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RISK ANALYSIS AND ECONOMICS

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ABSTRACT

Risk analysis is an area of growing interest for the veterinary profession, especially with respect to international trade of livestock and livestock products. The major outcome of such analyses is a certain probability with respect to the occurrence of a specific event. The decision maker(s) then must decide whether a chance of virus import of one in so many thousands of tons or hundreds of years of imports is acceptable or not. In this paper it is argued that for most decision makers such an outcome is too difficult to interpret and decide upon, if possible at all. Therefore, it is suggested to bring the current approach of risk analysis one step further, by combining it with economic analysis. That would make it possible to convert the concept of risk into some sort of money value. The basic framework for such an integrated approach -- including issues of welfare theory and demand/supply analysis -- is presented and discussed, and illustrated with a simplified example.

SAMENVATTING

Risicoanalyse is een gebied dat snel aan belang en aandacht wint binnen de veterinaire wereld. Dit geldt in het bijzonder als het gaat om internationale handel van vee en veeproducten. Het belangrijkste resultaat van een (standaard) risicoanalyse is een kansverdeling van een bepaalde uitkomst. De beslisser moet aan de hand hiervan beslissen of de kans op insleep van bijvoorbeeld een bepaald virus (1 op de zoveel duizend) acceptabel is of niet. In deze bijdrage wordt duidelijk gemaakt dat dit onmogelijk is voor de meeste beslissers en beleidsmakers. Derhalve wordt voorgesteld om de (standaard) risicoanalyse een stap verder door te voeren door het te combineren met een economische analyse waarin de uitkomst in een bepaalde economische waarde (meestal in geld) wordt uitgedrukt. Het basisraamwerk voor een dergelijke economische stap wordt in deze bijdrage verder uitgewerkt en bediscussieerd aan de hand van een voorbeeld.

1. INTRODUCTION

Decisions in real life have to be made under conditions of uncertainty, which means that there is imperfect knowledge about the various input factors included and/or about the outcome of possible actions. This is also the case for decisions with respect to animal health.

Traditional economic analyses of decision making have distinguished two types of imperfect knowledge: risk, when the probabilities of the uncertain outcomes are known, and uncertainty, when they are not. However, this distinction is of little practical use and is discarded by most economists today. Probabilities can be "known" only for the so-called stationary stochastic processes, i.e., for events where there is variability but where the sources and nature of the variability remain constant through time. Such processes are rare in practical decision making. In modern economic analyses, therefore, the terms risk and uncertainty are used interchangeably.

In the area of Animal Health Economics increasing efforts are being made to quantify the costs and benefits of measures to control disease and reduce the risk of occurrence. Various techniques are available to help perform this kind of analysis, ranging from simple partial budgeting, to decision-tree analysis and stochastic computer simulation and optimization [5,6,8]. These techniques differ considerably in complexity, but have in common that they all can convert risks for and consequences of disease into costs and benefits, and hence into money values. Money values are easy to interpret by decision makers, including farmers and government officials.

The major outcome of most risk analyses, at least those with respect to trade issues, is a certain probability with respect to the occurrence of a specific event. The decision maker(s) then must decide whether a chance of virus import of one in so many thousands of tons of animal products or hundreds of years of imports is acceptable or not [13]. Such an outcome is for most decision makers too difficult to interpret and decide upon, if possible at all. In our view, therefore, the current approach of risk analyses should be brought one step further, and combined with economic analyses. That would make it possible to convert the concept of risk into some sort of money value. Economic effects to be included are, on the one hand, the benefits (i.e., utility) to consumers who actually buy the product and the profit (if any) made by those who import and trade the product under consideration. On the other hand, there are losses involved when the virus introduction causes an outbreak of the disease. These losses include direct costs (e.g. affected animals and control measures) -- but may also include indirect losses through export bans (at least for major exporting countries).

The type of economic analysis that is able to quantify these benefits and costs is based on welfare theory and demand/supply analysis. Moreover, specific choice criteria (such as a utility function and stochastic efficiency criteria) are needed to discriminate between the (uncertain) outcomes. In this paper, the basic principles of such an approach will be presented and illustrated with a simplified example.

2. THE CONCEPT OF DEMAND AND SUPPLY TO MEASURE WELFARE EFFECTS

2.1. Producer and consumer surplus

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 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.

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 "causes" a larger percentage change in quantity, the demand or supply curve is called "elastic" (i.e., 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 (i.e., inelastic) demand and supply curves. In other words, relatively small changes in quantities may have considerable price effects.

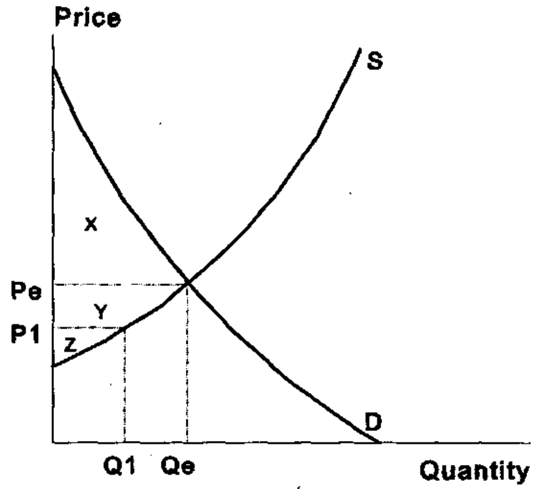

Figure 1. Graphical representation of demand and supply functions

The area between the supply and demand curves to the left of their point of intersection 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 1 the production of Q_1 units of output would have been realized at 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 determines a unit price of any commodity as a valuation, some producers actually obtain more value (or benefit) from the sale of their products than they might 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 last unit of output at Q_1. When adding up the surpluses associated with all other units of output between the origin and the equilibrium output Q_e, the total economic surplus is given by the area Y+Z (see Figure 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 were less abundant. They need not do so in the circumstances described, and so they benefit from getting their product cheaper than they otherwise would.

2.2. Losses due to export bans

The concept of producer and consumer surplus can also be used to quantify the losses from export bans, in case the import of a risky product causes an outbreak of a contagious disease. This is illustrated in Figure 2. Figure 2 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 and influencing the welfare of both producers and consumers. 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 the drop in price; their gain is 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 (i.e., the price elasticity of demand) influences the increase in consumer surplus.

Not only is it possible to identify the net effects on producers and consumers respectively, but also to summarize the consequences for a society as a whole (i.e., for people irrespective of whether they are producers, consumers or both). Within the theory of welfare economics, however, there is discussion about the aggregation of benefits and costs at the national level [10]. 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 [14]. It is, therefore, recommended to report both the separate effects for producers and consumers, and their equally-weighed total -- leaving policy makers the opportunity to apply their own weights.

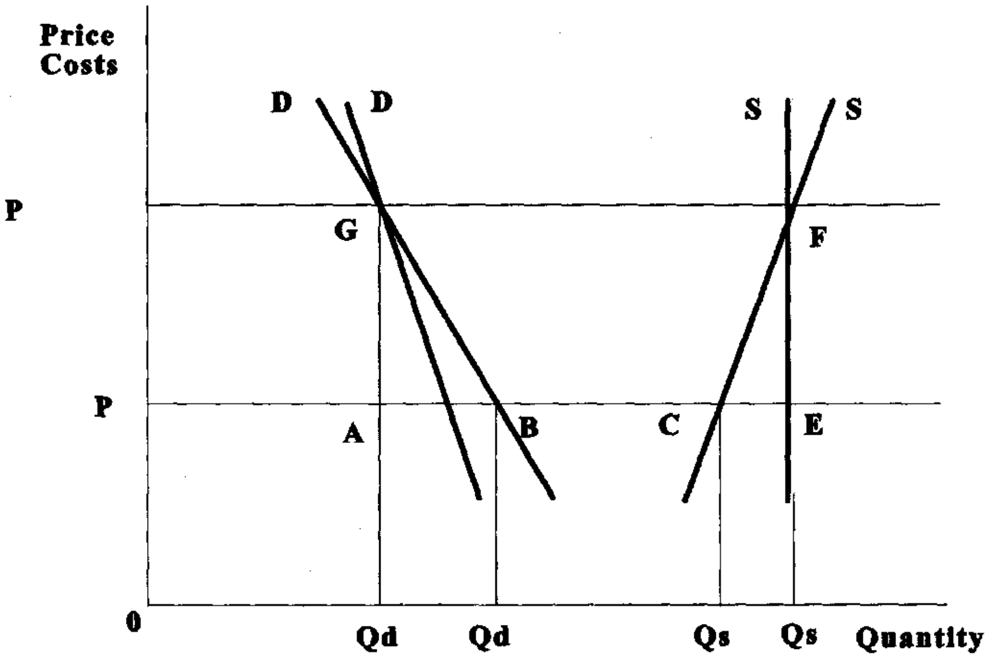

Figure 2. Supply and demand curves in case of an exporting country

For the Netherlands, a modeling approach has been developed to quantify these losses related to outbreaks of Foot-and-Mouth Disease [3, 9]. This approach is general and could also be applied to other countries and disease conditions.

3. CHOICE CRITERIA TO DISCRIMINATE AMONG UNCERTAIN OUTCOMES

3.1. Components of a risky decision problem

Any risky decision involves five components: acts, states, probabilities, consequences and a choice criterion [1, 8]. Acts (a_i) are the relevant actions available to the decision maker. They constitute the relevant set of mutually exclusive alternatives among which a choice has to be made. Examples of acts in animal health management are "treat" versus "do not treat" an animal, and "import" versus "do not import" animal products from a specific country. The possible events or states of nature (t_i) must also be defined by a mutually exclusive and exhaustive listing. Examples of states of nature are "good", "average" or "poor" rainfall, or "severe", "normal", "minor" or "no" outbreaks of a certain disease. The essence of a risky decision problem is that the decision maker does not know for certain which state will prevail. Some state variables are intrinsically continuous (e.g., herd-health status), but generally a discrete representation (such as good, average or bad) will prove adequate. Prior probabilities (P_i) reflect the degrees of belief held by the decision maker about the chance of occurrence of each of the possible states. Such probabilities are considered subjective or personal in nature. They can be based on outcome from experiments or field research, but -- when not available -- also on expert opinion or one's own experiences. Example prior probabilities for a disease problem can be as follows: a probability of 0.2 for a "severe" outbreak, 0.3 for a "normal", 0.25 for a "minor" and 0.25 for "no" outbreak of a certain disease. Depending on which of the uncertain states occurs, choice of an act leads to some particular consequence, outcome or payoff. Finally, some criterion of choice is necessary to compare the possible consequences of any act with those of any other act. One such criterion is the expected monetary value, defined as the summation of the possible money outcomes multiplied by their probabilities.

Consider a simplified case in which a choice has to be made between two acts, i.e., to import (a_1) versus not to import (a_2) a product from a specific country. "No import" is the current situation and defined to have a zero payoff. The payoffs of the import options are expected to differ according to whether or not an outbreak of the disease under consideration will occur. These "states of nature" can be no outbreak, minor outbreak or severe outbreak for a specified time frame, with an estimated prior (i.e., subjective) probability of 0.80, 0.15, and 0.05

respectively. Benefits and losses are calculated according to the producer and consumer surplus approach (explained before). Results are summarized in Table 1.

Table 1. Payoff matrix for two import options (1000 US$)

States of nature (t_i)	P(t_i)	Import (a_1)	No import (a_2)
No outbreak (t_1)	0.80	750	0
Minor outbreak (t_2)	0.15	-100	0
Severe outbreak (t_3)	0.05	-5000	0
Expected monetary value		335	0

When taking into account the mean outcome (i.e., expected monetary value) to compare the alternatives, import (a_1) is the preferred option. This choice holds for so-called risk-neutral decision makers (i.e., decision makers who implicitly put an equal weight on one dollar above or below the expected outcome). Most people, however, tend to be risk averse (i.e., decision makers who consider a relatively big loss as a more-than-proportional threat). With respect to the example in Table 1, this means that they put a higher weight on each dollar loss with a severe outbreak than on each dollar involved with no outbreaks. That may lead to a different choice than one based strictly on the expected-monetary-value criterion.

3.2. Subjective expected utility model

One of the most-widely applied conceptual models for studying decision making under risk is the subjective expected utility (SEU) model [8]. Using the model, actions are ordered according to the beliefs and risk attitude of the decision maker. Each outcome is assigned a utility value (i.e., preference), according to a personalized, arbitrarily scaled utility function. The utility values for each possible outcome of an action are weighed by their (subjective) probability and summed across outcomes. The resulting expected utility is a preference index for that action. Actions are ranked according to their levels of expected utility with the highest value being preferred.

The implementation of the SEU model requires the risk preferences of decision makers (i.e., the utility function) to be known. The notion of certainty equivalent is central to the measurement of these preferences, and hence to the elicitation of the utility function. When given a choice between (a) payment of US$1000 for sure versus (b) a chance of winning US$5000 with a probability of 0.25, for instance, most people will opt for (a) -- even though (b) has a higher expected monetary value. The certainty equivalent (CE) of a risky prospect then is the value which the decision maker is just willing to accept in lieu of the risky prospect. So, the relationship between the CE and the expected monetary value of the outcomes tells something about the decision maker's attitude towards risk. If the person is averse to risk (which is usually the case) he or she will assign a CE less than the expected monetary value. For people that have a preference for risk CE will be greater than the expected monetary value -- while in the case of risk indifference CE equals the expected monetary value.

Methods of eliciting utility functions involve asking people to specify their CEs for specified risky prospects. According to Anderson et al. [1], the simplest recommended method is based on considering an Equally Likely risky prospect and finding its Certainty Equivalent. In using this so-called ELCE-method, the first step is to find the CE for a hypothetical 50/50 lottery with the best and worst possible outcomes of the decision problem as the two risky consequences. The next step is to find the CE for each of the two 50/50 lotteries involving the first-established CE and the best and worst possible outcomes. This process of establishing utility points is continued until sufficient CEs are elicited to plot the utility function. In order to obtain meaningful values, it is important to provide enough realism for this type of game setting [15]. Moreover, reliable outcomes require utility functions to be described in a mathematically sound way, thus making the choice of the function form very important.

Suppose that for a risk-averse decision maker, the utility function for gains and losses is adequately represented by:

$$U(x) = 1 - e^{-0.0005\,X}$$

where X denotes thousands of US dollars.

This function makes it possible to convert the money values in Table 1 (with a probability of occurrence of 0.80, 0.15 and 0.05 respectively) for each of the alternatives (a_1 and a_2) to utility values (U). The utility of 750 thousand US dollars (in case of import (a_1) and no outbreak), for instance, is $1 - e^{-0.0005x750} = 1 - e^{-0.0375} = 1 - 0.687 = 0.313$. In this way, the total utility (TU) can be obtained for each of the alternatives, taking into account also the probabilities of occurrence of 0.8, 0.15 and 0.05 respectively:

$$TU(a_1) = 0.8U(US\$750) + 0.15U(US\$-100) + 0.05U(US\$-5000)$$
$$= 0.8(0.313) + 0.15(-0.0053) + 0.05(-11.183) = -0.317$$

$$TU(a_2) = 0.8U(US\$0) + 0.15U(US\$0) + 0.05U(US\$0) = 0.00$$

So, taking into account the risk-averse attitude of the decision maker makes option a_2 the preferred one (i.e., the one yielding the highest subjective expected utility).

3.3. Stochastic-efficiency criteria

Utility functions may not always be easy to elicit (if possible at all). Moreover, the model of risky choice as outlined above, relates primarily to a situation where there is one decision maker whose preferences are to be used in the analysis and who also bears the consequences of the choice. Often, however, more than one person will be involved in any decision and/or affected by the consequences, as is the case with trade issues. Unfortunately, the extension of the methods of decision analysis to multi-person decision problems is not a simple matter.

Policy makers often tend to react in a risk-averse fashion, fearing the personal consequences of being seen to have made decisions that turned out bad. The uncertainties of particular public projects or programs, however, are often rather insignificant when measured against the total performance of the economy. That is why economic theory teaches that governments make the best economic choice among risky projects by using risk-neutral decision rules such as the expected monetary value criterion [12]. There are two major reasons to consider risk-related (rather than risk-neutral) decision rules to be appropriate for the choice among projects: (1) when the projects are unusually large (e.g., affecting 10% or more of national income), or (2) when the project's consequences are not spread widely -- and fairly evenly -- among the population. The latter will often apply to contagious-disease outbreaks, since losses primarily affect producers' income (especially on farms and in areas that are actually affected by the disease) [2].

A better insight into the potential consequences of the various decision rules and risk attitudes may be helpful in these situations, anyway, to provide useful information for a better-thought-out and more-rational decision-making approach. Stochastic efficiency criteria are proposed as a useful alternative for this type of situations. Stochastic-efficiency rules satisfy the axioms of the expected-utility model but do not require precise measurement of risk preferences. However, as opposed to the complete ordering achieved when risk preferences are known, they provide only a partial ordering [11]. Stochastic-efficiency criteria are implemented by pair-wise comparisons of cumulative distribution functions of outcomes (y) resulting from different actions [8].

First-degree stochastic dominance (FSD) holds for all decision makers who prefer more to less (i.e., whose first derivative of the utility function is positive). No assumptions are made about risk preferences of the decision maker -- which widens the possibilities of application but limits its discriminatory power. Graphically, these conditions mean that the cumulative probability of the dominant (i.e., preferred) distribution must never lie above the cumulative probability of the dominated distribution. In Figure 3, for example, F(y) dominates G(y) by FSD, but neither F(y) nor G(y) can be ordered by H(y), in which y are outcomes in money values (i.e., milk returns, pig sales, etc.).

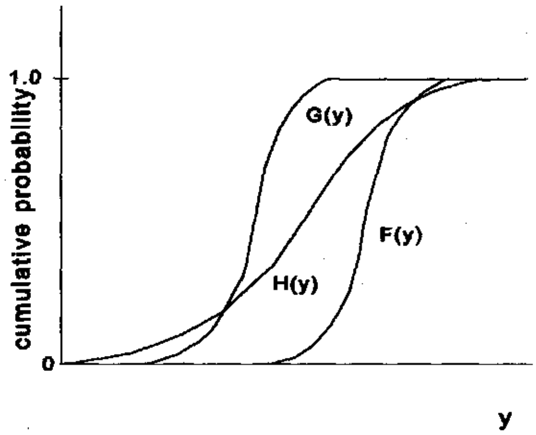

Figure 3. Graphical representation of stochastic efficiency criteria

Second-degree stochastic dominance (SSD) assumes that decision makers (in addition to preferring more to less) are risk averse, with utility functions having positive, non-increasing slopes at all outcome levels. Under SSD, an alternative with the cumulative distribution F(y) is preferred to a second alternative with cumulative distribution function G(y) if

$$\int F(y)\,dy \leq \int G(y)\,dy$$

for all possible values of y, and if the inequality is strict for some value of y. SSD has more discriminatory power than FSD, but still may not effectively reduce the number of alternatives. Graphically (because the accumulated area under F(y) in Figure 3 is always less than or equal to that under either G(y) or H(y)) only F(y) is in the so-called SSD-efficient set of these three alternatives. When only G(y) and H(y) are considered, neither one dominates the other by SSD, since the accumulated area under G(y) is less than the area under H(y) for low values of y, while the opposite occurs at high values of y.

Stochastic dominance with respect to a function (SDRF) is a more-discriminating efficiency criterion that allows for greater flexibility in reflecting preferences -- but also requires more-detailed information on those preferences. Formally stated, SDRF establishes necessary and sufficient conditions under which the cumulative function F(y) is preferred to the cumulative function G(y) by all decision makers whose risk attitude lies anywhere between specified lower and upper bounds. The method is flexible enough to include and investigate the impact of any specified value [8, 11].

PC-software has become available to perform the stochastic efficiency analyses [7]. This type of software was also used to carry out the analyses for the example given in Table 1. Results are summarized in Table 2.

Table 2. Outcome according to the various decision criteria (US$) (The preferred options are underlined or indicated with an *; ? means no ordering)

Criteria	Import options	
	import	no import
Expected monetary value	<u>335</u>	0
Utility function	-.317	<u>0</u>
FSD	?	?
SSD	?	?
SDRF (with risk aversion assumed to be):		
- low	*	
- considerable	?	?
- high		*

Table 2 shows that choices appear to vary according to the criteria. The expected-monetary-value criterion (assuming risk neutrality) leads to the choice of option 1 (import), while with the more-risk-averse type of criteria (e.g., utility function) option 2 (no import) is preferred. The latter is also the case with the SDRF-criterion -- at least with higher boundaries for the risk-aversion interval.

4. FINAL REMARKS

Risk and uncertainty are undoubtedly important factors in animal health management. Advice and modelling that are to support decisions in this area, therefore, should include appropriate probability estimates for the relevant variables under consideration. Decision analysis is considered a worthwhile approach for ensuring that farmers get advice and make decisions which are consistent with (a) their personal beliefs about the risks and uncertainties surrounding the decision, and (b) their preferences for the possible outcomes. It can also help to provide a rational basis for decision making in the public domain, and to determine the economic value of additional information to reduce and/or predict the risks and uncertainties. A good risky decision, however, does not guarantee a good outcome. That would only be possible with perfect foresight (i.e., in the absence of uncertainty). It does assure, however, that the decision made is the best possible one given the available information.

Appropriate decision criteria are considered a major component of a risky decision problem [4]. The most-widely used expected-monetary-value criterion does not always tell the whole story, as shown in the -- simplified -- example in this paper. Utility functions make it possible to provide the most-comprehensive approach (including a trade-off between the average outcome and variance) but will not always be easy to carry out and apply in actual field advice. Stochastic-dominance criteria are commonly considered promising tools in this type of analysis. User-friendly software has become available to make the application of this type of advanced criteria much easier and accessible [7]. In this way it becomes possible to transform the current outcome of risk analyses (ie, a certain probability) into values that are easier to interpret and to compare.

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