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Modelling the economics of risky decision making in highly contagious disease control

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Objectives

From this chapter the reader should gain knowledge of:

- the basic theory of demand and supply
- the concept of producer and consumer surplus
- the economic principles of quantifying the indirect losses due to export bans in case of contagious animal diseases

The approach is illustrated for foot-and-mouth disease outbreaks.

12.1 Introduction

In Chapter 2 on 'economic decision making in animal health management' it was shown that a producer's optimal level of output is determined by input prices, efficiency of the inputs used and output prices. Given sufficient data concerning a firm's production, it is possible to construct the production functions, and from those the average and marginal physical products. If also the output prices are known, the total, average and marginal return functions can be determined. These functions permit the location of the optimal (profit maximization) level of production for an individual firm.

Going beyond this, it is of interest to see how the input and output prices faced by the producer are determined. In market economies these are a result of demand and supply. **Demand** is the relationship between the market price of a good or service and the quantity people are willing and able to buy. **Supply** is the relationship between the market price and the quantity producers are able and willing to sell. The study of demand and supply, and the way they interact, forms a fundamental part of economics (Hill, 1980).

In this chapter, the development and interactions of demand and supply are examined. Special attention is focused on determining the losses due to market disruptions because of export bans. The basic underlying principles of these losses are presented and discussed, and illustrated for foot-and-mouth disease (FMD) outbreaks in the Netherlands (Berentsen *et al.*, 1990).

12.2 Demand and supply - the price mechanism in a market economy

It is common practice, and an invaluable aid to comprehension, to express demand and supply schedules in graphical form, with prices on the vertical axis and quantity on the other (see Figure 12.1). Such a graph is often called the scissors graph because of its shape; most demand curves slope downwards from left to right - more of the commodity is demanded as price falls - whereas supply curves slope upwards from left to right - more is supplied as price rises. Where the two curves cross is the equilibrium price at which the quantities demanded and supplied are in exact balance.

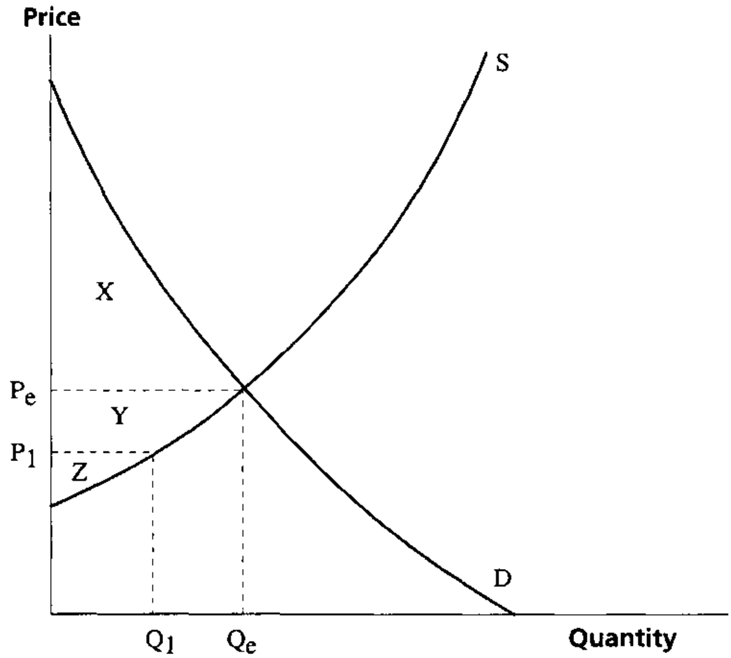

Figure 12.1 Demand (D) and Supply (S) curves

A measure of the responsiveness of the quantity demanded or supplied to changes in the market price of that good is referred to as the **price elasticity** of demand or supply respectively. Specifically, it is the percentage change in quantity divided by the percentage change in price. If the percentage change in price affects a larger percentage change in quantity, the demand or supply curve is called elastic (ie, price sensitive). Inelastic response refers to a smaller percentage change in quantity resulting from a given change in price. Agricultural products are characterized by rather steep (ie, inelastic) demand and supply curves (Hill, 1980). In other words relatively small changes in quantities may have large price effects.

The area between the supply and demand curves to the left of their point of intersection is very important with respect to the indirect losses from disease (Howe & McInerney, 1987).

It provides basic information on the welfare effects for producers, consumers and the society as a whole. For instance, the supply curve tells us that some producers would have been willing to produce in return for prices below P_e. To give an example, in Figure 12.1 the production of Q_1 units of output would have been realized for a price as low as P_1. In practice, all of those units of output which comprise the total of Q_1 sell at price P_e. Because the market determined a unit price of any commodity as a valuation, some farmers actually obtain more value (or benefit) from the sale of their products than they might necessarily have sought or expected. In other words, they obtain a kind of economic surplus. To be precise, this surplus equals P_e-P_1, not for the total production Q_1 but for the marginal unit of output at Q_1. When adding up the surpluses associated with all other units of output between the origin and equilibrium output Q_e, the total economic surplus is given by the area Y+Z in Figure 12.1. This total area measures what, for fairly obvious reasons, is called the **producer surplus**. By analogy, **consumer surplus** is equal to area X. All consumers pay P_e for each unit of the product, but some would be willing to pay more if supply was less abundant. They need not do so in the circumstances described, and so they benefit from getting their product cheaper than otherwise.

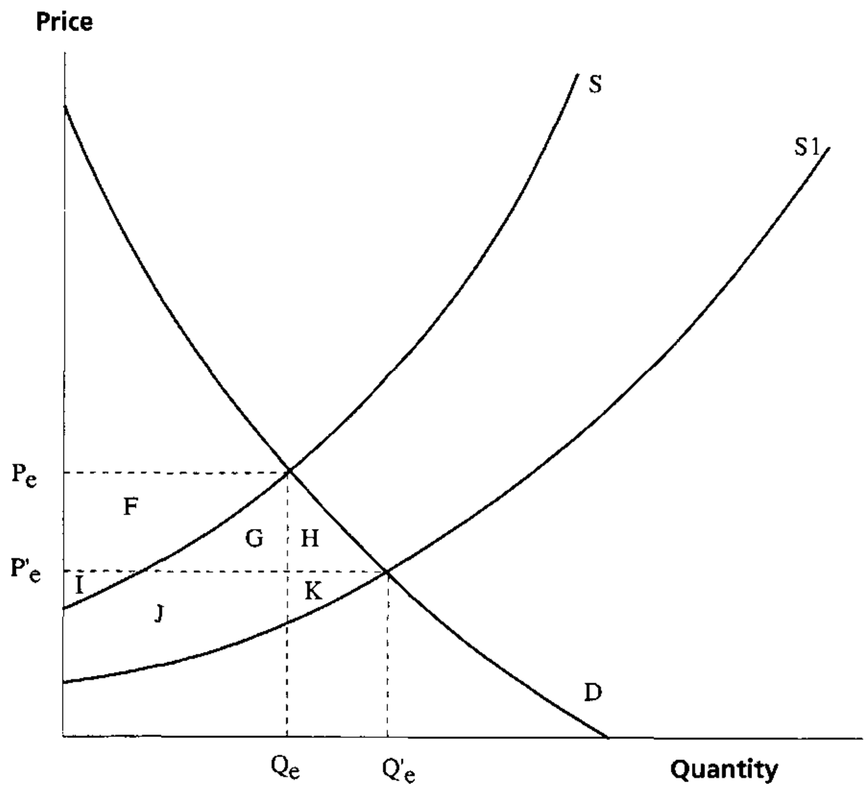

Figure 12.2 The change in consumer and producer surplus after reaching a new market equilibrium

By the same token, effective control of animal disease increases the (long-term) productivity of resources in the affected population. The outcome is to shift the supply curve for livestock products to the right, ie, farmers are able to produce more at whatever is the current price. This is illustrated in Figure 12.2
The welfare consequences of the change in Figure 12.2 can be summarized as follows:

	Gain	Loss	Net
Producers	I+J+K	F+I	J+K-F
Consumers	F+G+H	—	F+G+H
Society	(I+J+K+F+G+H)	(F+I)	(J+K+G+H)

Notice that it is not only possible to identify the net effects on producers and consumers respectively, but that it is also possible to summarize the consequences for a society as a whole, ie, for people irrespective of whether they are producers, consumers or both. Within the theory of welfare economics, however, there is a discussion about the aggregation of benefits and costs at the national level (Just *et al.*, 1982). Simple aggregation of these effects presumes an equal weight of benefits and costs for each group and individual, which is usually not the case. From an investigation of EU dairy policy over the years 1980 to 1987, for instance, it emerged that one dollar of producer income was considered twice the weight of one dollar of consumer income (Oskam, 1988). It is, therefore, recommendable to report both the separate effects for producers and consumers, and their equally-weighed total, leaving policymakers the opportunity to include their own weights.

12.3 Determining the indirect effects due to export bans

Outbreaks of contagious animal diseases are understandably feared, especially in major exporting countries such as the Netherlands. Control of this type of disease goes beyond the influence of the individual farmer, and needs to be carried out at national or even international level. To make economically sound decisions on this type of control, an integrated approach is required that includes the effects of different conditions and scenarios considering (1) the spread of the disease, (2) the direct cost of prevention and eradication, and (3) the indirect effects due to export bans. Research publications in this field are sparse and hardly go beyond the first two stages. Therefore, research was started to develop a method for quantifying and including the indirect losses owing to export bans (Berentsen *et al.*, 1990).
The basic principle for determining the indirect effects due to export bans is illustrated in Figure 12.3. This figure shows the supply curve (S) and the demand curve (D) for a country, exporting a certain product. At the basic price level P, producers supply amount Q_s, while consumers demand amount Q_d, with the difference (Q_s-Q_d) being exported. When export bans are in effect, a new equilibrium will arise at a lower price level, influencing the welfare of both producers and consumers.

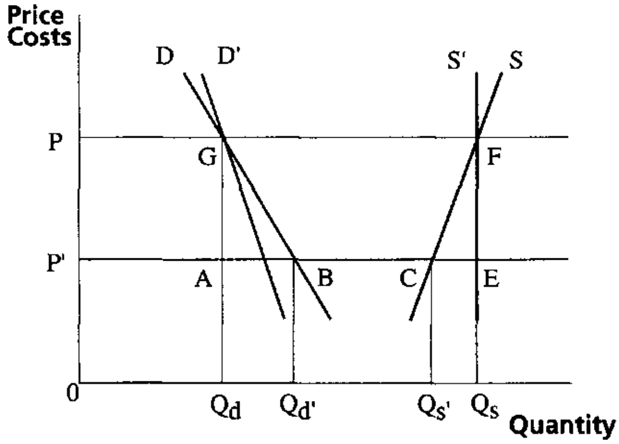

Figure 12.3 The market situation for a country, exporting a product

Assuming producers strive after maximum profits on competitive markets, the supply curve (S) is the same as the rising part of the marginal cost curve, the curve of which was indicated in Chapter 2. The producer surplus is formed by the gross returns (quantity times price) minus the variable costs (the area under the supply curve). This surplus can be considered the net return to fixed inputs. Consequently, the losses to the producers due to a drop in price from P to P' is the reduction in producer surplus (area PFCP'). In the short term, a large part of the costs is fixed and the supply curve will be steep. With disease outbreaks that do not last long, therefore, the vertical supply curve (S') can be used to quantify the losses in producers income. Actual losses to the producers are reduced by any compensation paid by the government. Consumers gain from a drop in price, indicated by the increase in consumer surplus (area PGBP'). From the alternative demand curve (D') it can be concluded that the slope of the curve (ie, the price elasticity of demand) influences the increase in consumer surplus.

12.4 Foot-and-mouth disease outbreaks as an example

12.4.1 Framework of the modelling approach

The economic feasibility of continued preventive vaccination is a regular topic for discussion in many countries still vaccinating. The discussion within the EU concerning this subject led to the decision to stop annual vaccination in all member countries, taking effect from 1 January 1992. In preparing this decision, research was carried out for the Netherlands to develop a dynamic modelling approach, integrating the epidemiological and economic aspects. First, a Markov chain model was designed in which the spread of the disease can be simulated for different control strategies, in a population with and without preventive vaccination. From the spread of the disease and the control strategy applied, the direct economic effects were calculated. Subsequently, this approach was further extended by modelling the indirect effects of potential export bans, resulting in a user-friendly computer model which makes it easy to determine the impact of uncertain epidemiological and economic input values (Berentsen *et al.*, 1990).

In Figure 12.4 a flow chart is presented of the entire modelling approach, including three submodels (the epidemiological model, the disease control model and the export model) and an integrating part. For each of the strategies under consideration the annual costs of following a specific strategy are calculated using the three models and the integrating part.

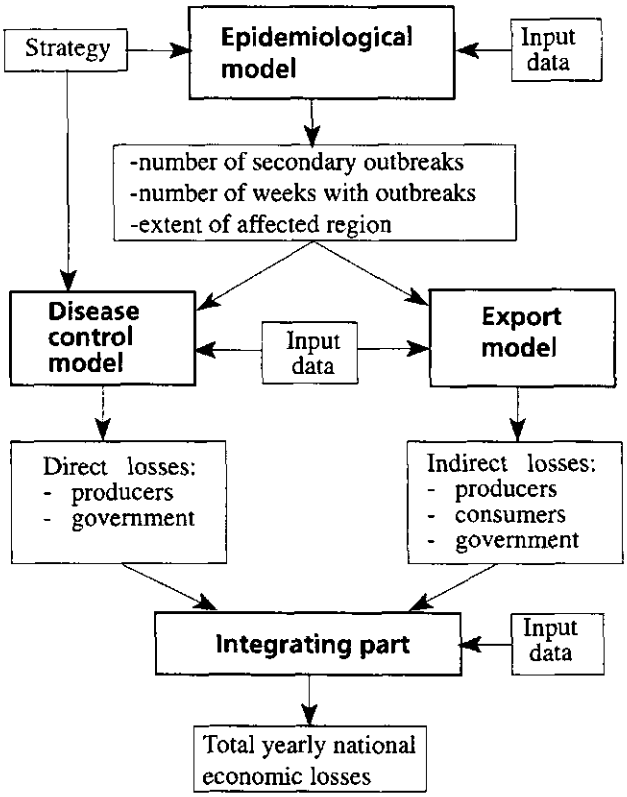

Figure 12.4 An overview of the FMD-modelling approach

In the epidemiological model the spread of the disease after a primary outbreak is simulated, taking into account the control strategy under consideration, disease specific input values and demographic data. Relevant output to be used for further - economic - calculations concerns the number of secondary outbreaks that follow a primary outbreak, the number of weeks with outbreaks and the size of the infected area. The disease control model calculates the direct losses to producers and government and asks for additional input data on the costs of ring vaccination, the costs of stamping out and the costs of idle production factors for farmers and industry. The export model calculates the indirect losses to producers, consumers and government and requires a specification of: (a) the products, affected by trade embargoes, (b) the markets to which these products are delivered, and (c) the actual reactions on these markets. Finally, the integrating part is used to quantify the yearly national economic losses from following the specific strategy, combining the direct and indirect financial losses. For these calculations additional input is required on: (1) the expected frequency of primary outbreaks, (2) the costs of yearly routine vaccination, and (3) the price premium for the products under consideration of getting access to FMD-free markets. In the entire modelling approach, about 80 input parameters can be modified.

12.4.2 Assumptions underlying the export model

The export model is product-oriented, ie, the effects of export bans on producer and consumer income and on the government budget are calculated for each product separately (ie, meat and cattle in case of FMD). In calculating these effects, it is necessary to know the market structure for each product. The market structure is described by the number of markets to which the product is exported and by the following characteristics per market: the volume of export, the level of consumption, the price elasticity of demand and the transport costs per unit of product. For the domestic market, also import and price of the product are of importance.

Some countries (such as the USA, Japan and South Korea) do not accept meat from countries with an annual FMD-vaccination scheme. As a result the price for meat paid on this so-called FMD-free market is about 10% higher than on other markets. This is the reason to assume that the market structure will change after ceasing annual vaccination. So, for a correct evaluation of strategies it is necessary to define a market structure per product for both, a situation with and without annual vaccination.

In calculating the indirect effects, it is necessary to know what reactions from importing countries can be expected in case of an FMD outbreak in the Netherlands. Within the EU, countries usually close their borders for meat and cattle from only the infected area until four weeks after the latest outbreak. Some countries outside the EU close their borders for these products from the entire country, until one or two years after the latest outbreak. In simulating the price effects of temporary export bans, the following assumptions are essential: (1) the reaction of producers to temporary changes in prices. Because an FMD outbreak is likely to be temporary, producers are assumed not to react to changes in prices of agricultural products, and (2) the way in which market prices and quantities react in the short term to changes on export markets. It is quite normal in models of international trade to consider markets completely fluid: if quantity changes, this will be apparent on the complete market. Such an assumption, however, is not very useful in the FMD approach because short-term reactions are not fluid at all. Therefore, the following additional assumptions were made: (a) there is a capacity limit for each export market, which is related to the usual volume of the export, (b) increasing exports to a particular market can only be realized by means of a price reduction (derived from the export demand curve for this particular market), and (c) the storage behaviour of participants on the market follows a rational approach: producers store products when the expected future market price minus the storage costs is higher than the present market price. The basic principles of this approach are illustrated in Figure 12.5.

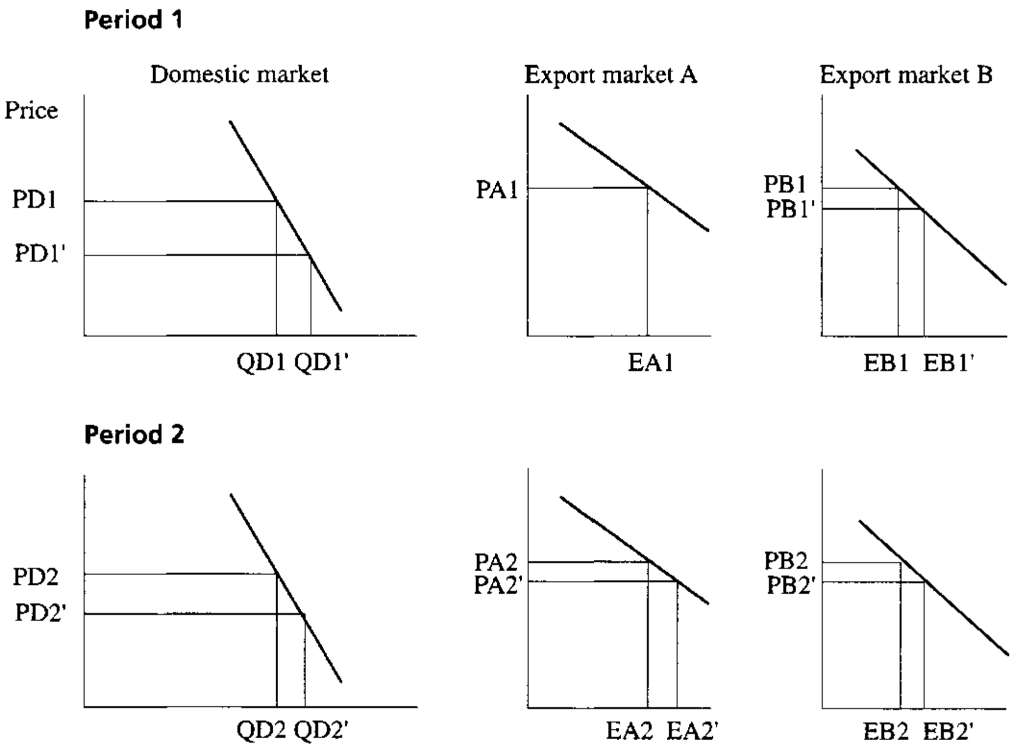

Figure 12.5 Basic principles of the export model

Here, country A imposes an export ban in period 1: the exports fall from EA1 to 0. Owing to this export ban, domestic prices and export prices decrease from PD1 to PD1' and PB1 to PB1' respectively. The export quantity to country B is limited to EB1'. A part of the production in the first period will be stored (and brought on the market again in period 2). This storage is just that size that PD1' plus the storage costs equal PD2'. In period 2, market participants face a market situation with an open export market again for country A. Also in period 2, additional exports to markets A and B are limited by the capacity limits (being set at 10% of the normal export).

12.4.3 Modelling outcome with respect to annual vaccination

Table 12.1 presents the losses resulting from a primary outbreak in the Netherlands in a situation with and without annual vaccination respectively.

Table 12.1 Economic losses resulting from a primary outbreak

	Vaccinated population		Non-vaccinated population		
Strategy [a]	**Ia**	**Ib**	**IIa**	**IIb**	**IIc**
Number of herds removed	33	27	688	240	138
Direct losses (US$ m)	4	4	100	36	20
Weeks with market disruption	60	58	81	112	60
Indirect losses (US$ m)	124	113	370	367	238
of which:					
- *producer losses*	*195*	*179*	*539*	*521*	*350*
- *consumer losses*	*-71*	*-66*	*-169*	*-154*	*-112*
Total losses (US$ m)	128	117	470	403	258
Annual losses (US$ m)	39	37	26	19	5

[a] Stamping out infected farms (Ia and IIa); stamping out infected farms plus ring vaccination (Ib and IIb); stamping out infected and risky contact farms (IIc).

The highest number of secondary outbreaks occur, as could be expected, in a non-vaccinated population with stamping out infected herds as the only control strategy (Table 12.1). Routine vaccination, however, is not necessarily the only remedy against a dramatic spread of the disease. The total number of outbreaks and the period of time over which they occur can also be considerably reduced by eradication of risky contact herds as well (IIc). However, it is doubtful whether public opinion would allow the slaughter of animals from herds without clinical signs of the disease.

The calculated direct losses show to be highly related to the length and extent of the outbreak. The indirect losses are by far the highest in the situation without yearly vaccination (as could be expected). This is mainly caused by the considerably longer-lasting reactions on the FMD-free markets.

The final comparison of strategies is done on a yearly basis, taking into account the expected frequency of primary outbreaks (ie, once each 5 years in a vaccinated population and once each 10 years in a non-vaccinated population), the total costs per outbreak, the costs of yearly vaccination and the extra profits from export to FMD-free markets. Strategies without yearly vaccination turn out to be the most preferable, despite the higher costs in case of outbreaks.

12.4.4 Risky decision making on control strategies

The model of Berentsen *et al.* (1990) was further used to simulate total losses in a non-vaccinated population for two control options under consideration, ie, stamping out and ring vaccination, with outbreaks occurring in three different areas of the Netherlands considering herd density and five different levels of disease spread within each area. Herd density ranges from relatively low to medium to high for Dutch conditions, with 2.1, 3.3 and 4.4 cattle and pig herds per km^2 respectively.

Table 12.2 Simulated losses from a theoretical outbreak of foot-and-mouth disease in a non-vaccinated population in the Netherlands (US$ m)

		regional livestock density (herds per km^2)					
		low (2.1)		medium (3.3)		high (4.4)	
Dissem. rate (i)	P(i)	stamp. out	ring vac.	stamp. out	ring vac.	stamp. out	ring vac.
dr-30%	0.05	248	360	282	379	318	390
dr-15%	0.20	279	370	341	392	451	416
default[a]	0.50	326	377	495	416	736	448
dr+15%	0.20	444	394	769	447	1658	500
dr+30%	0.05	591	411	1622	493	3154	577

[a] The default values were assumed to range (ie, to decline) from 3.8 in week 1 to 0.7 in week 6 and further in the region with a low livestock density, from 4.5 tot 0.8 in case of a medium density, and from 5.3 to 0.9 in a high-density region.

Disease spread within each area was based on default values for the dissemination rate *dr* (indicating the average number of farms to which the virus is spread by one affected farm), as well as on values that were set at 15% and 30% above and below default. Probabilities for these 5 classes of dissemination rates to occur were assumed to be symmetric, ie, 0.05, 0.20, 0.50 (default class), 0.20 and 0.05 respectively. The simulated outcomes for a theoretical outbreak of foot-and-mouth disease in the Netherlands are summarized in Table 12.2.

The choice based on the most likely outcome of the deterministic simulation model (presented under 'default') would be to apply the stamping-out strategy in case of an outbreak in the area with the low herd density, and ring vaccination in the others. This choice, however, does not hold for all situations considering disease spread and may lead to a considerable increase of losses in some of the cases. An above-normal dissemination rate, for instance, would make ring vaccination rather than stamping out to be the strategy that results in the lowest losses in the area with the lower herd density. A similar (but opposite) change occurs in the other areas with below-average dissemination rates. This is a classical example, therefore, of decision making under risk and uncertainty. Combining the simulated losses from Table 12.2 and the stochastic dominance rules, as described in Chapter 10, provides the outcomes presented in Table 12.3.

The first-degree stochastic dominance rule (FSD) cannot rank the strategies in any of the areas, because each respective pair of cumulative distributions intersects (as shown in Table 12.2). The more powerful second-degree stochastic dominance rule (SSD) does provide a preference for the areas with medium and high herd densities (ie, ring vaccination), but not for the low one. In case of a risk-averse attitude, therefore, stamping out no longer ranks highest in areas with a low herd density, as was the case with, among other things, the expected monetary value criterion. Stochastic dominance with respect to a function (SDWRF) shows, however, that at the lower levels of risk aversion the stamping-out strategy is still preferred. Ring vaccination becomes the dominating strategy when risk aversion is high.

Table 12.3 Stochastic dominance rules to rank the control strategies in case of a theoretical outbreak of foot-and-mouth disease in a non-vaccinated population in the Netherlands

	regional livestock density (herds per km²)					
	low (2.1)		medium (3.3)		high (4.4)	
Decision rules	**stamp. out**	**ring vac.**	**stamp. out**	**ring vac.**	**stamp. out**	**ring vac.**
FSD	*[a]	*	*	*	*	*
SSD	*	*		*		*
SDWRF,with risk aversion:						
-low	*			*		*
-considerable	*	*		*		*
-high		*		*		*

[a] Indicates the dominant strategy. With FSD the two strategies turn out to be equally dominant in all three areas under consideration. The same occurs with SSD and one of the SWDRF-alternatives in the area with the low herd density.

12.5 Concluding remarks

Indirect losses due to export bans can be of major importance with respect to foot-and-mouth disease outbreaks, as shown in this chapter. A further increase of trade between countries calls for an accurate and coordinated policy for contagious animal diseases. To anticipate these demands, a modelling environment is desired in which 'what-if' scenarios can be performed to explore the epidemiological and economic effects of the various diseases and control strategies. This requires input flexibility regarding (1) the type and density of farming in the region or country under consideration, (2) the type of disease, (3) the prevention and control strategy to apply, (4) the extent and segmentation of export markets, including intervention possibilities, (5) the country-specific probabilities of trade restrictions, and (6) the various prices and demand/supply elasticities. A combined approach across countries would make it possible to examine the impact of a coordinated strategy within a group of trading partners. The system thus derived will be a flexible tool to support real-life policy-making in an increasingly important area (Jalvingh *et al.*, 1995).

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