gezien de voorkeur wanneer een exportbod van levende dieren van tenminste 2 jaar wordt verwacht binnen 10 jaar nadat met het vaccinatieprogramma is gestart. Wanneer dit niet het geval is heeft niet vaccineren economisch gezien de voorkeur. Dus het risico van een exportverbod van levende dieren is economisch gezien de belangrijkste reden om het virus via vaccinatie uit de Nederlandse populatie uit te roeien.
- Voor de huidige Nederlandse situatie is het economisch gezien beter om met bloedonderzoek te starten en alle gE-positieve dieren af te voeren in plaats van door te gaan met vaccineren, althans indien het extra risico van introductie van het virus voldoende beperkt blijft.

ZUSAMMENFASSUNG

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Die Krankheit von Aujeszky ist eine ansteckende Viruskrankheit, die das zentrale Nervensystem von Schweinen angreift. Verschiedene Ausrottungsprogramme stehen zur Verfügung, von denen jedes andere epidemiologische und wirtschaftliche Ergebnisse liefert. Bei der Bestimmung der besten Strategie spielt das wirtschaftliche Ergebnis eine wichtige Rolle.

Durch EU-Vorschriften können Länder oder Regionen, die Aujeszky-frei sind, Importe von Zuchttieren, die Antigene der Krankheit in sich tragen, verbieten. Transport von (Auf-) zuchttieren von Aujeszky-freien Gebieten in andere Gebiete erfolgt unter strikten Konditionen und Vorschriften, die von einem wohl oder nicht vorhandenen EU-genehmigten Bekämpfungsprogramm des Herkunftslandes abhängen. Wenn wichtige Importbestimmungen den Aujeszky-freien Status erreichen, werden Exportländer, in denen die Krankheit noch vorherrscht, hart bestraft. Dies ist der Grund dafür, daß in Zukunft mehr beschränkende Maßnahmen zu erwarten sind, falls die Krankheit von Aujeszky in den Niederlanden nicht ausgerottet werden sollte. Um dies genauer antizipieren zu können, wurde im Rahmen der Zielsetzung dieser Untersuchung ein Computersimulationsmodell entwickelt, mit dem "was-wenn" Szenarien ausgeführt werden können, um die epidemiologischen und wirtschaftlichen Effekte unterschiedlicher Ausrottungsprogramme für die Krankheit von Aujeszky zu bestimmen und zu vergleichen. Hiermit kann die Wahl des epidemiologisch und wirtschaftlich optimalen Ausrottungsprogramms unter variierenden Umständen gestützt werden.

Zuerst wurde ein flexibles wirtschaftliches Rahmenwerk entwickelt, mit dem das Ausrottungsprogramm für die Krankheit von Aujeszky bewertet werden kann. Dieses Rahmenwerk wird anhand eines Beispiels illustriert (Kapitel 1). Das Rahmenwerk besteht aus vier Unterteilen: Veränderungen im Prozentsatz infektiöser Betriebe, Veränderungen in den Produktionsmengen, Veränderungen in Produktpreisen und der wirtschaftlichen Integration. Jedes Unterteil ist speziell definiert und hat seine eigenen In- und Outputdaten, die von der entsprechenden Kontrollstrategie abhängen. Mit diesen Elementen kann die Krankheit in der Zeit verfolgt werden.

In einem illustrierten Beispiel werden Verteilungen der Anzahl infektiöser Betriebe, jeder Kontrollstrategie zugeordnet, verglichen und die optimale Strategie wird je nach Risiko-Einstellung der Führungskraft gewählt. Das Rahmenwerk kann als ein standardisiertes Vorgehen für das Vergleichen und Selektieren von Kontrollstrategien in der Tiergesundheit durch die

Integration von technischen und wirtschaftlichen Grundsätzen und Daten betrachtet werden.

Auf der Grundlage der epidemiologischen Simulation der Krankheit von Aujeszky wurde ergänzend ein Simulationsmodell entwickelt und ausgearbeitet (Kapitel 3). In diesem Modell wurde die Betriebspopulation in vier Betriebstypen unterteilt: Kern- + Unterzucht-, Aufzucht-, Vermehrungs- und Mastschweinebetriebe. Pro Betriebstyp wurde jeder Betrieb in einen der 32 Statusse eingeteilt. Diese Statusse basieren auf (1) der Reproduktion ratio R_{ind}, die als die Anzahl Schweine definiert ist, die innerhalb eines Betriebs durch ein infiziertes Schwein angesteckt werden, (2) die Prävalentionsklasse pro Wert von R_{ind} und (3) die zu erwartende Anzahl infizierter Tiere auf einem infektiösen Betrieb innerhalb jeder Prävalentionsklasse. Die verschiedenen Werte von R_{ind} basieren soviel wie möglich auf Experimenten und Praxisdaten, bei denen die unterschiedlichen Impfstrategien angewandt wurden.

Die Transitionsmatrix mit den Übergangschanchen von einem Status zu einem anderen wird auf Wochenbasis berechnet. Mit dieser Matrix findet man die Verteilung von Betrieben über die Statusse heraus. Um die nicht-Linearität des Transmissionsprozesses zu simulieren, hängen die Übergangschancen von nicht-infiziert nach entweder nicht-infiziert oder infiziert vom Vektor ab, mit dem die Verteilung über die Statusse wiedergegeben wird. Die Fraktion Betriebe, die infektiös werden, ist gleich einem Minus der Fraktionen der Betriebe, die nicht mit dem Virus infiziert werden.

Berechnungen zeigen, daß die Infektion ohne Impfung nicht aus der niederländischen Schweinepopulation verschwindet, auch nicht bei einem Impfschema, in dem Sauen weniger als 3 mal pro Jahr und Mastschweine 1 mal pro Zyklus geimpft werden (Kapitel 4). Die Infektion wird jedoch innerhalb von 2 oder 3 Jahren ausgerottet, wenn Sauen 3 oder mehrere Male und Mastschweine 2 mal pro Zyklus geimpft werden. Die Ergebnisse schienen für den Umfang von anderen als Tierkontakten und die Anzahl neuer effektiver Viruseinschleppungen pro Zeiteinheit empfindlich zu sein.

Die Struktur der Produktionspyramide und der Betriebsdichte in den betroffenen Regionen sind andere wichtige Faktoren, die die Entwicklung der Krankheit beeinflussen. Um den Umfang zu erforschen, wurde die Gesamtanzahl Betriebe nicht nur in Betriebstypen, sondern auch in Regionen (Nord, Ost, West-Mitte, Süd) unterteilt.

Die Ergebnisse zeigen, daß der Prozentsatz infektiöser Betriebe in der Gleichgewichtssituation des Simulationsprozesses bei Aufzuchtbetrieben am höchsten (76.3%) und bei Kern- + Unterzuchtbetrieben am niedrigsten (20.0%) ist, wenn keine Impfung stattgefunden hat. Der Betriebstyp "Mastschweinehaltung" hat größere Auswirkung auf die Effektivität der Impfstrategien als Vermehrungsbetriebe. Dieser Unterschied wird je nach Anwendung intensiverer Impfstrategien geringer. Neben dem Unterschied nach Betriebstyp und Betriebsdichte spielt der Prozentsatz nicht-impfender Betriebe auch eine wichtige Rolle im Ausrottungsprozeß.

Nach Erhalt der epidemiologischen Informationen wurden Marktergebnisse und Produktionserträge hinsichtlich der Schließung von Exportmärkten für Ferkel und Mastschweine bei verschiedenen Szenarien simuliert (Kapitel 5). Wenn die Niederlande die Krankheit von Aujeszky nicht eher als ihre Handelspartner ausrottet, könnten die Industrie- und Exporterträge mittelfristig um respektive 9% und 10% sinken von einem Ferkelexportverbot . Wenn auch der Export von Mastschweinen verboten wird, sind Rückgänge von respektive 26% und 32% zu verzeichnen. Die Sauenhalter werden hierbei schwerer getroffen als die Mastschweinehalter. Das Modell gibt auch an, daß die Kapazität der Schweineindustrie um mehr als 50% sinken wird, wenn die Exportmärkte für Schweinekarkassen auch schließen würden.

Zum Schluß wurden vier Kontrollstrategien zur Entfernung der Viruskrankheit von Aujeszky aus den Niederlanden epidemiologisch und wirtschaftlich verglichen (Kapitel 6). Impfung verringert die Produktionsverluste. Diese Verringerung ist am größten beim Übergang von nicht impfen zur am wenigsten intensiven Impfstrategie, aber die Zusatzimpfungen in den intensiveren Impfstrategien haben noch immer Einfluß. Die dementsprechenden Kosten sind pro gestorbenem Tier (besonders bei Zuchtsauen) und pro Abort am höchsten. Wachstumsverzögerung bei Zuchtsauen und Ferkeln sind weniger bedeutend.

Besonders die Umsatzverteilung auf dem Ferkelmarkt (Import, Export und auf dem Heimmarkt) wird durch Impfung beeinflußt, während der Ertragsrückgang weniger als 4.3% betrug, außer für die Anzahl importierter Ferkel und lebender Tiere, die respektive um mehr als 15% und 9% abnahm. Die dazugehörenden Gesamterträge für Ferkel und Mastschweine sind am höchsten, wenn keine Impfung erfolgt. Verglichen mit den Erträgen in dieser Strategie ist der Unterschied im Ferkelmarkt am größten, wo der Rückgang etwa 3.6%

beträgt, während dies im Mastschweinemarkt etwa 0.55% ist.

Gemäß den berechneten Bar-Nettoerträgen über einen Zeitraum von 10 Jahren, ist nicht impfen wirtschaftlich gesehen die beste Lösung, wenn keine Exportbehinderungen zu erwarten sind. Demgegenüber wird die intensivste Impfstrategie wirtschaftlich gesehen bevorzugt, wenn innerhalb eines Zeitraums von 10 Jahren nach Beginn der Impfstrategie ein Exportverbot für lebende Tiere von mindestens zwei Jahren beispielsweise nach Deutschland zu erwarten ist. Eine Verlängerung der Dauer der Impfstrategie verstärkt nur die Wahl dieser Strategie. Dazwischenliegende Impfstrategien sollten wirtschaftlich gesehen niemals gewählt werden.

Die wichtigsten Schlußfolgerungen dieser Doktorarbeit sind:

- Computersimulation ist eine geeignete Methode, um die Transmission des Virus der Krankheit von Aujeszky zu studieren. Die gewonnenen epidemiologischen Informationen können zur wirtschaftlichen Bewertung der unterschiedlichen Impfstrategien verwendet werden.
- Die Krankheit von Aujeszky wird nur ausgerottet, wenn die intensivste Impfstrategie (≥ 3 mal pro Jahr) bei Zuchtsauen angewandt wird, und Mastschweine mindestens 1 mal pro Zyklus geimpft werden.
- Wenn die intensivste Impfstrategie angewandt wird, dauert es bei einem mittelständischen Betrieb etwa 200 Wochen, in seiner Gesamtheit nicht infiziert zu werden.
- Der relative Einfluß anderer als Tierkontakte auf die Anzahl neuer Viruseinschleppungen steigt von 4% auf 98%, wenn man von nicht impfen auf das intensivste Impfprogramm übergeht.
- Unterteilung der Gesamtpopulation in Betriebstypen und Regionen ist wichtig für einen besseren Einblick in die Transmission des Virus durch die Schweinepopulation und zur Unterstützung der Politik auf regionalem Niveau.

- Preisgleichgewichtsmodelle können die Preisveränderungen sowohl kurzfristig als auch mittelfristig gut schätzen. Es ist hierfür jedoch wichtig, daß genügend historische Angaben über Mengen, Preise und bereits vorgekommene Krankheiten vorliegen, um die benötigten Parameter genau schätzen zu können. Ein monatlicher Datensatz von etwa 10 Jahren schien ausreichend zu sein.
- Direkte Produktionsverluste durch die Krankheit von Aujeszky sind weniger als 6% der Impfkosten, wenn geimpft wird. Über 80% der Verluste werden durch Wachstumsverzögerung der Mastschweine verursacht.
- Die intensivste Impfstrategie, bei der Sauen 3 oder 4 mal pro Jahr und Zucht- und Mastschweine 2 mal pro Zyklus geimpft werden, hat wirtschaftlich gesehen den Vorzug, wenn ein Exportverbot von lebenden Tieren von mindestens 2 Jahren innerhalb von 10 Jahren nach Beginn des Impfprogramms zu erwarten ist. Falls dies nicht der Fall ist, hat nicht impfen wirtschaftlich gesehen den Vorzug. Somit ist das Risiko eines Exportverbots von lebenden Tieren wirtschaftlich gesehen der wichtigste Grund, um den Virus durch Impfung der niederländischen Population auszurotten.
- Für die heutige Situation in den Niederlanden ist es wirtschaftlich gesehen besser, mit Blutuntersuchung zu beginnen und alle gE-positiven Tiere abzuführen anstatt mit Impfung fortzufahren, jedenfalls solange das zusätzliche Risiko von Einschleppung eines Virus genügend begrenzt bleibt.

CURRICULUM VITAE

Johannes Antonius Adrianus Maria (Toin) Buijtels werd op 31 mei 1967 geboren in Eindhoven. In juni 1985 behaalde hij aan het Hertog-Jan College te Valkenswaard het VWO diploma. In september 1985 begon hij met een studie Veefokkerij aan de toenmalige Landbouw Hogeschool (later: Landbouwuniversiteit, LUW) te Wageningen. In maart 1991 werd deze studie afgerond met als afstudeervakken veefokkerij, veehouderij en agrarische bedrijfseconomie en twee onderzoeksstages in respectievelijk Guelph, Canada en Armidale, Australië.

Na zijn afstuderen startte hij onmiddellijk als assistent in opleiding bij het toenmalige Instituut voor Veeteeltkundig Onderzoek "Schoonoord" (IVO-DLO) te Zeist. Echter na drie maanden stapte hij over naar de vakgroep Agrarische Bedrijfseconomie. Vanaf 1 juni 1995 werkte hij deels als gastmedewerker en deels als toegevoegd onderzoeker aan de afronding van zijn proefschrift en aan het in praktijk brengen van het rekenmodel voor de ziekte van Aujeszky.

Vanaf 1 september 1996 is de auteur werkzaam als "spezialist schweinehaltung" bij Hendrix Deutschland GmbH te Goch.