University of Southern Denmark · Syddansk Universitet

Valuing changes in mortality risk

By:
Jytte Seested Nielsen
Institute of Public Health, Health Economics
University of Southern Denmark, Odense
&
National Environmental Research Institute
Department of Policy Analysis, Kalø

Health Economics Papers
2006: 3

UNIVERSITY OF SOUTHERN DENMARK

Foreword

The present paper by Jytte Seested Nielsen on valuing changes in mortality deals with a subject related to health economics and environmental economics as well.

The paper was written as a part of Jytte Seested Nielsen's Ph.D. fellowship which is financed by the National Environmental Research Institute, Kalø. She has been supervised by professor Kjeld Møller Pedersen, SDU and professor Mikael Skou Andersen, NERI.

Terkel Christiansen

Abstract.

When valuing a change in mortality caused by a change in the level of air pollution it has been widely debated whether to use the "Value of a Statistical life" approach or the value of a life-year lost.

The present paper establishes a theoretical rationale for the valuation of a change in the probability of dying, which aggregated can lead to the Value of a statistical life. A theoretical valuation of a change in the survival curve is established as well as the subsequent valuation of the aggregated change in life expectancy. Finally, the empirical and theoretical possibilities for valuing a life year lost are discussed.

The underpinning foundation for the valuation of changes in mortality is the expected utility theory. However, this framework has been widely criticised. Based on several empirical studies attention is given to special problems with the expected utility theory in relation to both the valuation of a change in the probability of dying and the valuation of a change in life expectancy.

1. Introduction.

1.1 Background

Particulate air pollution has long since been recognised for its harmful effects on health. Both in Denmark and within the European Union considerable efforts have been devoted to investigating the different aspects of air pollution.

In this context, the so-called "impact-pathway" approach has evolved through a range of EU projects named ExternE[1] (Externalities of Energy). The method has been developed in order to be able to link the measurement, identification and valuation of the impacts of air pollution (see Figure 1.1). This is a "bottom-up" approach, where the point of departure is a particular emission from, for example, a power plant followed by measurement of the way in which the emission in question is dispersed. The impact is subsequently estimated, for example in the form of dose-response functions, which estimate the physical effects on human morbidity and mortality. Finally, economic methods are employed to assign values to the effects which can be avoided by reducing the pollution.

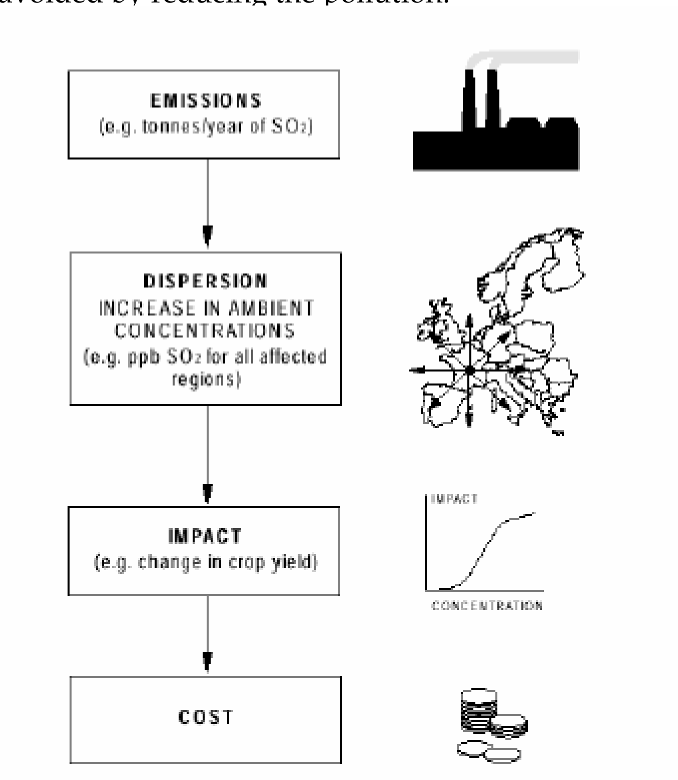


Figure 1.1. Impact pathway, (Holland, Berry, & Forster 1998).

This approach has subsequently been adapted directly to the Danish context, refer to (Andersen et al. 2004) and (COWI 2004). Recently, the EU presented the Thematic Strategy on Air Pollution which has been evaluated in a Danish context (forthcoming in (Bach et al. 2006)).

However, when studying the ExternE approach and its subsequent application, it is apparent that there are some limitations with using this method. Some of them have a direct relation to the economic valuation phase and are mentioned here:

i) The approach in the ExternE framework is to investigate the consequences of a "blip" in air pollution (e.g. an increase in air pollution for one year after which the pollution returns to the previous level). This is not always a fair presentation of reality, but a "blip" has been chosen in order to be able to isolate the effect and will also form the basis for the investigation in this paper (as opposed to a parametric change in air pollution – refer to (Johannesson, Johansson, & Löfgren 1997) for a discussion of the difference in an economic setting).

ii) Morbidity and mortality are two separate issues in the ExternE approach (the approach does, however, give some attention to the avoidance of double–counting). The valuation of mortality and morbidity are intrinsically linked. This paper, however, will look closely at mortality and mention possibilities for incorporating morbidity issues as well.

iii) The most apparent economic issue in application of the ExternE method is the variety of ways to handle the valuation of a change in mortality caused by a change in air pollution. This is clearly illustrated in the Thematic Strategy on Air Pollution. As a result of extensive discussions among environmental economists and epidemiologists, it was decided to report the results based on two different approaches: 1) a value for each life year lost and 2) a value for each premature life lost.).

Many of the difficulties arise because the original framework for dealing with life in Cost Benefit Analysis was developed within the traffic sector. Here, the so-called "Value of a statistical life" approach has evolved (refer to Chapter. 3).

---

[1] ExternE's studies are published in a range of reports *ExternE Externalities of Energy Vol 1-10*. See also http://www.externe.info/

However, the epidemiologists prefer to calculate the change in mortality which is due to a change in the level of air pollution in terms of life-years lost. Technically the number of life-years lost is found based on the results reported in (Pope et al. 1995;Pope et al. 2002). The study by Pope is based on a study of over 500,000 individuals in the U.S. and the outcome of the study is a Risk Ratio for a change in the mortality caused by a change in the concentration of fine particulate matter. By multiplying this relative risk ratio with the probability of dying in a specific year, the loss of life-years in a given cohort of individuals due to a one-year increase in fine particulate matter is calculated. This method is inspired by work by (Brunekreed 1997) and allows us to take into account that a premature death from an increase in air pollution often takes place after a latency period ("chronic death"). This differs from most traffic-related deaths, which will follow the accident immediately (often called "acute death").

Nevertheless, this epidemiological method has generated the need for a welfare economic value for a life-year lost.

The discussion on how to values a change in mortality is of great importance, because in the existing analyses the value of a change in mortality can constitute over 80 % of the damage estimates (in DKK per kWh) refer to (Andersen, Frohn, Jensen, Nielsen, Sørensen, Hertel, Brandt, & Christensen 2004)). In 2000, the EU's DG Environment invited a range of highly regarded environmental economists to a workshop in order to establish a recommendation in this area, refer to (Cropper 2001;European Commission 2001). The official recommendation turned out to advocate using the Value of a Statistical Life (VSL) framework and a value of 1.4 million Euro was recommended for a VSL, based on a meta-survey from the UK of a range of empirical VSL's for traffic accidents, refer to (Dalvi 1988;Jones-Lee 1987). However, the value was adjusted downwards to 1 million € to take into account that it is mostly the elderly that experience the change in the mortality rate (refer to Chapter 4 for a discussion of this adjustment).

Yet, discussion on how to deal with the valuation of a change in mortality has continued. The work on the valuation of a change in mortality has now commenced within the realm of EU research in the project NEEDS (New Energy Externalities Developments for Sustainability), which empirically investigates the possibilities of valuing a change in life expectancy.

This paper constitutes the first part of a PhD project that forms part of the AIRPOLIFE project[2]. The empirical work of the PhD project will be carried out in connection with the NEEDS project mentioned above in order to value a change in life expectancy by use of the contingent valuation method.

However, the intent of this paper is theoretical and the overall purpose is to examine the possibilities of dealing with questions about life and death within the welfare economical framework. As will become apparent, the object of this paper is not how to put a price on some identified person. Instead, the possibilities for valuing a change in the probability of dying and a change in life expectancy will be examined, and these issues will be assessed by examining some related questions:

1. What is a possible economic foundation behind valuing a change in the probability of dying? *(Chapter 3)*
2. What is a possible economic foundation behind valuing a change in life expectancy? *(Chapter 5 and 6)*
3. What are the empirical perspectives of 1) and 2)? *(Chapter 4 and Chapter 6)*

1.2 Structure of the paper.

In addition to this introduction, the present paper includes 5 chapters and a conclusion. Chapter 2 contains a general investigation of the welfare economic framework and the foundations of Cost Benefit Analysis. This chapter is relatively thorough, because it is essential to be fully aware of the possibilities and the limitations of the expected utility framework in order to be able to make a distinction between analysing the problems with the valuation of the specific goods treated in this paper and the overall problem with the expected utility framework.
The framework for valuing a change in the probability of dying in a static context is outlined in Chapter 3 with theoretical point of departure in a model by Jones-Lee (Jones-Lee 1974). After a description of the model, different problems with the model are discussed. These problems are partly rooted in the general expected utility

[2] AIRPOLIFE (Air Pollution in a life time health perspective) www.airpolife.ku.dk

framework and some are specific to the valuation of change in the probability of dying.

Subsequently, different empirical methods are summarised and discussed in Chapter 4, which contains a discussion of different empirical studies and their empirical findings.

Moving to Chapter 5, the perspective changes to incorporate how the value of life varies throughout a life-time. This is analysed in terms of life-cycle consumption models and especially the influence of age and latency on the valuation is discussed. The discussion in the chapter is based on the model by Cropper and Sussman (Cropper 1990b). However, some possibilities for extending the model are discussed.

Chapter 6 contains a discussion and comparison of three ways to value a life-year lost. The empirical possibilities and restrictions are discussed.

Appendix D contains a description of the different variables and abbreviations used in the paper.

2 Cost Benefit Analysis.

Resources are scare and in order to allocate resources in an efficient way, prioritisation is needed. Where markets work well, individual self-interest leads to an efficient allocation of resources (Bateman et al. 2002). However, given the presence of public goods externalities[3], and other forms of market failures, Cost Benefit Analysis (CBA) has developed in order to help guide decisions-makers. The purpose of a CBA can, in this context, be seen as a *market simulation strategy*, simulating the workings of an ideal competitive market (Sugden 2003). Accordingly, CBA can be used when analysing the impacts of a policy decision on non-market goods.

2.1 Foundations of welfare economic valuation

The essential problem in assessing any policy decision is to determine whether welfare would be higher if the policy change is implemented than if not (Winch 1971). A definition of welfare is, therefore, provided in the following section.

2.1.1 Welfare.

The fundamental idea behind the utilitarian view is the idea that welfare in a society can be described as the sum of individuals' utilities. Utility is seen as the individual's transformation of their preferences. Since it is a part of an individual's freedom to determine his or her preferences, it has been argued that it is not appropriate to ask how these preferences are formed. This idea can be described further by the concept of consumer sovereignty (Whitehead 1991) and, consequently, the following applies:

"There is no social entity over and above the individual, so that society is always the aggregation of the individuals." (Quote p 87, (Pearce 1998))

The aggregation of individual's utility functions is illustrated below and is often referred to as the classical utilitarian function or the welfare (W) function.

$$W = \sum_{i=1}^{n} u_i(x_i) \qquad \text{for i = 1;n} \qquad \text{[EQ 2.1]}$$

[3] The definition of a public good and an externality will be presented in Chapter 3.

The utility of the individual depends on the individual' s consumption of good and services – described by the vector x_i . This way of describing welfare rests on the assumption that two social states can be ranked on the basis of personal utilities in the respective states (irrespective of the non-utility features of the states) (Sen 1979). The summation of the utilities is based on the assumption that W is separable and that the utilities of the individuals are mutually independent (Møller 1996).

Methodologically, the preferences are considered as given in any period of time and can be described graphically in terms of indifference curves, which are formed by the bundles for which the consumer is just indifferent. These curves are normally assumed to be "well-behaved", by which is meant that more is better and this assumption is often referred to as monotonicity of preferences. The slope of the indifference curve is the marginal rate of substitution, which is calculated as the ratio of marginal utilities and measures the rate at which the consumer is willing to substitute one good for the other. The marginal rate of substitution can be interpreted to measure the marginal willingness to pay and will be discussed later, in Chapter 3. At an interior optimum, the marginal rate of substitution must equal the slope of the budget constraint ($-p_1/p_2$) which graphically is illustrated by the tangency of the budget line and the indifference curve (Varian 1999).

2.1.2 The Pareto Criteria.

The welfare function above describes that which (Sen 1979) has named welfarism. Keeping this terminology, utilitarianism satisfies what Sen called the "Pareto-inclusive Welfarism". The Pareto preference rule or the Pareto Criterion says that if anyone has at least as much utility in x as in y, and if someone has more utility in x than in y, then x is socially better than y. By combining welfarism and the Pareto preference rule, social welfare becomes an increasing function of personal utility levels, which Sen terms "Pareto-inclusive Welfarism" (Sen 1979).

From the Pareto Criterion follows the goal of Pareto efficiency which is established if no alternative allocation of goods can make at least one person better off without making anyone else worse off (Boardman et al. 2001). The first theorem of Welfare Economics tells us that an equilibrium allocation achieved by a set of competitive markets will necessarily be Pareto efficient. An implication of this is that *simulating* the equilibrium state of an ideal competitive market implies achieving Pareto efficiency (Sugden 2003).

Pareto efficiency is a necessary condition for the maximisation of social welfare and accordingly the goal of Pareto efficiency provides the conceptual basis for a CBA. However, if only Pareto efficient policies were to be adopted, this would, in practice, result in society forgoing many policies that would offer positive net benefits. This is due to the fact that among other it would require that the analyst measured not only aggregate costs and benefits but measured costs and benefits for each person and the administrative costs of actually making specific transactions would be very high. Therefore a CBA utilises a modified form of the Pareto Criterion introduced by Kaldor and Hicks in the 1930s and 1940s (Pearce 1998). The Kaldor-Hicks Criterion establishes that projects are justified when gainers *could* compensate losers, and this criterion is often called the hypothetical Kaldor-Hicks Criterion[4] and provides the basis for the potential Pareto efficiency rule, or the net benefits criterion: Only policies with positive net benefits should be adopted (Boardman, Greenberg, Vining, & Weimer 2001).

The potential Pareto efficiency rule illustrates that a CBA is based on an ex-ante perspective, meaning that the valuation should reflect private tastes and preferences as these exist *at the time* of the social decision (Jones-Lee 1979). The distinction between the ex-ante and the ex-post perspective will be discussed further on in this chapter.

2.1.3 Consumer Surplus.

In a CBA, the value of the change in welfare arising from a marginal change in consumption possibilities is estimated. The traditional measure for benefits in the economy is "consumer surplus", which is illustrated in Figure 2.1 below, where the curve AH shows the marginal utility from the consumption of X, assuming that the

[4] Strictly speaking, the Kaldor potential compensation test differs from that of Hicks. The test named after Kaldor asks whether it is possible for the winners to compensate all of the losers from the proposed policy change and still leave some individuals better off. On the other hand, Hicks' version asks whether it is possible for the losers to bribe the gainers to obtain their consent to forgo the proposed policy change (Freeman III 2003).

volume of all other goods is constant. If consumption rises from OF to OG there is an increase in utility of FBDG utils.

By assuming that the individual's total income and all other prices are fixed, and further assuming that the marginal utility of income is constant, the individual will now maximise utility at any price of X by buying all those units for which marginal utility exceeds price multiplied by the marginal utility of income. Because the marginal utility of income is constant, the vertical axis can be calibrated in money rather than utils and AH is the (Marshallian) demand curve. A gift of FG of X would result in a gain in utility of FDBG but now measured in units of money instead of utils. If the increase in quantity results form a fall in prices from OC to OE; the total rise in consumer surplus would be ECBD (Winch 1971).

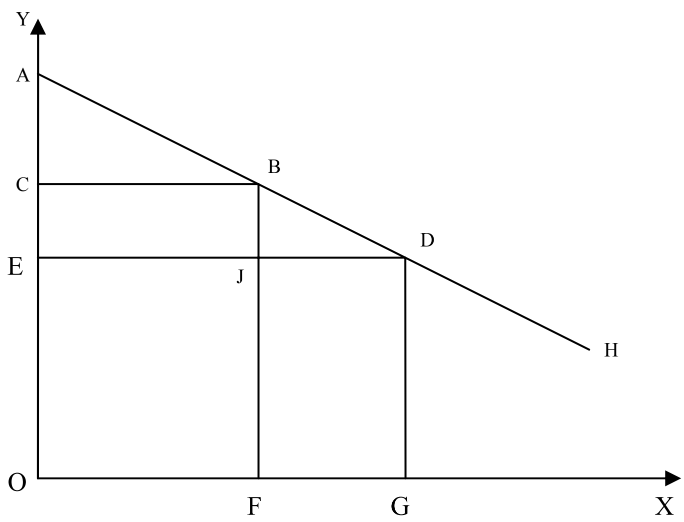


Figure 2.1 Consumer Surplus, Winch(1971)

This measure has been further developed by Hicks, especially as the assumption of a constant utility of money is not acceptable (refer to Chapter 5 for further discussion). Hicks developed 4 different measures:

Hicks' Compensating Variation (CV)
Equivalent Variation (EV)
Compensating Surplus (CS)
Equivalent Surplus (ES)

Only the first two measures will be examined here. The CV closely resembles the CS and, likewise, the EV resembles the ES. The difference is that in the variation measures no restrictions are placed on the individual's adjustment of the consumption models, whereas in the surplus measures restrictions are placed on adjusting the purchase of x_1 in response to a compensating change in income (Freeman III 2003)[5].

The two measures are illustrated for a welfare gain (a decrease in price) by means of indifference curve analysis in Figure 2.2 and Figure 2.3. The analysis is based on (Møller 1996), (Boardman, Greenberg, Vining, & Weimer 2001) and (Winch 1971) and can also be applied for a welfare loss.

In the analysis below it is assumed that x is a product on which the consumer spends only a fraction of their income and Y is a composite good on which the consumer spends all the rest of their income. The good Y can serve as an approximation of the consumer's total income and the slope of the budget constraint, therefore, indicates the price of the good X.

The line GI is the initial budget constraint and point a is the initial situation on the indifference curve U_1. If the price of X decreases this would change the consumer's equilibrium to point b on a flatter budget constraint GH and at a higher indifference curve. In order to place the consumer on the same indifference curve as before the change in price we need to take some money away from the consumer. This would shift the budget constraint back to JK and the consumer would move back to the original indifference curve. However, the consumer would not choose the same point but choose point c instead and accordingly the utility is kept constant. The difference between point J and G on the vertical axis represents the money that would have to be taken away from the consumer in order to arrive at the *same* utility level after the decrease in price – and thus represents the CV.

The EV can be illustrated as well. The difference in relation to the CV is that, in this case, it is the original budget constraint which should be shifted in order to arrive at the amount which for the consumer would be just as good as the gain in welfare

[5] Freeman argues that the restriction placed on the surplus measures is arbitrary, whereas Møller argues that the CS measure is the theoretically correct measure when a non-marketed good is analysed.

(point d). This amount is the EV and is the difference between M and G on the vertical axis.

From Figure 2.2, the demand schedules can be approximated (in Figure 2.3 with straight lines and with the vertical axis measuring MRS=p_x = slope of the indifference curve). Looking at CV first, the movement from x_a to x_b reflects the total change in demand. According to the **Slutsky identity** (Varian 1999), the total change in demand equals the substitution effect plus the income effects and hence this movement belongs on the normal (Marshallian) demand curve[6]. However in the movement from x_a to x_c, utility is kept constant and this movement incorporates, therefore, only the Hicksian substitution effect. The income adjustments offsets the income effects and the change in demand can be measured on the Hicksian demand schedule - also called the utility- compensated demand schedule. The change in consumer surplus measured with a Hicksian demand (p_1p_2ac) schedule equals the CV found in Figure 2.2.

The EV is illustrated in Figure 2.3 as well. The change in consumer surplus measured with the Hicksian demand schedule equals p_1p_2db, and the EV in Figure 2.2.

A special case must be considered – the case with zero income effect.
In this instance, the Marshallian schedule and the Hicksian demand schedules coincide. The CV and EV can be measured by means of the Marshallian demand curve and are exactly the same size.
It is therefore apparent that since it is mostly the Marshallian schedule that is available, biased estimates of the CV and WTP will result – (if the income effect differs from zero.)

[6] The substitution effect reflects the change in demand due to the change in the rate of exchange between the goods. The income effect, on the other hand, reflects the change in demand due to having more purchasing power.

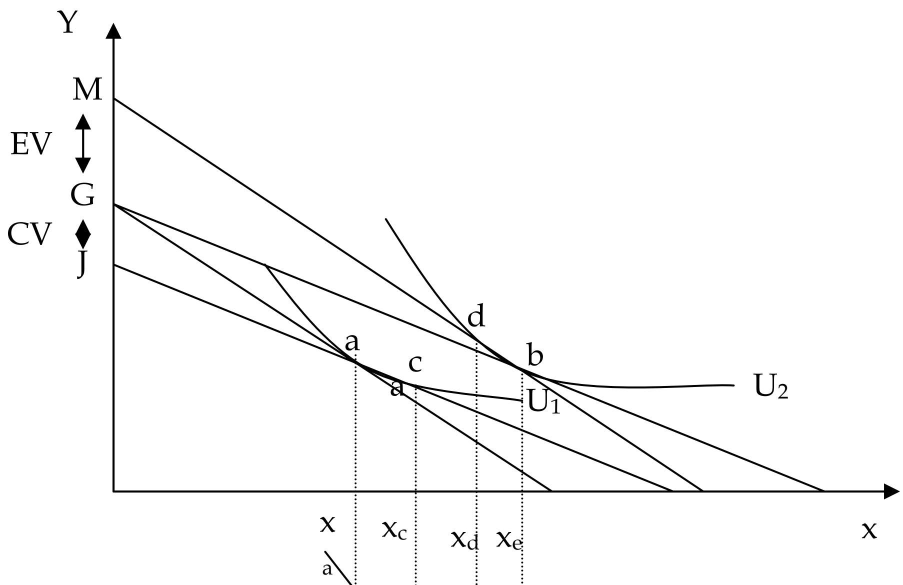


Figure 2.2

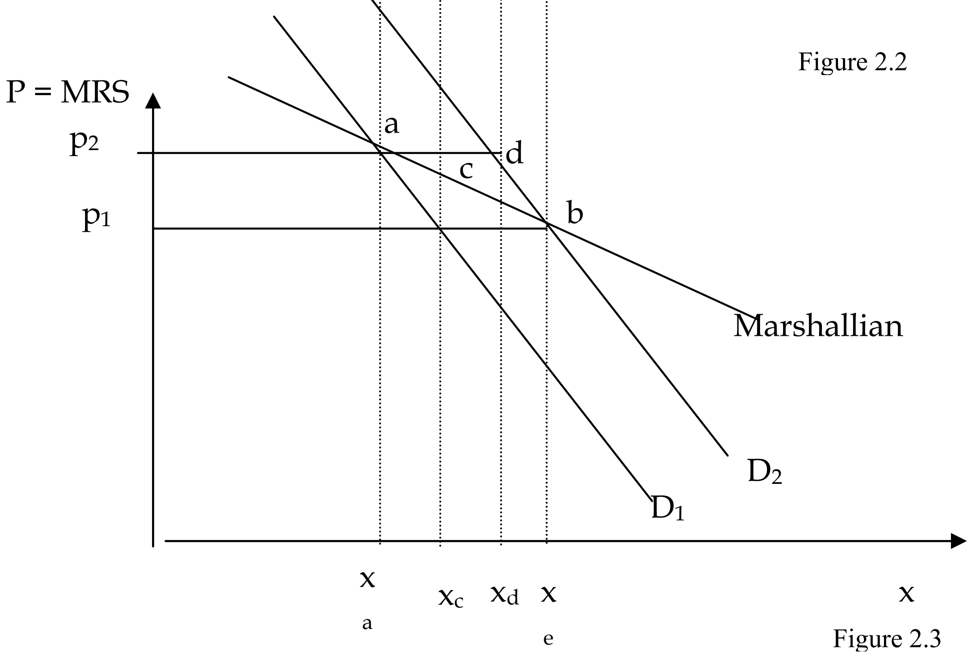


Figure 2.3

The intuitive explanation of the measures above is that when looking at a potential welfare economic benefit gained from a higher level of environmental quality, CV is the money income that needs to be taken away from the consumer in order to place them on the same indifference curve (and hence the same utility level) as before the provision of the public good. EV, on the other hand, measures the minimum sum an individual would require in compensation in order to derive a higher utility level, if an improvement in environmental quality does not occur (Willingness to Accept, WTA) (Venkatachalam 2004). The difference between the two concepts is that the CV relates to an individual's original welfare level, whereas the EV refers to subsequent levels (Linneroth & 1982).

2.1.3.1 The relation between the different measures of Consumer Surplus.

Still looking at a proposed welfare gain, the CV is a WTP measure and the EV is a WTA measure. However, when looking at a proposed welfare loss, this is reversed (Venkatachalam 2004). This can readily be seen by repeating the analysis above for a price increase, with the result that the CV for an increase in price equals the EV for a decrease in price and the EV for an increase in price equals the CV for a price decrease. As can be seen from Figure 2, for a decrease in price, EV>CV. Similarly, WTA>WTP for a proposed welfare gain, whenever the indifference curves are convex to the origin and the good is normal (Bateman, CArson, Day, Hanemann, Hanley, Hett, Jones-Lee, Loomes, Mourato, Özdemiroglu, Pearce, Sugden, & Swanson 2002). However, as mentioned earlier, when there is no income effect EV=CV = CS.

On realisation that EV ≠CV, it is appropriate to discuss whether the EV or the CV is the theoretically correct measure. According to (Møller 1996), EV is theoretically the correct measure, because 1) it is measured with prices from the original situation, whereas in the measurement of CV new prices for each change in price are used, and 2) a consistent rank in accordance with the underlying change in utility is secured with the EV measurement. The last argument is accepted by (Mitchell & CArson 1989). However, in their opinion, the CV measure is theoretically the correct one, because policy interest lies in the potential benefits as measured from the consumer's current or initial level of utility, and the problems with ranking seem very small, in practice, and would appear unlikely to be able to be picked up in practise.

It is apparent that there is no consensus on the matter[7]. However, it seems as if the choice between CV and EV would depend on the perspective of the analysis. Furthermore, the CV has the advantage of being easier to understand, intuitively, whereas the EV has the advantage of providing a consistent ranking of policies (even though the potential Pareto criterion provides no basis for ranking) (Freeman III 2003)).

[7] In (Freeman III 2003), the argument is that the choice between CV and EV depends on whether it is desired that the proposed change should pass the Kaldor (CV) or the Hicks (EV) potential compensation test. This issue will not be discussed further in the text.

A related problem is whether to use the Willingness to Pay (WTP) or Willingness to Accept (WTA) measure in empirical surveys or analysis. When using the Contingent Valuation Method (CVM), the official recommendation is to use WTP (Arrow et al. 1993). Obviously this is not a recommendation of use of the EV or the CV. Rather, it is a consequence of the fact that the difference between the WTP and the WTA for the same good can be very large (with the largest difference for non-marketed goods) (Horowitz & McConnell 2002). As a result of all the problems mentioned in Chapter 4 concerning CVM surveys, the WTP measure, which is the conservative measure, is recommended.

2.1.4 The distributional effects.

As explained in Section 2.1.1, society is an aggregation of individuals. However, from a societal perspective, this means that the a rich mans willingness to pay is given more weight than the poor mans willingness to pay. This is a basic objection to the normal aggregation procedure as this replaces the principle of "one person, one vote" with "one pound, one vote" (Chilton et al. 1997). If equality of income is a relevant goal as well as efficiency, a distributionally weighted CBA represents an alternative decision rule to the maximization of benefits is. This is done by calculating net benefits for some groups distinguished by e.g. income or wealth. The net benefits for each group are then multiplied by a weighting factor to reflect some distributional concerns. However the problem is obviously to arrive at some distributional weights. Weighting schemes based on tax rates has been suggested as one solution (this could be presumed to reflect the political concern about distributions). (Boardman, Greenberg, Vining, & Weimer 2001) However this is of cause very controversial. Still incorporating distributional effects can work as a sensitivity test illustrating the effect of distribution weights in a CBA.

2.2 Expected Utility.

The discussion so far has only focused on situations in which the utility is known. However, CBA often requires us to predict the future. One way of dealing with the uncertainty from predictions in a cost-benefit analysis is by analysing expected value. Expected values take account of the dependence of benefits and costs on the occurrence of specific contingencies in the future. The uncertainty in the predictions about the future becomes a problem of dealing with risk if it is possible to assign probabilities of occurrence to the different contingencies. However, modelling uncertainty as risk must begin with the specification of a set of contingencies that are exhaustive and mutually exclusive.

Expected utility theory goes as far back as Bernoulli who, in 1728 proposed that people maximise expected utility rather than expected monetary value (Bernoulli 1954)[8]. However, it was von Neumann and Morgenstern (NM) who,

"practically defined numerical utility as being that thing for which a calculus of expectations is legitimate" (Quote p. 28 (von Neumann & Morgenstern 1944))

The general EU model can be described as one which predicts or prescribes that people maximise;

$$W = \sum_{i=1}^{n} F(p_i) u_i(\bar{x}_i) \qquad \text{for i = 1;n} \qquad \text{[EQ 2.2]}$$

where

$\sum_{i=1}^{n} p_i = 1$, F(•) is some kind of probability transformation and x_i are the different outcome vectors (Schoemaker 1982).

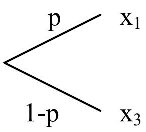
2.2.1 von Neuman and Morgenstern axioms.

In order for N-M predictions to be reliable some assumption on respondents' behaviour are needed. Von Neumann and Morgenstern proved that if the following five basic axioms are fulfilled greater expected utility corresponds to higher preferences (Schoemaker 1982). The five basic axioms can be formulated in different ways – the following presentation is based on the terminology of (Baumol 1958;Schoemaker 1982).

1) Preferences for lotteries (L) are complete and transitive. Completeness means that for any choice between lotteries L_1 and L_2, either L_1 is preferred to L_2 (denoted $L_1 >$

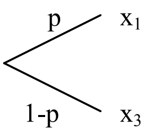
L_2), $L_2 > L_1$ or both are equally attractive. Transitivity implies that if $L_1 > L_2$ and $L_2 > L_3$ then $L_1 > L_3$.

2) Continuity of preference as a function of P. This means that if $x_1 > x_2 > x_3$, then there exists some probability p between zero and one, such that the lottery

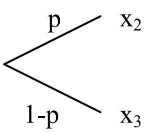


is as attractive as receiving x_2 for certain.

3) Independence. If objects x_1 and x_2 (being either risky or risk-less prospects) are equally attractive, then lottery

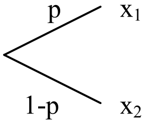


and lottery

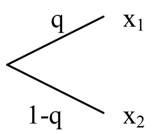


will also be equally attractive (for any values of p and x_3).

4) One would prefer an outcome with an investment opportunity with the greatest probability of a favourable outcome. Consider two lotteries between x_1 and x_2 and the lotteries only differ in probabilities.



[8] The observation was based on the so-called Petersburg Paradox, refer to (Bernoulli 1954)



If $x_1 > x_2$, then the first lottery will be preferred over the second if, and only if, $p > q$.

5) A compound lottery (i.e. one whose outcomes are themselves lotteries) is equally attractive as the simple lottery that would appear as a result of multiplying probabilities through, according to standard probability theory.

2.2.2 Discussion and critique of the Expected Utility Theory.

It is crucial to be aware of the assumptions behind the theory in order to be able to interpret the results. When examining the basis for the Expected Utility Theory, it can be very useful to study some of the substantial part of literature devoted to these axioms and the empirical questions on whether individuals react in accordance with the axioms.

The theory on expected utility has been exposed to sharp criticism due to, amongst other things, that no empirical grounds exist for individuals to act in accordance with the assumptions in the axioms formulated by Neuman & Morgenstern. This discussion is based on several empirical tests, with many of these tests carried out in connection with the contingent valuation methods and dealt with in the discussions on biases in a contingent valuation survey. However, some of the issues in the critique will be discussed at this point, especially in relation to bias in the probability estimation, which is of greatest importance in relation to the subject matter of the next chapters.

A substantial amount of work has been carried out by Kahneman on this topic and, in 2002, he received the Nobel Prize for his work in this field. In co-operation with Amos Tversky, Kahneman began to develop the prospect theory in the 1970s, which takes what he terms “Bernoulli’s Error” as a theoretical starting point. The expected utility theory formulated by Bernoulli is independent of respondents’ initial situation. Prospect theory takes into account that individuals’ preferences are dependent on the initial situation. It is argued that utility-related gains and losses only can be measured if this is taken into account (Kahneman D. 2003). This can be interpreted as a rejection of the assumption that people have definite, transitive preferences, and this has been demonstrated in other empirical tests as well (Schoemaker 1982).

The underlying assumption of Axiom 2 is that people have established a continuity of preferences as a function of P. However, Allais (Allais & Hagen 1979) discovered that people overweight outcomes that are considered certain relative to outcomes that are merely probable. Hence, a reduction of the probability of an outcome by a constant factor has more impact when the outcome is initially certain than when it is merely probable. This phenomena has been labelled the certainty effect by (Tversky & Kahneman D. 1981).

From (Rottenstreich & Hsee 2001), it follows that preferences depend on the outcome – while some outcomes are relatively affect-rich (e.g. kisses and electric shocks) others are affect-poor (money), this not being consistent with the axioms. The authors showed that, in relation to affect-rich outcomes, respondents are more sensitive to departures from impossibility and certainty, but less sensitive to intermediate probability variations.

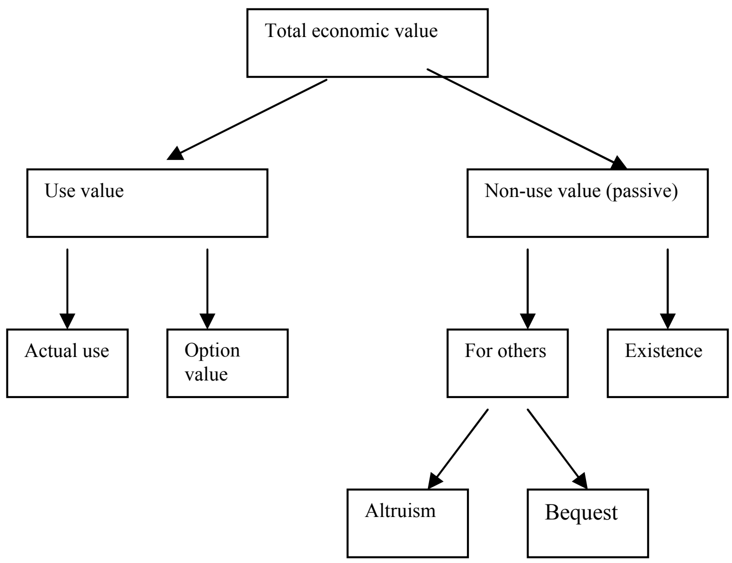
The fifth axiom can be shown to be violated due to so-called "anchoring bias". When estimating probabilities in a compound lottery many individuals will – after estimating the initial probability – use some heuristic (mental short-cuts or rules-of-thumb) to simplify the task of estimating the subsequent probabilities (Chilton, Jones-Lee, Loomes, Robinson, Cookson, Covey, Spencer, Hopkins, Pidgeon, & Beattie 1997). However, the adjustments made by the respondent are not always sufficient to arrive at an answer that assures that the valuation of a compound lottery will appear as attractive as the simple lottery. The fact that preferences are not independent of problem description has been labelled the pseudo-certainty effect (Tversky & Kahneman D. 1981).

Naturally, this critique raises some concerns on how to interpret the results from analysis in the expected utility framework. Schoemaker's point of view is that the expected utility models can be used as a benchmark – as a common point of departure and a theory with which individuals' behaviour can be compared. In using the model framework, opportunities are afforded to achieve a deeper insight into problems and to pose more refined questions (Schoemaker 1982).

2.3 Total economic value.

In the field of environmental economics, it is usual to divide the total economic value into use and non-use values. Use values can relate to both actual and planned use and, additionally, use value can be divided into actual use and option value. The concept of option value will be treated in the next section. According to Figure 2.4 below, non-use value can be classified as 1) existence value, which is characterised by the fact that the individual has no intention of using a particular good, and 2) the value of the good for others. The value for others can take an altruistic form, which means that the individual is concerned with whether the good is available to others in the current generation, or the form of a bequest value, where the concern goes to future generations (Bateman, CArson, Day, Hanemann, Hanley, Hett, Jones-Lee, Loomes, Mourato, Özdemiroglu, Pearce, Sugden, & Swanson 2002).

The concept of total economic value can be illustrated by the following figure:



Total economic value, figure 2.4 (Bateman, CArson, Day, Hanemann, Hanley, Hett, Jones-Lee, Loomes, Mourato, Özdemiroglu, Pearce, Sugden, & Swanson 2002)

However, consensus on how to define non-use values or existence value is far from being reached. There has been an intense debate which partly concerns whether these values can be measured and partly whether it is appropriate to include them in a CBA (Freeman, 2003).

In this discussion, it can be useful to take a step backwards and keep the original definition of the welfare function in mind. This assumes 1) that an individual's utility is dependent on the consumption of goods and services and 2) one individual's utility is independent on other individuals' utility.

By the very definition of existence value, it is not dependent on consumption of goods. However, the utility from an existence good could be included in the utility from the consumption of a related good. Accordingly, it would be included in the aggregation of the "use values". With regard to concern for others and for future generations, this could actually violate the assumption of mutual independence. Refer to Chapter 3 for a discussion of different forms of altruism.

However, the point is that, by the very definition of a welfare function, it takes only the value received from consumption into account (with regard to pure altruism, refer to Chapter 3 for a discussion). Accordingly, one can perceive the division of the total economic value into use and non-use values as an attempt to take into account that total welfare is perceived as more than an aggregation of the utility from consumption of goods and services.

2.4 Option price and option value.

Option value can as mentioned (Figure 2.4) be seen as part of the total economic value and it is also related to expected utility theory. The idea of option value was introduced in (Weisbrod 1964) and is relevant when uncertainty in demand is present. The commodity used in the paper by Weisbrod was a visit to a particular national park. From this example, Weisbrod makes the point that user charges are an inadequate guide to the total value of a park. Instead, this ought to be comprised of the sum of user charges and the value of an option-demand. The value of an option-demand arises from the existence of people who anticipate purchasing the commodity at some time in the future, but who never in fact purchase it. These people will (if they behave as "economic men") be willing to pay something for the option to consume the commodity in the future.

2.4.1 Definition of option value.

Since the article by Weisbrod, the literature has offered numerous contributions on this concept. However, there has been some confusion on how to define option value. The confusion centres on two points: 1) the relationship between consumer surplus (CS) and option value (OV), and 2) whether option value exists (Cicchetti & Freeman III 1971). It seems as if some kind of consensus on the following definition, which will be used in this paper, has developed (Bishop 1982), (Boardman, Greenberg, Vining, & Weimer 2001;Freeman III 1993):

$$OV = OP - E(CS) \qquad \text{[EQ 2.3]}$$

Assuming that the each person knows the probabilities of each of the contingencies that would occur under a policy, then this definition tells us that the Option Price (OP) is the maximum amount that the consumer would be willing to pay for a policy, prior to knowing which contingency will occur. E(CS), on the other hand, is the expected value of Consumer Surplus (CS), calculated by estimating CS under each contingency and multiplying this by the probability of each of the contingencies. Option Value (OV) is the difference between the two, i.e. E(CS) and OP[9]

In (Cicchetti & Freeman III 1971), it is demonstrated that OV will always be positive for risk-averse individuals. However, subsequently, in (Schmalensee 1972), it was proved that OV can be positive, negative or zero depending on "circumstances and individual preferences", refer to (Anderson 1981) for an explanation of the difference in the assumptions made by Freeman and Schmalensee). These arguments were later accepted by Freeman (Freeman III 1993).

---

[9] However Freeman argues that option value can not be measured separately because in a way OP and E(CS) are just two alternative ways of measuring the same welfare change and therefore the difference between the expected values can not be a separate component. Whereas E(CS) focuses on the consequences of the policies ex post after the uncertainty about the states have been resolved – hence E(CS) reflects a concern with *outcome*. (Freeman III 1989) From this definition it is clear that the ex ante and ex post terms refer to the timing of the evaluation and not the timing of the payment. However in (Wright & Williams 1988) it is preferred to use the terms *non-contingent* (ex ante) or *contingent* (ex post) instead. This way the confusion between the ex ante and ex post terms are avoided.

2.4.2 Analysis of the relation between WTP and Option Price, when uncertainty is present.

In the following, it is assumed that an individual's utility depends on the level of income Y and the adverse advent A*. There are two possible levels of the adverse advent: A* > 0 (welfare loss) and A* = 0. Following (Freeman III 2003) and (Freeman III 1985), the compensating surplus can be described in the following way:

v(Y,A*) = v(Y-D,0) [EQ 2.4]

D is the maximum sum of money the individual would give up to experience A* = 0 instead of A*. v(Y,A) is the ex-post indirect utility function which shows the maximum attainable utility given Y,A. Thus D is a form of compensating surplus (CS) measure of welfare change with the reference level of utility being the utility realised if A* occurs. Freeman's interpretation is that the value of reducing A* to 0 is the expected value of the monetary equivalent of avoiding a sure A* or πD (he assumes that individuals know the magnitude of the adverse advent and the probability (π) of its occurrence) and accordingly E(CS) is defined as πD.

However, the OP is a value seen from an ex-ante perspective and is defined for a reduction in the probability from π to π' by solving the following equation:

$$\pi v(Y, A*) + (1-\pi) v(Y,0) = \pi' v(Y - OP^{\pi}, A*) + (1-\pi') v(Y - OP^{\pi}, 0) \quad \text{[EQ 2.5]}$$

The option price represents, in this way, the state-independent willingness to pay ex-ante and is defined as the maximum payment the individual would make to change from the *status quo* risk to a situation in which A* would not occur. OP^{π} is also a form of CS, but the reference point is defined in terms of expected utility – and the similarity with the expected utility theory appears. By substituting EQ 2.4 in EQ 2.5, the following is arrived at:

$$\pi v(Y - D, 0) + (1-\pi) v(Y,0) = \pi' v(Y - OP^{\pi}, A*) + (1-\pi') v(Y - OP^{\pi}, 0) \quad \text{[EQ 2.6]}$$

The two different reference levels imply that OP and πD will not generally be the same.

The marginal value of a change in π (non-contingent) can be derived from the equation above by taking the total differential of the equation above, setting it equal to 0 and holding dA* at 0 in the following way:

$$\pi v(Y-D,0)+(1-\pi)v(Y,0)=0 \qquad \Leftrightarrow$$
$$\pi v'(Y,A^*)dY + d\pi v(Y,A^*) + v'(Y,0)dY - (\pi v'(Y,0)dY + d\pi v(Y,0)) = 0 \qquad \Leftrightarrow$$

$$\frac{dY}{d\pi} = \frac{[v(Y,0)-v(Y,A^*)]}{[\pi v'(Y,A^*)+(1-\pi)v'(Y,0)]} \qquad \text{[EQ 2.7]}$$

which is an expression of the willingness to pay ex-ante for a change in the probability of A*. The expression is positive when $d\pi<0$, indicating a positive willingness to pay for reductions in π. The formula illustrates that WTP ex-ante is the difference between the two states of nature (0 and A*) converted to a monetary unit by a weighted average of the marginal utilities of income in the two states of nature (Freeman III 2003).

Option price is now considered as being the correct measure of the benefit in a CBA with the presence of uncertainty (Boardman, Greenberg, Vining, & Weimer 2001;Freeman III 1989).

However, in practice, option price is difficult to estimate and, therefore, analysts most often estimate benefits in terms of expected surplus. As mentioned before, the sign of OV is dependent on several conditions and, hence, one cannot say anything on the direction of the bias.

2.5. Concluding remarks.

In this chapter, the foundation underlying CBA has been analysed and it has been demonstrated that the theory of consumer surplus and the potential compensation principle, together, provide a conceptual framework in which proposed policy changes can be analysed. Furthermore, the issues of uncertainty have been discussed together with the associated implications for CBA.

Some of the underlying assumptions of the utilitarian framework give cause for great concern with regard to the usefulness of the analysis - for example, that utility in its

original form only depends on consumption, the mutual independence of utilities and the given preferences.
However, the idea of using the net benefit criterion is, in itself, intuitively appealing and the methodology provides the basis for a thorough and consistent investigation of the costs and benefits with a given project. The framework can, therefore, in my opinion, be a useful starting point for analysis of non-market goods and, accordingly, a CBA can represent an important *input* to decision makers.

3 Valuing a change in the probability of dying.

In Chapter 2 it was stated given the presence of market failures, CBA has developed in order to help guide decisions makers. One example of a market failure is an externality and this has been defined in various ways. The definition by Pigou, below, has been widely used within environmental economics:

"Here the essence of the matter is that one person A, in the course of rendering some service, for which payment is made to a second person B, incidentally also renders services or disservices to other persons (not producers of like services) of such a form that payment cannot be exacted from the benefited parties or compensation enforced on behalf of the injured parties" (Quote (Pigou 1932)p. 183)

As can be understood from this definition, there are two essential points worth emphasising: 1) An externality concerns an effect on third parties – people not involved in the consumption or production of the good and 2) an externality can be categorised as either positive or negative.

One example of an externality is the change in mortality caused by a change in the level of air pollution. The purpose of the next section is the derivation and discussion of a theoretical framework for valuing a change in this particular non-market good. However, first of all, a definition of the good in question is needed.

3.1 Definition of the good.

Under ordinary circumstances it is reasonable to assume that no sum of money is large enough to compensate a man for the loss of his life. Accordingly, as pointed out by (Mishan E.J 1971), when accepting that the theoretical rationale should be a potential pareto improvement it would not be economically feasible to consider this when the benefit in question is number of identified lives. But Mishan further argued:

"It is never the case, however, that a specific person or a number of specific persons can be designated in advance as being those who are certain to be killed if a particular project is undertaken. All that can be predicted, although with a degree of confidence, is that out of a total of n members in the community an additional x members per annum will be killed (and, say, an additional ten x members will be seriously injured) (Quote p. 693 (Mishan E.J 1971))

This leads to the important finding that the good in question is the **value of a change in the probability of dying**.

The work by (Mishan E.J 1971) together with work by (Schelling 1968) are in the literature often cited as the first main works behind this concept. However, (Drèze 1962) was in fact the first to realize that the good in question is a change in the probability of dying. It follows from this discovery that we are dealing with decision-making under uncertainty and that the theoretical framework is maximisation of expected utility.

Drèze formalised the expected utility framework for dealing with changes in the probability of death. This framework was further elaborated by Prof. Michael Jones-Lee. He published his first article on the subject in 1969 (Jones-Lee 1969) and has since published a range of articles on this matter. His book from 1976 (Jones-Lee 1976) and the book which he edited, (Jones-Lee 1982), still represent some of the main contributions to the valuation of life literature.
The following analysis is based on the model developed in (Jones-Lee 1976) and (Jones-Lee 1974).

3.2 The static discrete-time problem.

Initially a single-period, discrete-time problem is considered.

The individual in the model begins the current period with wealth $\bar{w}$ and associates a *subjective* probability $\bar{p}$ with the outcome of his own death during this period. Using the expected utility framework and accepting the underlying axioms (refer to Chapter 2), his initial expected utility is then given by the following:

$$E(U) = (1-\bar{p})L(\bar{w}) + \bar{p}D(\bar{w}) \qquad \text{[EQ 3.1]}$$

With L(w) and D(w) being utility of wealth functions conditional on survival and death.
L(w) and D(w) are at least twice differentiable functions and in addition L(w) must be strictly increasing and strictly concave;

$$\frac{dL}{dw} > 0 \quad \text{and} \quad \frac{d^2L}{dw^2} < 0 \qquad \text{ASSUMPTION 3.1}$$

meaning that if an individual expects to survive the current period then it is assumed that he prefers to start the period with more wealth rather than less.
The individual is supposed to be financially risk-averse as well and, accordingly, the utility of wealth function is strictly concave (since it is preferred to have the expected value of wealth rather than facing a gamble).

On the other hand D(w) must be a non-decreasing and concave function, that is;

$$\frac{dD}{dw} \geq 0 \quad \text{and} \quad \frac{d^2D}{dw^2} \leq 0 \qquad \text{ASSUMPTION 3.2}$$

meaning that the individual will be assumed not to be misanthropic to his heirs in the sense that the individual will not wish to leave a negative bequest behind – but can prefer a bequest of zero. Besides, it is assumed that the individual does not wish his heirs more rather than less financial risk (see Jones-Lee 1974).

Furthermore the following is assumed;

$$L(W) > D(W) \qquad \text{ASSUMPTION 3.3}$$

Saying that the individual prefers the state of the world "life" to the state of the world "death". Moreover, it is believed that the individual is more sensitive either to the variant wealth or financial risk, if he expects to live rather than die during the current period and hence:

$$\frac{dL(W)}{dW} > \frac{dD(W)}{dW} \qquad \text{ASSUMPTION 3.4}$$

Consider next a situation in which the individual is offered the opportunity to reduce the probability of his death from $\overline{p}$ to p (p < $\overline{p}$), which represents a gain in welfare for the individual.

Based on EQ 3.1 and when V represents the maximum sum that the individual is willing to give up to leave him with the same level of *expected* utility as in the initial situation – the following appears:

$$(1-p)L(\overline{w}-V)+pD(\overline{w}-V)=(1-\overline{p})L(\overline{w})+\overline{p}D(\overline{w}) \qquad \text{[EQ 3.2]}$$

According to Jones-Lee, V represents, in this way, the Hicksian compensating variation in wealth from a change in probability from $\overline{p}$ to p (as defined in Chapter 2). However, in (Smith & Desvouges 1987), it is emphasised that V is actually an Option Price. This is also apparent from the following:

Differentiating the equations with respect to p, presents us with the following result:

$$L'\frac{\partial V}{\partial p}-(L+pL'\frac{\partial V}{\partial p})+D+pD'\frac{\partial V}{\partial p}=0 \qquad \Leftrightarrow$$

$$(L'(1-p)+pD')\frac{\partial V}{\partial p}=L-D \qquad \Leftrightarrow$$

$$\frac{\partial V}{\partial p}=\frac{L-D}{L'(1-p)+pD'} \qquad \text{[EQ 3.3]}$$

Where

L = L(W-V) , D = D(W-V) , L′ = $\frac{\partial L(\overline{W}-V)}{\partial V}$, D′ = $\frac{\partial D(\overline{W}-V)}{\partial V}$;

$\frac{\partial V}{\partial p}$ exactly corresponds to e the ex-ante willingness to pay for a change in p derived in Chapter 2 [EQ 2.7].

As mentioned in Chapter 2, the interpretation of EQ 2.7, and accordingly EQ 3.3, is that the willingness to pay ex-ante is the difference between the utility of the two states of nature (0 and A* or D and W) converted to a monetary unit by means of a weighted average of the marginal utilities of income in the two states of nature.
However, as mentioned in Chapter 2, marginal willingness to pay is an expression of the *marginal rate of substitution*, as well. EQ3.3 is, therefore, an expression of the

relation between marginal utility of wealth and a change in survival probabilities and, thereby, a measure of marginal utility in the expected utility sense[10].
The numerator in EQ 3.3 is always positive due to assumption (ass) 3.3.

From ass. 3.1 and ass 3.2, we know that $\frac{dL(W)}{dW} > 0$ and $\frac{dD(W)}{dW} \geq 0$. With L and D depending only on W and with V being a part of W this means that $\frac{\partial L(\overline{W} - V)}{\partial V} < 0$ and $\frac{\partial D(\overline{W} - V)}{\partial V} \leq 0$

When accepting that $\frac{dL(W)}{dW} > \frac{dD(W)}{dW}$ (ass. 3.4), one can then infer that $\frac{\partial L(\overline{W} - V)}{\partial V}$ < $\frac{\partial D(\overline{W} - V)}{\partial V}$ ≤ 0 [11].

Hence, the denominator in EQ 3.3 is negative and one can conclude that $\frac{\partial V}{\partial p} < 0$.

Moreover, from further calculations it can be shown that $\frac{\partial^2 V}{\partial p^2}$ < 0. Refer to (Jones-Lee 1974)

Therefore, the function of V is characterised by a decreasing slope, concavity and has the general form as depicted in Figure. 3.1

[10] However it must be emphasised that marginal utility has a rather different meaning in the expected utility theory and in the classical economics. In the classical economics marginal utility refers to certain increments in pleasure under certainty whereas in the expected utility theory marginal utility is referring to "the marginal rate of substitution between (the ratios of the marginal utilities of) income and the probability of winning the prespecified prize." (p. 669) (Baumol 1958)

[11] A more intuitive interpretation; V↑ → (W-V)↓ . With D and L depending only on W; an increase in V means a larger change in the value of L than D due to the assumption above.

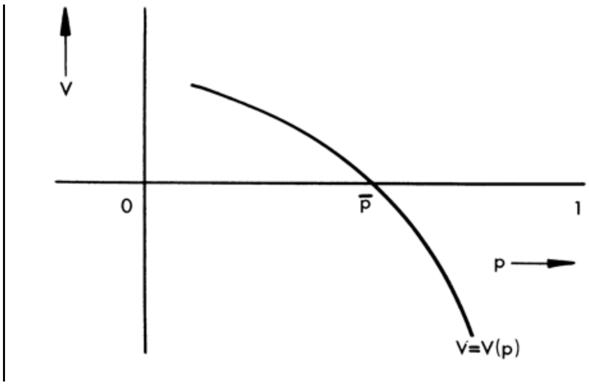


Fig 3.1 The functional form of V(p) Jones-Lee(1974)

From Figure 3.1, it can be seen that for p < $\bar{p}$, V is positive since the individual will be prepared to give up wealth in order to obtain improvements in safety. On the other hand, for p > $\bar{p}$, V is negative since the individual will require compensation in order to accept a deterioration in his or her safety.

For policy purposes the primary concern is the small effects upon the safety of life and, therefore, $\frac{\partial V}{\partial p}$ evaluated at p = $\bar{p}$ is especially interesting.

When p = $\bar{p}$, it follows that V= 0 and $\frac{\partial V}{\partial p}$ evaluated at p = $\bar{p}$ is then given by the following:

$$\left(\frac{\partial V}{\partial p}\right)_{\bar{p}} = \frac{L(\overline{W}) - D(\overline{W})}{(1-\bar{p})L'(\overline{W}) + \bar{p}\overline{D}'(\overline{W})} \qquad \text{[EQ 3.4]}$$

$-\left(\frac{\partial V}{\partial p}\right)_{\bar{p}}$ is an expression of the marginal value of a decrease in risk seen from the initial risk level and it is interesting to investigate how this expression varies with initial risk. Using the product rule of differentiation, the following result appears.

$$\frac{\partial(\partial V/\partial p)_{\bar{p}}}{\partial \bar{p}} = \frac{(D-L)(D'-L')}{\left[(1-\bar{p})L' + \bar{p}D)\right]^2} \quad \text{[EQ 3.5]}$$

Due to the assumption that L>D and L′≤ D′, the expression above is negative or 0.

However, EQ 3.4 and EQ 3.5 represent the situation in Figure 3.1 with p > $\overline{p}$ and V being negative, since the individual will require compensation in order to accept a deterioration in his safety.

Then intuitively it is more understandable to rewrite EQ 3.5 and look at a situation with p < $\overline{p}$ instead:

$$\frac{\partial(-(\partial V)/\partial p)_{\overline{p}}}{\partial \overline{p}} = -\frac{(D-L)(D'-L')}{\left[(1-\overline{p})L'+\overline{p}D)\right]^2} > 0 \quad \text{[EQ 3.6]}$$

This interpretation is that the marginal value of a decrease in risk is **an increasing function of initial risk.**

By differentiating with respect to W instead, the following appears:

$$\frac{\partial(\partial V/\partial p)_{\overline{p}}}{\partial \overline{W}} = \frac{\left[(1-\overline{p})L'+\overline{p}D'\right](D'-L')+(L-D)\left[(1-\overline{p})L''+\overline{p}D''\right]}{\left[(1-\overline{p})L'+\overline{p}D'\right]^2}$$

Based on the assumption that L>D, L'<D'≤ 0 and L''<D''≤0, the expression is negative and, therefore, the marginal value of a decrease in risk is an increasing function of initial wealth and a safety-improvement is a **normal good.**

To sum up, the analysis above shows that the marginal value of a decrease in risk is an increasing function of **initial risk** and an increasing function of **initial wealth**. According to the previous analysis, the aim of a CBA should be an allocation of funds in a way that relatively more is allocated to marginal reductions of high income individuals with higher-level risk.

3.2.1 Some determinants of the willingness to pay.

As demonstrated above, the initial risk and initial wealth are some essential determinants of the willingness to pay for a change in the probability of dying and will, therefore, be given specific interest in this section.

3.2.1.1 Initial risk.

An imaginary game of Russian Roulette has often been used in order to illustrate the findings of how the initial risk influences the value of a decrease in risk, see e.g (Weinstein, Shepard, & Pliskin 1980). One can picture a game of Russian Roulette and, to begin with, assess the willingness to buy for the removal of one bullet, with all six chambers loaded. Then, when five chambers are loaded, the willingness to buy for the removal the next bullet is assessed. According to the findings of Jones-Lee, the willingness to pay for the removal of one bullet would be monotonically decreasing, from the highest base probability (bullets in all six chambers) to the lowest.[12]

The intuitive reason for the higher WTP is that marginal assets are valued more highly in life than in death. When the underlying probability of death is high, the individual will be more willing to give up money, because then it is relatively more likely that the payment would come out of the legacy instead of the lifetime assets (Weinstein, Shepard, & Pliskin 1980) .

3.2.1.1.1 Empirical evidence.

However, the empirical evidence on this theoretical finding has been mixed.

Studies by (Horowitz & Carson 1993;Viscusi & Evans 1990) both conclude that the additional compensation required to accept an increase in risk (based on a subjective assessment) is greater for a high base risk – as predicted by the economic model of Jones-Lee. However, based on the empirical evidence, the study by Horowitz also offers some alternative explanations of the results (refer to (Horowitz & Carson 1993)).

On the other hand, in (Smith & Desvouges 1987) it is demonstrated empirically that the estimated marginal valuation of risk decreases with increases in initial risk and, therefore, the Jones-Lee conclusion is rejected. As (Horowitz & Carson 1993) argue, this could be due to the fact that, in the study by Smith, "objective" measures of risk are used and not subjective assessments as in the Jones-Lee framework and in the

[12] It must be stressed that the analysis by Jones- Lee concerns marginal changes, whereas the changes in the game of Russian Roulette cannot be called marginal. Still, a point is illustrated. However (Hammit & Graham 1999) note that the movement from 2 to 1 may have an illusion of superiority, because of the relative percentage difference (50% as opposed to 16.7 %), but this temptation is eliminated by focusing on the absolute risk reduction.

empirical works by (Horowitz & Carson 1993). However, others have argued that the theoretical findings from Jones-Lee empirically do not apply. Based on the imaginary game of Russian Roulette, Raiffa (as quoted in (Weinstein & Quinn 1983)) argues that individuals would not behave as assumed. Instead, individuals would pay more to reduce the number of bullets from 1 to 0 instead of from 5 to 4. This is what has been called the "Russian Roulette Paradox" or, more generally, "certainty effects" by (Kahneman D. & Tversky 1979). As discussed in Chapter 2, the certainty effect is a common seen violation of the expected utility framework and is not specific to the valuation of a change in the probability of dying.

In the Jones-Lee model, we are not dealing with reductions that eliminate the risk of dying from a specific cause. It seems as if there is evidence indicating that individuals value a change in the probability of dying higher when the initial risk is higher. Still the "Russian Roulette Paradox" raises concern of whether individuals perceive a change in the probability of dying in accordance with the NM axioms.

3.2.1.2 Initial wealth – empirical evidence.

As previously stated, the theoretical framework presented by Jones-Lee implies that valuation of a change in risk is an increasing function of initial wealth (the willingness to pay depends on the ability to pay).

This result has been empirically tested. However, it is rarely possible to test the relation between initial wealth and the value assigned to the risk reduction empirically. Another option is, then, to view income as a substitute for wealth. However, one can imagine this might not comprise a good approximation in all cases. In most cases a positive relation has been found between income and risk reduction – see e.g. the surveys by (Jones-Lee, Hammerton, & Phillips 1985);(Kidholm 1992) in which positive elasticities between 0 and 1 are found. Accordingly, if income is a proxy for wealth, the results from Jones-lee apply empirical.

3.2.2 A note on distribution.

Based on the results from the Jones-Lee model and the empirical findings, one can conclude that a conventional CBA seems to direct scarce safety improvement resources towards individuals with a relatively high-income and a high baseline risk of dying. This illustrates the importance of the discussion on distributional effects mentioned in Chapter 2.1.4. The discussion on distribution, however, will be postponed to another occasion. As a result, the essential discussion on the value of a change in the probability of dying in developing countries as compared to industrialised countries will not receive attention in this paper.

3.2.3 Other determinants of the willingness to pay.

There are determinants of the value of a change in the probability of dying other than initial risk and wealth. One of them is whether a latency period from the policy change to the experienced change in probabilities influences the valuation. However in order to analyse the effect of latency the time dimension has to be included and, accordingly, latency will be analysed in a multi-period setting in Chapter 5. By introducing a time dimension, it is also possible to analyse how the age of the individual influences the valuation. Evidently, in the static setting it is possible to compare how *different individuals* value a change in the probability of dying. This will be carried out in Chapter 4, where the empirical use of the static period framework is analysed. However, as can be seen from the analysis in Chapter 6, some very useful considerations can arise from an analysis of how values change throughout life in the multi-period setting. Moreover, the influence of the preferences for bequest will also be analysed in the multi-period setting.

3.2.3.1 Health

One could presume that the health status of the individual could influence the valuation of a change in the probability of dying. Hence, it is interesting to take a look at EQ 3.3 and attempt to determine whether, in the static setting, there is something to note on this matter.

If poor health limits the individual's opportunity to improve well-being by spending money, the marginal utility of wealth may be smaller if survival will mean poor health. This means that the denominator in EQ 3.3 will be smaller if survival means bad health. However, if the utility of being alive with a poor health-status is smaller than the utility of survival in good health, then the numerator will be smaller as well. In this way, the sign of the difference between WTP(good health) and WTP(bad health) depends on whether the effects of the health status on the marginal value of wealth outweigh the effects on the total utility of surviving (Hammit 2000). Some empirical results on this matter will be presented in Chapter 4.

In order to combine the QALY (Quality Adjusted Life Year) measure used in health economics with the valuation of the change in the probability of dying the influence of the health status has been analysed in a multi-period setting (refer to Chapter 6).

3.3 **Problems with the traditional welfare measures**.

In subjecting the Jones-Lee model to closer examination, the need for a multi-period setting has already been demonstrated. However, it is the case that some additional problems and issues arise.

3.3.1 Anxiety.

In (Smith & Desvouges 1987), it is emphasised that the value V in the terminology of Jones-Lee is an option price as defined in Chapter 2. A reflection on the consequences of this is found in (Mooney 1977). The argument here is that one could perceive the valuation of a change in a mortality risk as consisting of the valuation of risk *per se* and the associated anxiety (a so-called "fear factor") In Weisbrod's (Weisbrod 1964) framework, this is equivalent to value in use (risk *per se*) and value in anticipation/ option price (anxiety). One can argue, as does (Schelling 1968), that there are good reasons to believe that the value of a risk reduction *per se* is proportionate (or nearly proportionate) to the absolute reduction of the risk consequences. However, this is unlikely to hold when valuing anxiety:

"Relief from anxiety is a strange kind of consumer good. What the consumer buys is state of mind, a picture in his imagination, a sensation. And he must decide to do so by using the same brain that is itself a source of his discomfort or pleasure." (quote (Schelling 1968) p. 146)

Anxiety could explain some of non-linearity in changes in probabilities seen empirically (Dwyer 1986)(refer to Chap. 4). In particular, anxiety could clarify some of the "certainty effect" (the Russian Roulette Paradox) as well. The "certainty premium" does appear in an empirical study by (Viscusi, Magat, & Huber 1987). This can partly be explained by the fact that when all risks are eliminated, anxiety associated with uncertainty is reduced and any decision-making costs associated with thinking about a probabilistic outcome are eliminated.

The discussion about anxiety is important in the discussion of whether a change in life expectancy should be valued instead of a change in the probability of dying (Chapter 6).

3.3.2 Subjective vs. objective probabilities.

The set- up of the Jones-Lee model is based on subjective probabilities and in that sense $\bar{p}$ represents the respondent's personal assessment of the risk he is facing. There are no reasons to believe that subjective and objective probabilities are equal, or even of the same functional form. One could imagine that subjective assessments of probabilities, as a function of objective probabilities, follow a step-wise functional form or will display a so-called "hysteresis effect", as shown in the figure below, in which p_s is the subjective and p_o the objective probability.

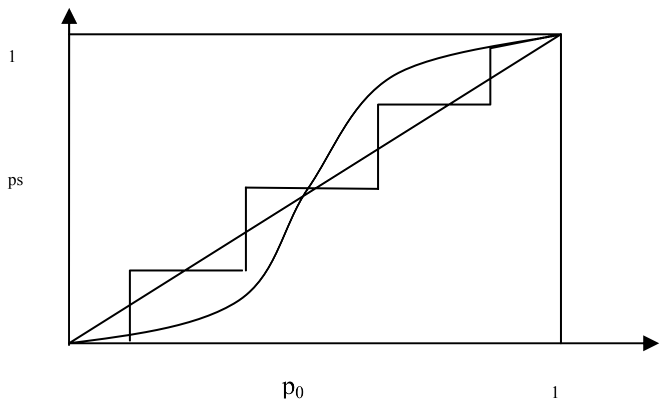


Figure 3.2 (Jones-Lee 1980)

Both the step-wise form and the "hysteresis" form imply that most people, in fact, may ignore a very small change in risk, which is not in accordance with the NM axioms. Jones-Lee's view on that matter is that one should try to determine the sums that people *would pay* for a given initiative if their subjective assessments of the consequent risk reduction corresponded with the expert's assessments (the objective probability). However, this is very hard to do in practise and the best one can do is to use available information on preferences and attitudes to form an educated guess.

Jones-Lee emphasises the problem of estimating the marginal rate of substitution between the subjective probabilities and wealth as being the most serious critique of his model. This critique is obviously related to the assumption of the "typical individual" being an expected utility maximiser behaving in accordance with the von Neumann Morgenstern axioms.

3.3.3 Contextual factors.

The analysis above is carried out in the framework of traffic safety. However, the VSL method has been used in many other areas as well. In this connection, it is appropriate to consider whether one should expect the same trade-off between money and changes in the probability of dying in different areas. To put it in other words; to find out whether "a universally transferable" value exists for the prevention of a fatality?

Context effects arises as;

" a result of people's perception of, and attitudes towards, the context or circumstances in which an accident might happen"
(Quote p 187 (Jones-Lee & Loomes 1995))

It has been suggested that the following characteristics of a risk could influence value: voluntariness of exposure, control and responsibility.

The direction of the influence of the mentioned factors has been investigated theoretically as well as empirically and the results have been very mixed. Refer to (Vassanadumrongdee & Matsuoka 2005) for a description of different studies concerning the risk characteristics. Anxiety must be mentioned as a contextual factor as well. People will attach different sorts of anxiety to different ways of dying – e.g. one would imagine that an individual is more risk-averse to death resulting from exposure to carcinogens as opposed to death caused by an airplane accident. The next chapter will contain a description of different empirical VSL studies together with the various characteristics relating describing risk in the different surveys.

Even if empirically there seems to be some contextual effect, one could argue that "a value of a change in the probability of dying" for consistency reasons should be given equal value no matter what context. However, if the individual's value depends on context and society's valuation is based on aggregation of individuals, then assigning equal value to a change in the probability in different contexts should be grounded on some kind of distributional reasons.

3.3.4 Public or private good.

A problem related to the issue of context is whether one can characterise the change in risk as a public or private good.

The definition of a public good is that it is **non-exclusive** and there is **non-rival consumption.** I.e. an individual cannot be excluded[13] from using the good and an individual's consumption of the good does not reduce the utility other individuals can derive from the good (Folland, Goodman, & Stano 2004).

One cannot exclude individuals from receiving a risk reduction from a public project which is implemented and, moreover, one individual's risk reduction does not reduce the utility of other person's risk reduction. However, if valuation of a reduction in risk is carried out through considerations of individual treatment (e.g. the intake of medicine), individuals can be excluded from the risk reduction. Hence, a change in the probability of dying should rather be described as a private good (Krupnick et al. 2002);(Alberini 2004). Accordingly, a change in an individual's risk of dying can be characterised as a public or a private good, depending on how this risk reduction arises.

However, not all valuation methods allow valuation of risk reduction as a public good. This discussion will be returned to in the next chapter.

[13] The characteristic of non-excludability can result in the "free-rider problem". Free-riding means that someone who benefits from the public good will not voluntarily contribute to its provision.

3.3.5 **Altruism**.

Altruism has already been mentioned in Chapter 2. Altruism arises if the WTP of an individual reflects not only concern for their own consumption but concern for the consumption of others as well (Bateman, CArson, Day, Hanemann, Hanley, Hett, Jones-Lee, Loomes, Mourato, Özdemiroglu, Pearce, Sugden, & Swanson 2002). Hence, the presence of altruism can have consequences for the summation of the individualistic valuations of the change in the probability of dying. The consequences depend on the nature of the altruism. The different kinds of altruism have been given much attention in the literature and many different definitions have developed (refer to (Sen 1977) for one example).

However, the definition and discussion of altruism in this paper will be based on the definition used in (Jones-Lee 1991;Jones-Lee 1992), where altruism in the valuation of a change in the probability of dying is analysed. Based on the framework developed by (Bergstrom 1982), Jones-Lee analyses different types of altruism on a continuum with pure self-interest and safety-focused altruism as the opposite extremes, and pure altruism and pure paternalistic altruism as the middle cases.

*Pure self-interes*t is the situation in which the individuals are concerned only with their own utility, as assumed in basic welfare theory, refer to Chapter 2[14]. If people's concern for others relates solely with their safety, it is called *safety-focused altruism*. A situation in which people are concerned about the general level of utility for other individuals (and thereby respecting their preferences) is labelled *pure altruism*. *Pure paternalism* is a description of the situation in which one could imagine other people simply as extensions of one's own person. Hence, if a person is concerned for another individual, the concern would be based on that the individual has the same preferences as oneself.

Jones-Lee demonstrated theoretically that a situation with pure self-interest, pure altruism or pure paternalistic altruism will result in the same aggregated value of the valuation of changes in the probability of dying (Jones-Lee 1992). Yet this seems not to be the case when safety-focused altruism is present. The definition of safety-focused altruism is, as mentioned above, that people are only concerned with other

[14] As emphasised by Strand, the concern for other people can be purely selfish as well – e.g. the presumable negative utility from the event that the spouse dies or if the survival of the spouse affects ones consumption.(Strand 2005)

people's safety and, in addition, ignores other factors that contribute to their utility. However, to push values of safety beyond the level implied by people's willingness to pay for their own safety would exactly result in an overprovision of safety relative to the other determinants of their utility. This is the reason why inclusion of a sum reflecting people' WTP for other person's safety is appropriate in these cases.
Accordingly, it is important to find out which form altruism takes. Whether altruism is mostly pure or safety-focused is, of course, an empirical matter and in Chapter 4, an empirical investigation of altruism will be presented. A related problem is the concern for the preferences of future generations (preferences for bequest), related to bequest value, which will be discussed in Chapter 5.

3.3.6 Money and survival as complementary goods.

A question raised by Linneroth in (Linneroth & 1982) is whether traditional welfare measures (Hicks' CV and EV) can be used when the good to be valued is a change in mortality risk. The reason why Linneroth raises this question is that money and survival probabilities are complementary goods, because when a person's survival chances decrease, the value of the money decreases too, since they may not be around to enjoy it. Accordingly, money as an evaluator has a value that is not independent of what it is valuing (or money is not a substitute for the benefit in question (Bateman, CArson, Day, Hanemann, Hanley, Hett, Jones-Lee, Loomes, Mourato, Özdemiroglu, Pearce, Sugden, & Swanson 2002)).
Linneroth does not argue that the value of life is infinite, but points out a difficulty in measuring it in monetary terms. Due to the above-mentioned difficulties in measuring the value of life in monetary terms, she argues that the difference between CV and EV turns out to be very important when applied to valuing changes in mortality risk. However, the issue is not as important when dealing with marginal changes and, hence, one does not get captured in what she terms, "The Money-is-Worthless Trap" (p=0), which is an infinite compensation in the CV framework or "The Nothing-as-Bad-as-Death Trap (with the marginal utility of money going to 0)[15] in EV.

[15] A person may perceive a level of debt at which his life would no longer be worth living or alternatively a person may perceive life to be worth living no matter how bad the circumstances, Linneroth (p. 244).

In connection with the discussion on what can be measured and what cannot, it is important to remember the distinction between the ex-ante and the ex-post perspective introduced in Chapter 2. In the framework of valuing a change in the probability of dying, it is apparent that one cannot use the ex-post measure. The Consumer Surplus for a certain death is indefinite ("The Money-is-Worthless Trap". The ex-ante perspective is, hence, the only reasonable solution (a related argument was found in Mishan, mentioned at the beginning of this chapter).

3.4 **Value of a statistical life (VSL)**.

Up until this point, valuing a change in the probability of dying has been considered. However, in a CBA it is useful to aggregate the individuals' valuations of a change in the probability of dying. A procedure for aggregating empirical results has developed. This aggregation has been named "Value of a Statistical life" (VSL) and the procedure of aggregation is illustrated in EQ 3.7.

$$VSL = \sum_i WTP_i \Delta p_i \Big/ \sum_i \Delta p_i \qquad \text{[EQ 3.7]}$$

(Pearce 2000)

With $\sum_i WTP_i$ being the sum of individuals' WTPs for the change in the probability of dying over N individuals

Δp_i = the change in risk

N = number of persons exposed

$\sum_i \Delta p_i$ = Number of statistical lives saved or lost = $N \Delta p$

The value has been given another name by WHO: "Value of Preventing a Statistical Fatality (VPF) (Sommer et al. 1999). As I will argue later on, it is my opinion this name should be preferred.

3.4.1 The interpretation of VSL.

It is important to point out some matters before the aggregating procedure is discussed:

1) It has been demonstrated theoretically ((Jones-Lee 1974;Weinstein, Shepard, & Pliskin 1980), as well as empirically, that the marginal value of a risk change depends on the initial risk level.

2) Another matter which can be seen from Figure 3.1 is that the value (V) of a change in risk (keeping initial risk at a constant level) is not proportional to the change in risk (a decreasing slope of V(p), $\frac{\partial V}{\partial p} < 0$). This is also seen empirically and some additional theoretical and empirical explanations will be given in Chapter 4.

3) The aggregating procedure mixes subjective and objective changes in probabilities. VSL is an aggregation of the individual's value of their subjective changes in probabilities, divided by an objective measure of the change in probability. This has previously been discussed.
The name VSL could indicate that the value of saving a "statistical person" is found. However, if VSL is interpreted as the value of reducing one single individual's probability of dying from 1 to 0, then point 1) and 2) are ignored. VSL should, therefore, be labelled with conditions – ~VSL(initial risk, risk change) – and the correct interpretation should be, for example, the value of 1000 individuals' reduction in their probability of dying, from 4/1000 to 3/1000.
This illustrates why, in my opinion, the term VPF should be preferred. Eventually, we are all going to die – the death of an individual can be postponed, but a fatality can be avoided.

In addition to these obviously critical points with regard to the aggregation procedure, the term "Value of a statistical life" has lead to some misunderstandings in the discussions on the concept. The nature of these misunderstandings will be discussed in the following section.

3.4.2 The meaning of a statistical person.

The theory behind the value of a statistical life is formulated in terms of changes in probabilities. However, due to the fact that people have difficulties understanding probabilities, the phrase "1 out of 1000 persons will die" is often used in contingent value studies. Therefore, it has been argued by some, that the value found is the value of a "statistical person" and has nothing to do with valuing our own life. However, it is important to keep in mind that the theoretical foundation behind the valuation procedure is based on the valuation of a change in one's own probability of dying.

In this connection, it could be useful to distinguish between a so-called anonymous death and a statistical one. This distinction is found in (Keeney 1980) and, according to his terminology, an anonymous death is based on the valuation of a change in probabilities (one expected death), whereas a statistical death is the valuation of saving a certain unidentified person (i.e. the opposite way round compared with the Jones-Lee terminology). The two concepts will not be regarded equally desirable by society due to the different probability distributions (Hammerton, Jones-Lee, & Abbott 1982), but still they are, as mentioned, used interchangeably in empirical surveys. Accordingly no distinction is made between a statistical and an anonymous life.

3.5 The historical development.

3.5.1 The human capital approach.

Finally, it is appropriate to consider another approach which historically has been used.

The first published literature on the concept of "putting value on a life" was actually found as early as 1930 in the book by (Dublin & Lotka 1930). In this book the "money value of a man" was interpreted as the value of a wage-earner. Dublin's comparison of the valuation of a man with the valuation of industrial equipment has later resulted in the name "human capital approach". In his book, Dublin argued that putting a price on a man is not a new concept and mentions the traffic in slaves as the historical analogue.

Another of the earlier contributions in the literature is found in (Reynolds 1956). The contribution from this article was to consider the costs to society of a road accident in two parts:

(i) the pain, fear and suffering imposed by the occurrence, or the risk of occurrence of road accidents.

(ii) net loss output of goods and services and medical expenses, vehicle repairs and costs of administration.
Reynolds argues that it is beyond the competence of the economist to assign objective values to (i) and that is why his paper concerns itself with estimation of the costs in (ii).

3.5.1.1 Critique of the human capital approach.

The different variants of the human capital approach are criticised, among others, by Mishan (Mishan E.J 1971)) and (Bergstrom 1982). Mishan argues that using the loss of potential earnings as a proxy for the value of life can only be justified when accepting that the goal of economic policy is maximising GDP or net national product. Most writers regard GDP as only part of total measurement. However, use of the net output method can be justified by saying that

"what matters to the rest of the society is simply the resulting loss, or gain, to society following the death of one or more of its members" (Quote p 690, Mishan, 1971)

According to Mishan, the problem with this way of reasoning is that the approach focuses on surviving members of society – it ignores society ex-ante and concentrates on society ex-post. (Mishan E.J 1971)[16]
In addition to the loss of potential earnings and the net output method, Mishan examines two other methods. One approach would be to use implicit values with regard to saving lives in society as a result of political decisions. Another method would be to base the value on how much an individual is willing to pay in insurance premium and his probability of being killed when engaging in some specific activity.
The fundamental problem with all the four methods mentioned by Mishan is the reality that none of them are consistent with the theoretical rationale for Cost Benefit Analysis and the notion of a potential pareto improvement (see Chap. 2).
However, despite the heavy criticism, this method has, to date, been widely used empirically. In Denmark, the official recommendation is still to use the human capital approach in the traffic sector for the valuation of a death (Trafikministeriet 2004). Here, the human capital approach is supplemented with a so–called "welfare loss" (2

[16] As mentioned in Chapter 2, it is agreed by economists that CBA should be based on the ex-ante perspective (However. Broome is of the opposite opinion (Broome 1978)).

times the "person–related costs"). No theoretical or empirical justification is given for this factor of 2[17].

3.6 Concluding remarks.

The figure 3.3 below summarizes the findings of this chapter. As can be seen, a theoretical foundation for valuing a change in the probability of dying has been presented. In addition, it has been shown that the marginal value of a decrease in risk is an increasing function of **initial risk** and an increasing function of **initial wealth**. Accordingly, an increase in safety is a normal good and one could argue that, in relation to CBA, the goal should be an allocation of funds in a way that relatively more is allocated to marginal reductions of the higher-level risk.

However there are some problems with the framework derived in this chapter. In the figure they have been divided into the problems that can be attributed directly to the expected utility framework and the ones specifically attributable to the valuation of a change in the probability of dying. I realise that it is arbitrary to stress some problems as specific to the valuation of mortality because it is an assumption in the welfare economic framework that we have consistent well-established preferences no matter the good in question. Due to the exceptional characteristics of this good, I have chosen this division in order to illustrate some points.

One of the more worrying findings concerns the subjective assessment of probabilities. This has been discussed in this section and it one of the most serious objections to the framework.

In my opinion the finding that money and changes in the probability of dying are complements also makes valuing a change in the probability of dying complicated. However, one could argue that this is not a problem when only looking at marginal changes, which is the purpose of a CBA. Still, the difficulties with measuring very large changes in the risk of death with a money measure could mean that a standard based on years of life expectancy might be more appropriate. This is part of the logic behind using a cost-effectiveness analysis in health economics and using number of life-years saved as a measurement of the benefit. Hereby, the monetary measure is

[17] This way of calculating the costs has been removed in the recently updated version (February 2006). However no alternative calculation method is given.

avoided. However, this raises another discussion on whether one can apply the unit of a "life-year" to value changes in risk. Can one use the unit of "years of life expectancy" to measure e.g. the anxiety arising from a change in the death risk? Or, is this unit as problematic as money when valuing e.g. anxiety? Moreover, one could argue that a change in the risk of death changes the marginal value of a life-year as well as the marginal value of money. These questions will be examined in the life-cycle consumption models in Chapter 5 and 6.

Finally the term "value of a statistical life" has been criticised. This aggregation should in my opinion be avoided because the VSL is a confusing name and does not clearly say what is being valued. However I realise, that aggregation can be necessary aggregating in some CBA's – but then the VSL should at least be labelled VSL(risk change, initial risk) and I would prefer the VPF term to be used instead.

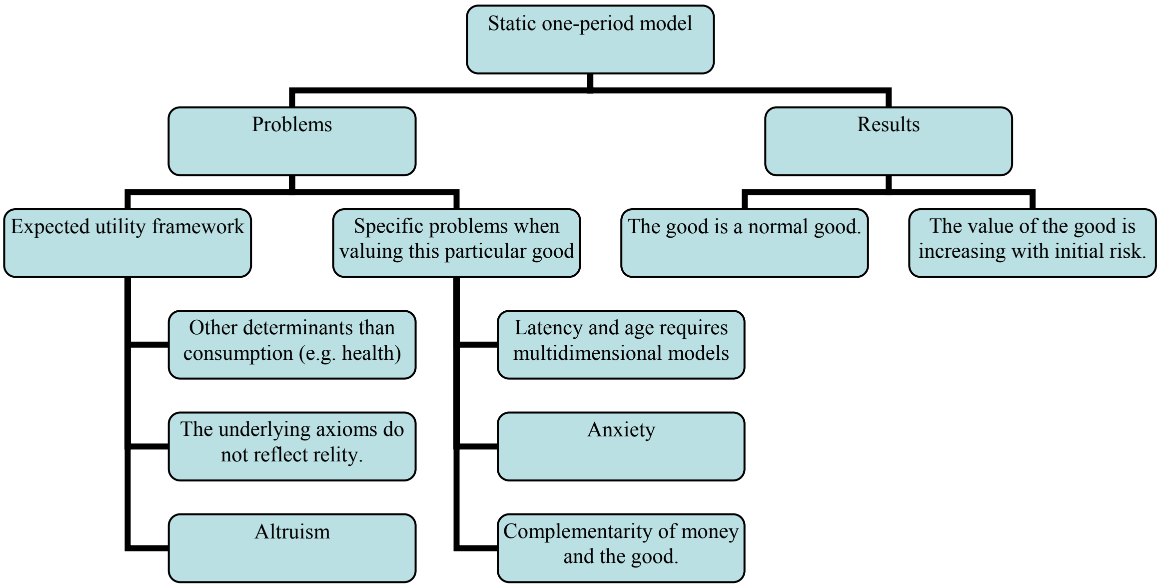


Figure 3.3. The Static one-period Model, main results and problems.

4 Empirical estimates – procedures and some results.

After the theoretical foundation of the valuation of a change in the probability of dying was presented in Chapter 3, this chapter now concerns some empirical issues. A description and evaluation of the different procedures of estimating willingness to pay, the determinants of willingness-to-pay and some estimates of the Value of a Statistical Life will be provided.

The principal distinction between the empirical methods used is based on the source of the data. (Mitchell & CArson 1989). The data can either be found directly from observations of people acting in the market or from people's responses to hypothetical questions. Hence, the willingness to pay can be estimated indirectly based on "revealed" preferences or directly via "stated" preferences (Freeman III 2003).

Since the empirical part of the PhD project will be based on the Contingent Valuation Method, the empirical estimates discussed in this section are mainly from Contingent Valuation surveys.

4.1 Revealed preferences.

4.1.1 Hedonic pricing

One way of deriving the WTP for a small change in the probability of dying is by means of the hedonic pricing methods. A hedonic price technique is;

"a method for estimating the implicit prices of the characteristics that differentiate closely related products in a product class." Quote p. 123 (Freeman III 2003)

A job can be considered as a differentiated good and wage differentials can be interpreted as the implicit prices of job characteristics. The wage-risk method has been widely used to estimate a change in the probability of dying – in particular in the USA (refer to (Viscusi & Aldy 2003)). In Denmark, there has been only one attempt (Pedersen 1983).

4.1.1.1 Hedonic wage methodology.

The basic foundation of a wage-risk study is that one is able to characterise a job by a vector of attributes such as accident risk, stress, noise, etc. The method builds on the suggestion by Adam Smith that individuals can be induced to take risky jobs through a set of compensating differentials in wage rates and, hence, the labour market can be viewed as providing a mechanism for implicit trading in risk[18] (Thaler.R. & Rosen 1975). Workers behave as if they maximise expected utility with accident risk being one of the arguments in the utility function. By accepting different assumptions regarding the variables in the wage-risk equation, it is possible to estimate the size of the compensation differentials in the specific population investigated.

The advantage of the hedonic wage methodology is clearly that it is based on actual choices made by the individual in the market. However, some concern with application of this method is raised and some of the problems will be examined below (refer to (Acton 1976) and (Viscusi & Aldy 2003) for a fuller examination).

- To determine a value for a risk change by this measure requires that the person is working and, therefore this method offers no solution to what value to put on the life of e.g. a retired person in a society perspective.
- Another concern is how representative the observed group is. *Self-selection* is likely to occur due to the fact that individuals who are the least risk-averse will enter a given occupation before those who are more risk-averse. Consequently, lower risk premiums will be given to those selecting the given occupation than to a randomly chosen individual.
- For there to be a risk-dollar trade-off, the individual exposed to the risk must have some awareness that they are making a trade-off, as pointed out by (Viscusi 1992). Such decisions place severe demands on the rationality of the decision-maker and it is not know for certain what risks of death or injury the individual assumed when accepting the wage offer. Refer to (Viscusi 1998) for a discussion of irrational behaviour in the presence of mortality risk which is inconsistent with expected utility theory. However, in this discussion it is important to be aware of the fact that the

[18] This can be geometrically illustrated by the market clearing wage-risk function (formed by tangency points between the workers indifference curves and the firm's offer curves) (Viscusi 1998).

Jones-Lee terminology is actually based on subjective probabilities and, hence, this discussion is equivalent to the discussion in Chapter 3 on subjective probabilities.

- The wage-risk premium is compensation for assuming an above-average risk and, for that reason, may not provide an appropriate measure of value for programmes which are designed to reduce risk (which is the point of view in the Jones-Lee framework.) This is one of the issues of concerns raised by Acton (Acton 1976). This is because the compensation which a risk-averse person would require to accept a Δp increase in the probability of his own death is greater than the amount he would be willing to pay for a Δp reduction in this probability (although the amounts will be close to one another for small Δp). Refer to figure 3.1.

It should, moreover, be mentioned that, as in all other studies of revealed preferences, the wages observed and applied are all market wages and, hence, equilibrium prices and do not necessarily reflect the maximum willingness-to-pay or willingness-to-accept, as implied by the welfare economic framework. Besides, it is generally assumed that no externalities exist and, thereby, that the market valuations equate to the workers' WTP for risk reductions in the workplace through diminished wages (Herzog & Schlottmann 1990).

In addition to problems associated with assumptions about the market, it is highly problematic to use the hedonic wage methodology when dealing with a reduction in mortality from a decrease in air pollution. This is due to the fact that it is very hard to find pollution-related risk-rates as specific as the wage-risk rates and, moreover, it would be very difficult to take account of the latency-period which appears in relation to impacts from air pollution (Cropper & Freeman III 1991). However, in (Cropper & Arriaga-Salinas 1980), an attempt is made to try to estimate the value of air quality based on a wage-risk study. The study is based on both the benefits of clean air at work as well as at home. Yet, the value is found by an aggregation of all the benefits from cleaner air and not only the changes in mortality. Since air pollution has consequences for health as well as other impacts on the environment this procedure leads to an overestimation of the value of a change in the probability of dying.

4.1.1.2 Hedonic Property Value Models.

Another hedonic method is based on property values. The theoretical background is Lancaster' s theory (Lancaster 1966) which suggested that utility is derived from the attributes of the good and not from the good, itself. Hence, a property value can be described as a vector of different attributes: the size of the dwelling, its age, special features, view, noise, air pollution, etc. In environmental economics, this method has among other things been used to estimate the marginal value of a reduction in air pollution – refer to (Smith & Huang 1995) for a meta-analysis.

In a screening of the literature, only one hedonic property model has been found when the topic is valuing an environmental-related reduction in the probability of dying. In (Portney 1981), an estimation of VSL in an air pollution context is derived based on house prices. However, the study has some drawbacks, because in order to derive the estimates the entire premium paid for improved air quality was attributed to risk of death. Since air pollution has consequences for health as well as other impacts on the environment, this procedure leads to an overestimation of the value of a change in the probability of dying. As in the hedonic wage model, one can not say anything about the level of subjective probability valued. [19]

However, a somewhat related hedonic property value survey is found in (Gayer, Hamilton, & Viscusi 2000). The analysis is based on data in the greater Grand Rapids Michigan housing market which contains 7 Superfund[20] toxic-waste sites. By evaluating the price gradient with respect to cancer risk an estimation of a statistical cancer case is derived. The statistical cancer case is obtained based on the same principles as the value of a conventional "Statistical life" in hedonic wage studies.

4.1.1.3 Another employment of the hedonic price methodology.

The hedonic price technique has been used in the car market as well. A Swedish study (Andersson 2005) is an example of this, with definition of the risk-variable as the number of registered fatalities or injuries for each make/model/year in a given year.

[19] The model takes account of that elderly are more vulnerable to air pollution and purchase greater risk reductions for the same housing price differentials.

4.1.2 The Averting Behaviour Studies.

Another way of revealing preferences is by studying the choices individuals make on the market in order to protect themselves and hereby decrease the risk of dying. This method has been frequently used in the market for traffic and thus for the estimation of a traffic-related VSL. The VSL has for example been inferred from observing highway speed, the purchase of bicycle and motorcycle helmets, and the choice to use a seat belt. Refer to (Blomqusit 2004) for a description of various studies of averting behaviour.

However, as emphasised by(Shogren & Stamland 2005)), it is unclear whether market forces exist in order to ensure that the cost of self-protection bears a relationship with the maximum willingness to pay for self-protection. All one can deduce is, in fact, that the self-protection devise is a lower bound on some people's willingness to pay (those who buy) and an upper bound on others' willingness to pay.

In addition, Shogren underlines that implicit within the standard view it is assumed that people are equally skilled in their personal ability to self-protect. But, as he points outs:

" just as people have unique preferences towards risky events, they also have unique levels of skill to cope with risk...a consumer who chooses self-protection reveals himself to be more averse to risk or to expect a higher risk reduction form self-protection or both." (Quote p. 101(Shogren & Stamland 2005))

This is actually the opposite problem as in the sample in the wage-risk methodology, where the sample consisted of individuals who were *less* risk averse than average.[21]

4.2 Stated preferences.

Using the revealed preferences technique requires the presence of a market for the good in question or a related good. For some public goods there are simply no, or very poor, market proxies or other means of inferring preferences from observations

---

[20] "A Superfund site is any land in the United States that has been contaminated by hazardous waste and identified by the Environmental Protection Agency (EPA) as a candidate for clean-up because it poses a risk to human health and/or the environment." Refer to www.epa.gov

[21] It is also essential to be aware of that there are situations in which there would appear to be elements of enjoyment in risk-taking. It is important not to neglect these elements; however in this paper it will be assumed that no such elements of risk-taking are present. (Mooney 1977)

from market behaviour. One of these is a change in the probability of dying caused by a change in air pollution.

4.2.1 Contingent valuation – the method

Ciriacy-Wantrup was the first in theory to propose asking the individuals directly about the valuation of a good (Ciriacy-Wanstrup 1947). Directly eliciting the willingness for respondents to pay for a hypothetical project by use of a sample survey has been labelled the Contingent Valuation Method (CVM). The name refers to the fact that the values are contingent upon the (hypothetical) market created and presented in the survey (Hanemann 1994).
Libraries, theatres or fire services provision are some examples of public projects valued by this method. An example of a Danish application of a CVM study is the valuation of the Royal Theatre where the following question was asked:

All Danes pay to the Royal Theatre through taxes. How much are you willing to pay at the most to the Royal Theatre through taxes? (Quote p22 (Hansen 1997))

Increasingly, the CVM has also been adopted as a means to value a wide variety of environmental impacts as air quality, natural habits or threatened species.
However, use of the CVM for environmental valuation has been very controversial. After the Exxon Valdez oil spill in 1989, the debate became especially heated, because it was known that a major component of the legal claims was likely to be based on contingent valuation estimates of non-use values. Following this, and on request from the NOAA (National Oceanic and Atmospheric Administration), a panel was appointed to put forward a range of recommendations on how a good CV study should be constructed (Arrow, Solow, Portney, Leamer, Radner, & Haward Schuman 1993). The use of values based on CVM for policy purposes and the NOAA panel's recommendations have been widely debated ever since e.g. (Diamond & Hausman 1994;Payne, Bettman, & Schkade 1999). However, the recommendations from the NOAA panel continue to be used as guidelines for construction of studies based on CVM.
The NOAA panel recommendations and the matter of how to construct an appropriate Contingent Valuation survey will be dealt with in another paper, describing the construction of a questionnaire used for the data collecting for the

PhD project. However, some of the issues in the debate on the CVM will be considered here in order to establish a background for a discussion of the different estimates found by using CVM.

4.2.1.1 An examination of the method.

In general, a survey instrument can be examined by looking at the reliability and validity of the instrument. With regard to reliability, it is required that measurements can be reproduced – at least on average, whereas the validity of a survey assesses how the survey measures what it sets out to measure (Litwin M.S 1995).

The hypothetical element of contingent valuation is, in fact, what makes the method very useful while at the same time is the basis for the massive critique of the method (Smith & Descouges 1986). Obviously, the advantage of using the method is that a good can be valued in spite of the absence of a market. However, the drawback is actually that the measurement of validity is complicated by the absence of a real market transactions with which the estimations can be compared (Mitchell & CArson 1989). Hence, attention to validity is of special importance in a CVM study.

4.2.1.1.1 Validity.

When assessing the performance of a survey instrument, several types of validity are measured. Table 4.1 below outlines the different types of validity which can be measured. The table will be followed by a general discussion about validity in CVM. Specific discussion about the validity when valuing a change in the probability of dying will be dealt with in Section 4.4.

Type of validity	Characteristics
Content (face)	Formal expert (casual) review of how good an item or series of items appears
Criterion: concurrent	Measures how well the item or scale correlates with "gold standard" measures of the same variable.
Criterion: predictive	Measures how well the item or scale predicts expected future observations
Construct: convergent validity	Asks whether the measure is correlated with other measures of the same theoretical construct
Construct: theoretical validity	Asks whether the measure is related to measures of other constructs in a manner predicted by theory.

Table 4.1 Validity ((Litwin M.S 1995) p. 45 and (Mitchell & CArson 1989) chap 9

The concurrent criterion validity has the greatest potential for offering a definitive test of a measure's validity. However, it is necessary to have a criterion which is unequivocally closer to the theoretical construct. An example is market prices, although the difficulties when dealing with a CVM survey are, as mentioned, that no market is normally available for the good in question. However, experiments have been carried out comparing a market price for a quasi-public good (from which people can be excluded) in a simulated market and the outcome of a CVM survey. There seems to be a strong correspondence from the hypothetical and the simulated market for goods that are well understood (e.g. admission to watch a TV show). However, this result cannot be directly transferred to the valuation of a pure public good.

Examining convergent validity concerns the correspondence between a measure and other measure of the same good. An example of a test for convergent validity will be provided in Section 4.4 where the results from wage-risk studies and a CVM is compared.

Theoretical validity can be examined in the econometric analysis by examining whether the signs and sizes of the estimated coefficients are in accordance with the theoretical expectations. Specifically, it is reasonable to carry out two tests: a price test and a scope test.

By fulfilling the *price test*, it is meant that the percentage of respondents willing to pay a particular price should fall as the price they are asked to pay increases (similar to negative price elasticity).

On the other hand, to satisfy the *scope test* it is required that respondents should be willing to pay more for a larger amount of a desired good (CArson, Flores, & Meade 2001) .

According to Carson, satisfying the price test is seldom a problem in CVM. Whether the scope test is fulfilled or not can be tested either externally (by varying the size of the good between samples) or internally (by asking the respondent the WTP for different amounts of the good). On the background of a review of a number of studies, Carson argues if the scope test is not fulfilled, then this is due to survey design or implementation of the study and, therefore, is not due to cognitive problems (CArson 1997;CArson, Flores, & Meade 2001).

However, due to the multidimensional character of validity and the absence of a clear-cut criterion against which to compare CVM values for public goods, it is appropriate to ask the following question:

"How do we establish the validity of a survey when we do not know how to establish the validity of the instrument?"

The above evidently represents a very serious concern regarding CVM. As a consequence, various strategies have developed in order to improve both the reliability and the validity of the surveys. Many of these strategies have been formulated in terms of biases which should be minimised in the construction of a CVM survey. Some of the different biases are listed in Appendix A, but will not be given any more attention in this paper to (Kriström 1990) for discussion of this topic.

Due to the trouble with measurement of validity, it can be argued that respondents, instead of expressing a value based on their existing preferences, are, in reality, expressing a kind of "moral satisfaction." In the literature, this effect is called a "warm glow" and the effect can give rise to doubt with regard to how far the value from a CVM study reflects the actual price of the good or simply reveals attitudes (Kahneman, Ritov, & Schkade 1999).

In this context, a related concern is whether people actually hold prior preferences toward non-market goods or whether preferences first need to be formed, i.e. the question of whether the task in a CVM study is to *discover* or *construct* preferences (Payne, Bettman, & Schkade 1999).

4.2.1.1.2 The value of a change in probabilities.

An additional complication of applying the CVM arises when valuing a change in probabilities. An example is quoted below.

As we said earlier, the risk of a car driver being killed in an accident is 10 in 100.000. You could choose to have a safety feature fitted to your car which will halve the risk of the car driver being killed, down to 5 in 100,000. Taking into account how much you personally can afford, what is the most that you would be prepared to pay to have this safety feature fitted to the car? Jones-Lee(1985)

As mentioned in Section 2.3.2, it has repeatedly been demonstrated that people do not act in accordance with the axioms underlying the expected utility theory. Of special interest is perhaps the findings in the prospect theory (Kahneman D. 2002). The theory suggests that people are risk-averse towards gains and risk-seeking toward losses, which is known as loss aversion (Kahneman D. 2002). This implies that whether the change in probabilities is formulated in terms of gain or losses is important and the presentation of changes in likelihood becomes central. The issue about communication has been discussed and investigated heavily in the VSL literature, refer to (Corso, Hammit, & Graham 2001) and to the discussion between anonymous and statistical lives (Refer to Chapter 3).

4.2.2 Choice experiment.

A further stated preference approach also exists. Among other names, this method has been labelled the "Choice experiment" or the conjoint analysis. The technique was initially developed and used in marketing – refer to (Louviere & Woodworth 1983) as the first application of the method in the field of marketing. The theoretical foundation is partly found in the theory of Lancaster (as described in the section on hedonic pricing) and partly in the random utility theory, which breaks down the conventional utility function into one deterministic part and an error part [22](Bateman, CArson, Day, Hanemann, Hanley, Hett, Jones-Lee, Loomes, Mourato, Özdemiroglu, Pearce, Sugden, & Swanson 2002).

In choice experiments, respondents are asked to rank or rate combinations of one or more attributes (one often being price), describing the good to be valued. The

[22] This could be a more realistic representation of preferences, but on the other hand assumptions have to be made concerning the error term.

different alternatives, consisting of different combinations of attributes, are called profiles. An advantage of the discrete choice experiment is that choice behaviour is a part of everyday life and, hence, it is easier for respondents to answer questions based on this (Tsuge, Kishimoto, & Takeuchi 2005). On the other hand, it can be quite challenging for respondents when several profiles are presented.

However, despite the apparent advantages, the discrete choice method has been given very limited attention in the literature on valuation of changes in mortality.

4.3 Empirical estimates –stated preferences

Since the survey by (Jones-Lee, Hammerton, & Phillips 1985), which was the first CVM survey on this subject with a representative sample, there have been numerous attempts to attempt to find a value of a statistical life by use of the stated preference technique.

Appendix B Tabel 1-3 illustrates an overview of several contingent valuation studies of VSL. The list contains published surveys (from journals or working papers). Surveys with a sample size below n=100 have been excluded. All values are listed in Euro(2000), deflated and corrected for PPs.[23][24]

In addition to the empirical estimates found, the table includes some of the determinants of the respective values. Whereas Chapter 3 included the theoretical discussion of these parameters, this chapter represents a discussion of the empirical results seen. Income and initial risk have been treated in Chapter 3 and will be not be dealt with in this chapter.

The determinants discussed in this section can be put into two groups: 1) the good proposed (change in the probability of dying, Table 1), and 2) the characteristics of the population (Table 2). In the following, special attention will be given to studies focusing on valuation in an environmental context.

4.3.1 The good (a change in the probability of dying).

This section will contain a discussion of the empirical results seen in relation to the characteristics of the risk change valued.

[23] Exchange rates, deflators and PPs are found at the Eurostat Home Page.

4.3.1.1 Context

In Chapter 3, it was suggested that the context in which the respondents are asked to value a risk change could influence the valuation. As illustrated in Table 1, most stated preferences studies are conducted in the traffic area, with very few in other areas. Yet in addition to the VSL-studies, different risk perceptions studies have been conducted in order to observe the influence of context on the valuation of life e.g. (Jones-Lee & Loomes 1995);(Chilton et al. 2002)

A recent, very interesting result was found in Thailand (Vassanadumrongdee & Matsuoka 2005). Two surveys were conducted. One of them dealt with the WTP for a change in the probability of dying from a traffic accident, whereas the other one asked the WTP for a change in the probability of dying from air pollution (health medical check-up – private good). Following the WTP question (which was presented as a double-bounded dichotomous choice question), respondents were asked to indicate their extent of agreement or disagreement with risk perception statements concerning air pollution and traffic accident risks. The survey used nine risk characteristics, which are listed in Table 4.2 together with the risk question asked in the survey.

Risk	Statements (binary coded)
Voluntariness	Whether air pollution risk will cause damage to me or not is up to me.
Severity	Air pollution related illnesses can cause fatality.
Controllability	I can avoid being affected by air pollution with my own efforts.
Dread	I feel more afraid of dying by air pollution than other risks.
Personal exposure	Air pollution risk can happen to my family and me.
Public exposure	Air pollution can cause damage to the overall public.
Immediacy	Air pollution can cause actual damages immediately.
Personal knowledge	I know the causes of air pollution.
Expert knowledge	Knowledge to science or experts: Regardless of my personal knowledge, I think there is enough research on the causes and impacts of air pollution risk.

Table 4.2 (Vassanadumrongdee & Matsuoka 2005)

[24] The table is supposed to illustrate an overview of different studies. It is not the purpose to conduct a meta-analysis or another comparison of different values. Hence, the choice has been made not to include confidence intervals.

The statements were binary coded in a log-logistic regression and it was found that controllability, dread and personal exposure had a positive, significant effect on the probability of saying "yes" to the WTP question in an air pollution context. This means that, as a rule, an individual who agrees or strongly agrees that he or she can avoid being affected by air pollution (controllability) will have a higher WTP for a risk change.

The conclusion from the study is that both WTP to reduce air pollution and WTP to reduce traffic accident are influenced by some risk characteristics. Nevertheless, the value of a statistical life (VSL) for both air pollution and traffic accidents are found to be at comparable levels.

Hence, the finding of this study, as well as a recent discrete choice experiment by (Tsuge, Kishimoto, & Takeuchi 2005), is that risk characteristics do not count as a good reasons for using different values in different contexts. [25]

However, as mentioned in Chapter 3, results concerning this matter have been mixed. The particular study by Vassanadumrongdee & Matsuoka has been given intention due to the comparison between an air pollution context and a traffic context, which is very relevant for this paper. However, it must be emphasised that both studies value the air pollution related risk change in a private context. As argued in Chapter 3, the change in the probability of dying caused by a change in air pollution is a public good. The issues that characterise a public context as opposed to a private context will be given attention in the next section.

4.3.1.2 Public - private.

In Chapter 3, the difference between a public and a private good was emphasised and that a change in an individual's risk of dying can be characterised as a public or a private good depending on how this risk reduction arises.

Appendix B, Table 1 presents whether the change in probability is valued in a private or public context. Most of the studies listed have investigated a risk reduction in a private context. One of the exceptions is the study by (Chanel.O. et al. 2003) in which VSL in an air pollution context has been valued. A number of other studies has, in

[25] The survey used 4 different attributes; price, risk reduction, risk type (accident, cancer, heart disease and general) and timing of the effect. In addition to the Choice experiment they asked respondents to rank their subjective perception of each risk. The subjective risk ranking consisted of 8 risk characteristics all, except immediacy, identical to the ones used in the survey by Vassandumrongdee.

addition, investigated opportunities for valuing a public good as well as a private good (see e.g. (Kidholm 1995b) and (Jones-Lee, Hammerton, & Phillips 1985).

A survey by (Strand 2004) compares the valuation of a public risk reduction with the valuation of a private risk reduction. The value from the private risk reduction is reported in Appendix B, Table 1.The construction of the survey by Strand implies that before the respondents were asked to answer the private risk reduction question, they were asked to value a public project in a survey combining choice experiment and contingent valuation. The projects differed in four different attributes: i) the number of lives saved ii) the number of years before saving occur iii) the cause of death (heart disease, environmental cause and traffic accident) and iv) the costs to households. After the respondents had chosen their preferred project, they were asked to indicate whether they were willing to pay the costs of their preferred project (dichotomous choice) and afterwards their maximum willingness to pay for the given project.

The results reveal that environmental effects result in the highest VSL, followed by traffic-accident and heart disease.

However, the respondents were also asked to split the VSL into three parts: pure self-interest, remaining members of their close family, and other persons or causes. The answers indicated that pure self-interest accounted for 30% of total VSL, 50% the lives of other family members and 20% other persons or motives. The self-concern fraction is rather stable across death causes, while "other family members" have a higher share of total values for traffic accidents and "other concerns" have a higher share of total WTP for environmentally-caused death.

The study by Strand, (Strand (2004)) sheds light on some very interesting issues.

1) The self-concern fraction of the public value roughly corresponds to the private value reported in Appendix B, Table 1.

2) Regarding the splitting of WTP by motives, Strand argues that the altruism concerning "other family members" can be described as pure paternalism[26] (using the Jones-Lee framework (Jones-Lee 1992). According to Jones-Lee, it would not be

---

[26] If the family share a common budget and a single decision-maker in the household has authority to make all its spending.

correct to add an extra sum to the valuation of a public good in order to take account of pure paternalism,[27] refer to Chapter 3.

Strand argues that since the concern for others had a high share of total WTP in the environmental context, this may imply that saving such lives implies a particularly large paternalistic (safety-focused) component. Accordingly, one could argue that from a society perspective, in order to reflect the altruistic preferences, an extra value should be added to the individualistic value of a change in the probability of dying in the environmental context.

However, in my opinion the "other concerns" could just as well reflect other factors, not captured by the survey. The environmental context is very different from the other contexts and, furthermore, a reduction in the level of air pollution has many other benefits as well. Accordingly, much of the "other concerns" could be due to "concern for the environment". Hence, in my opinion, it is difficult to conclude from this study whether or not the altruistic concern regarding environmentally-related death is different than in the other contexts.

Another concern regarding this paper is the private valuation question which related to a 1 % change of extending one's life by one year. This does not correspond with the methodology derived by Jones-Lee and is, hence difficult to compare with the other estimates in Table 1. However, it is a method to value a change in life expectancy. Other methods to value a change in life expectancy will be discussed in Chapter 6.

Another concern focuses on the formulation used in the survey e.g. saving 50 persons by a public project. This observation is not solely related to the survey by Strand, but to many other studies as well. The reason why the probability change is described in this way is that people have difficulty with the interpretation of probabilities. Many studies have been conducted in order to find out how the understanding of a change in probabilities could be improved and the wording above has been preferred by many (refer to (Corso, Hammit, & Graham 2001) for a description of different ways to communicate probabilities).

[27] A related question is whether to add altruism towards children to the purely selfish motivations, when valuing a private good. The valuation of the change in the probability of dying for children will not be treated any further in this chapter, refer to (Harbaugh 1999) for a discussion on this matter.

However, as mentioned in Chapter 3, valuing one statistical (unidentified) death is not the same as valuing one anonymous (expected) death[28]. Keeney argued that if society prefers a more equitable to a less equitable distribution, the loss of one anonymous life is socially preferred to the loss of one statistical death. Empirically, it has been demonstrated that people prefer the loss of a statistical (certain) death to the loss of an expected (anonymous) death. This has been explained with "catastrophic aversion" (meaning that there is a risk that society could lose two or more anonymous lives) (Hammerton, Jones-Lee, & Abbott 1982).

Hence, this disparity of wording between the two scenarios (public and private) in the study by Stand could have influenced the valuation as well.

In the Strand, (Strand 2004) study mentioned above, the willingness to pay for a public good exceeds that for a private. However, this is not the case in (Jones-Lee, Hammerton, & Phillips 1985) and (Johannesson, Johansson, & O'Conor 1996). This is interpreted by Jones-Lee as evidence of the "free-rider effect". Johannesson et al., on the other hand, emphasise that, because respondents had a tendency to overestimate their own WTP relative to others (as revealed in a follow-up question), a private value exceeding the public value should be the case, with individuals being pure altruists and the payment vehicle being a uniform tax increase for all car owners.

4.3.1.3 The magnitude of the proposed change in probability.

As mentioned, one of the issues in the VSL literature concerns how individuals understand and perceive changes in probabilities and whether it can be assumed that people actually react in accordance with the axioms described in Chapter 2.

In the contingent valuation framework, the test for scope is, as mentioned, one way of establishing the influence of the proposed risk change on subsequent valuation. If the test for scope is to be fulfilled, then WTP should change if the amount of the good in question becomes smaller or greater. Basically, all VSL studies include some kind of test of scope. However, to my knowledge only one study passes the scope test in the sense that an increase in risk has the same proportional effect on the value

[28] As argued in Chapter 3, I would prefer the reverse definition and hence a statistical death would correspond to a change in probabilities (Jones-Lee framework) and an anonymous death would be "to save 1 out of 1000". However, I will keep to the terminology used by (Keeney 1980).

((Strand 2004). Refer to (Hammit & Graham 1999) for a thorough discussion of the scope effect and the VSL.

In Chapter 3, several explanations were given for the lack of scope: anxiety, a decreasing marginal value of a risk change and complementarity of money and survival. However, the effect of these different factors can be neglected when the proposed changes are marginal. Still, in some surveys the stated amount does not change with a change in scope and the concern relating to insensitivity to scope will be given a more thorough examination in Section 4.4

When studying Table 1 it is clear that a smaller proposed change in mortality risk results in a higher VSL. This is due to the scope effects and the aggregating procedure. The issues about scope are another reason for why a VSL always should be labelled with the proposed change in risk, refer to Chapter 3.4.

4.3.1.4 Latency.

As mentioned in Chapter 3, when dealing with a risk reduction related to air pollution, latency becomes a central consideration. In the next chapter, the theoretical expectations will be derived in the life-cycle consumption framework. However, in this section some empirical investigations on that matter will be given.

In the surveys by Alberini in U.S.A and Krupnick in Canada (refer to Table 1, Appendix B), in addition to the conventional VSL question, people were asked what they were willing to pay for a risk reduction occurring in the future. The results indicate that WTP today for a risk reduction at age 70 is, for persons aged 40-60, less than half of WTP for a current risk reduction. Moreover, it was found that WTP today for a risk reduction at age 70 is lower for persons who have a lower self-assessed chance of surviving to age 70 and lower for persons who believe their health will be worse at age 75 than it is today.

The discrete choice experiment by (Tsuge, Kishimoto, & Takeuchi 2005) investigates the issue of latency (or timing) for private goods, as well. The conclusion from this study is that that respondents evaluate the earlier risk higher (a discount rate as high as 20%). In (Cropper, Aydede, & Portney 1994), the good in question was public and resulted in the median respondent requiring 2.3 lives to be saved 5 years from now for every life saved today – implying a discount rate of 16.8 %.

Accordingly it seems as if individuals value a risk reduction less when latency is involved. This will be solved by matter of discounting in Chapter 5.

4.3.2 The characteristics of the population.

In relation to valuing a change in the probability of dying in the air pollution context, two characteristics of the population have received special attention: age and health status. The reason for this particular attention is that it has been suggested that a change in air pollution mostly affects elderly people who are already in a poor state of health.[29]

Hence, this section will contain a discussion of some of the empirical results seen, compared with theoretical predictions. The empirical findings on these determinants, where the results have been reported by the author, are reported in Table 1.

4.3.2.1 Age

The theoretical expectation regarding the relationship between the individual's WTP and age will be investigated in Chapter 5. However, in the current chapter, some empirical findings from comparing the WTP of different individuals will be presented.

Some studies have found that the relationship between willingness to pay and age follows an "Inverted U-curve" peaking at about age 40 (an illustrative example is shown in Figure 4.1) (refer also to (Jones-Lee, Hammerton, & Phillips 1985);(Cropper, Aydede, & Portney 1994)).

[29] It has not been possible to find a theoretical reference on this claimed association. However, the relation arises because in the calculation of impacts a relative risk ratio is used (Pope, Thun, Namboodiri, Dockery, Evans, Speizer, & Health 1995;Pope, Burnett, Thun, Calle, Krewski, Ito, & Thurston 2002). Accordingly, elderly people with a higher probability of dying will be more affected.

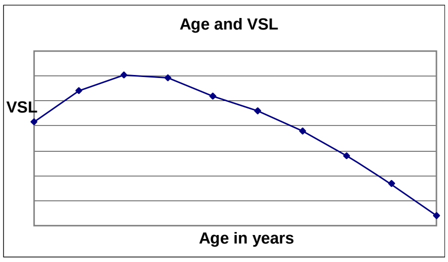


Fig 4.1 and "inverted U-form" illustrating the relation between age and VSL.

However, as can be seen from Appendix B, the results regarding this matter are mixed and other studies have found WTP to be a declining function of the respondents' age (Kidholm 1995a). In (Krupnick, Alberini, Cropper, Simon, O'Brien, Goeree, & Heintzelman 2002), it was found (respondents > 40 years old) that age did not have an effect on the WTP of the respondent up until the age of 70, where after WTP declined.

The discussion on age is important in two aspects. 1) Whether to adjust the VSL used for policy purposes when elderly people are affected (with a so-called "age-discount") and 2) in the discussion on whether it is possible to value life-years lost instead of VSL.

Regarding 1) it is fair to say, based on empirical results, that there is some indication of elderly people (above 65 to 70) valuing their life less than younger. However, based on empirical results, determining a specific number in order to establish a specific "age-discount" for policy purposes is very complicated. The "*Recommended Interim Values for the Value of Preventing a Fatality in DG Environment Cost Benefit Analysis*", however, advocates adjustment for age by multiplying the VSL by a factor of 0.7[30]. The empirical reference is the study by (Jones-Lee, Hammerton, & Phillips 1985).

The second aspect, concerning the relationship between VSL and life-years, is even more complicated and will be given a thorough investigation in Chapters 5 and 6. However, from the empirical results seen it is not evident that society actually perceives the value of life as proportional to life expectancy. This is actually a

[30] Refer to http://europa.eu.int/comm/environment/enveco/others/recommended_interim_values.pdf

requirement if one were to assign equal value to each life-year lost (no matter at what age) (Cropper, Aydede, & Portney 1994).

4.3.2.2 Health

As discussed in Chapter 3, the sign of the difference between VSL(good health) and VSL(Bad health) depends on whether the effects of health on the marginal value of wealth outweighs its effects on the total utility of survival (Hammit 2000).

In recent years it has been tested whether the self-assessed health of the respondents influences their WTP. In (Krupnick, Alberini, Cropper, Simon, O'Brien, Goeree, & Heintzelman 2002), the results revealed that people with a chronic condition did not value a change in probability any differently from people without a chronic condition. However, people with cancer valued a change in probability higher than people without cancer and people in a better mental health status stated higher valuations, as well. Yet, the results are mixed on this matter and some studies actually find no significant relation between the health status of the respondent and the valuation of a change in the probability of dying, refer to Table 2.

However, one of the limitations with the surveys carried out to date has been that, out of representative samples of about 1000 respondents, very few have had cancer or another chronic illness. Hence, it is very difficult to find significant relationships. In the value of statistical life surveys it is a relatively new idea to test the relationship between self-assessed health and the valuation of a risk change and, hence, results are few. However, there have been some theoretical considerations in the life-cycle consumption literature, as mentioned in Chapter 3.

Within health economics, the valuation of self-assessed health has received much attention as disclosed by the substantial amount of literature regarding QALY'S (refer to Chapter 6 for a description of a QALY).

However, what is even more interesting in relation to the valuation of changes in mortality, is the hypothetical value, quality-adjusted life expectancy. This is calculated by calculating average lifetime and correcting this with life quality (Pedersen et al. 2003). This method represents a more formal method to take years with poorer health into account than that which has previously been used in valuation exercises within environmental economics. However, for the time being, it

is apparently not possible to describe the course of the various air pollution related diseases with sufficient precision in order to use this method. However work on QALY and air pollution related morbidity has been carried out in (Johnson, Fries, & Banzhaf 1997) and (Vassanadumrongdee, Matsuoka, & Shirakawa 2004).
Besides, the QALY- method assesses life-years instead of life, which was discussed in 4.2.1 and will be treated again in Chapters 5 and 6. Based on the trade-offs people are willing to make between life-years in good and poor health, it follows that individuals value life-years in poor health less and hence that the value of saving a life-year is less for a person with a chronic disease, such as chronic bronchitis, than for a healthy person. The few empirical results regarding health status and VSL show no such unambiguous result and, as discussed in Chapter 3, there is no clear-cut theoretical prediction on that matter in the Jones-Lee model.
To sum up, based on the empirical results regarding health status and the implication for VSL, it is impossible to conclude anything about the relationship between these or whether people in poor health should be valued less or more for policy purposes in the environmental context.

4.3.3 Median/mean

When looking at the estimates in Appendix B, it is evident that the discrepancy between the median and the mean is very apparent. According to (CArson 2000) this is often the case for most environmental goods; the reason being partly that the income distribution is skewed and partly that a sizeable proportions of the sample are either indifferent to the good or care a great deal about its provision.
According to Carson there is no single "correct" measure. The mean is the traditional measure used in Cost Benefit Analysis. The median is a measure of central tendency and can be interpreted as the amount receiving majority approval and is a standard public choice criterion. And as Baron, argues:

"If we are trying to maximize utility through policy decisions we must take everyone's values into account. We cannot for example rely on the median valuation, as we might do if were trying to simulate a referendum." (Quote p 83(Baron 1997a))

On the other hand, the mean is very sensitive to extremes and hence the discussion of exclusions of outliers becomes central. When taking the wide dispersion of values into account, it is surprising that a great deal more debate is not found on this particular matter in the literature on CVM.

4.4 The validity of a CVM survey on VSL.

As mentioned in Section 4.2.1.1.1., convergent validity can be measured by finding out whether two different measures of the same theoretical construct are correlated. In the VSL literature, convergent validity has been checked by comparing values from wage-risk studies and CVM. In (Lanoie, Pedro, & Latour 1995), the value of life from the two methods is compared when applied to the same sample of individuals. They find different values for the sample of unionised manual workers, but show that the value of life estimates are more likely to be similar when risk-averse individuals are excluded from the sample.

In a recent survey by (Telser & Zweifel 2005), it is claimed that validity is found by comparing a VSL estimate from a discrete choice experiment with already published values found by the wage-risk method. Validity, here, is based on an age-correction of the VSL found in the stated preferences technique in order to take into account that the sample on average was older than in a normal wage-risk study. However, as previously discussed there is no clear-cut empirical justification for this discount factor.

Accordingly, the studies clearly illustrate the difficulties in assessing the convergent validity of a CVM survey. Bearing in mind that this is only one part of the validity measure, the validity problems are obvious.

4.4.1 Valuing the "value of life". A case of constructed preferences?[31]

The scope test as a measure of theoretical validity in the CVM has already been discussed in this chapter. However, this discussion will be expanded here.

In Chapter 3, the question was raised of whether it is possible to measure a change in the probability of dying with a monetary measure (due to among other things that money and a change in the probability of dying are complementary goods). Having the concerns above in mind the discussion on whether preferences are constructed or

[31] Quote p 123 (the title of the chapter), (Chilton et al. 2004a)

discovered is especially interesting in relation to a VSL survey. By a preference construction process is meant that;

..”people generate willingness-to-pay responses through a variety of context dependent strategies that are only loosely related (if at all) to the direct trade-off between monetary value and level of benefit being asked for in the CV question” (Quote p 136 (Chilton, Codey, Hopkins, Jones-Lee, Loomes, Pidgeon, Robinson, & Spencer 2004a)

This means that instead of reporting well-defined values (based on the definite, transitive preferences which are the assumptions behind the neoclassical economics), respondents construct their value at the time they are asked about it. The implications of constructed preferences are that small changes in task or question wording can result in wide and systematic variations in elicited values, raising serious concerns regarding the validity of CVM surveys.

There have been some studies on this matter in relation to the value of a change in the probability of dying. A particularly interesting study is found in (Chilton, Codey, Hopkins, Jones-Lee, Loomes, Pidgeon, Robinson, & Spencer 2004a) where economics and psychology are mixed by combining the qualitative approach to data generation with the traditional quantitative CV elicitation survey.[32] The study design consists of a focus group followed by one-to-one interviews of the members of the focus group and finally some feedback meetings. 52 respondents were presented with a programme which was expected to prevent 15 deaths on the roads over the next year and, subsequently, a programme expecting to prevent 5 deaths (hence, in the Keeney framework the value found is that of a statistical death).

The remarkable result from this study is the insensitivity to the size of the risk reduction (22 of the 52 non-respondents actually stated identical non-zero values).

The findings from the feedback meeting with the respondents indicated unwillingness to trade-off lives with money and the answers centred explicitly around a rejection of equating number of lives with cost, in that “saving life was saving life” and saving one life or 75 lives achieves the (infinitely) valued objective of saving life.

[32] The study is not included in Appendix B due to the fact that only 52 respondents were included. However, the interesting results are found in the qualitative part and deserve attention.

The unwillingness to trade-off lives with money supports an indication of that every aspect having to do with "putting a value on life" is a "protected value". By protected value, the following is meant:

"Protected values are those that resist trade-offs with either values, particularly economic values." Quote p 1 (Baron 1997b)

The existence of protected values is problematic for CBA, because it implies that one value is infinitely more important than others.[33] From the existence of protected values, it follows that quantity is irrelevant for protected values. The protected values apply to the *act* and not the *result* and, hence, destroying 1 species is as bad as destroying 100 (Baron 1997a). Therefore, the "scope test" will not be fulfilled when a protected value is of concern.

The important point to recognise here is that one can simultaneously hold the belief that "saving lives is a good thing irrespective of cost" and the preference that "saving 15 lives is better than saving 5". The respondents in the survey solve the dilemma of seeing life as a protected value and the need to value benefit in the WTP judgement by one of the two following ways:

1) Assigning equal value to each – saving 15 and 5 lives.

2) By attaching more weight to one belief over another by adjusting the figure for saving 52 lives downwards.

However, from the feedback, it can be seen that the weighting procedure implied by 2) depends on the particular circumstance under consideration and, hence, the preference construction is very depended on context.

The implication of this study is,

---

33 In this context, it is essential to establish that individuals' behaviour actually may be inconsistent with their values. Hence, even if pointed out to the individual that they actually make choices whereby a value on life is placed (e.g. refusing to buy a air-bag) they may feel guilty instead when realising that they have violated one of their values. Baron argues that if we are trying to do what is best for people, we should rather satisfy their values instead of the values revealed in their behaviour. In this connection, it is important to distinguish between this and a "merit good" which is a commodity thought to be good for someone regardless of the person's own preferences (Folland, Goodman, & Stano 2004). However, in the fundamental utility framework it is assumed that there is no such conflict between behaviour and values due to the definite preferences, and the ethical discussion on what to maximise will not be given any more treatment in this paper.

"That constructed preferences may severely limit the usefulness of CV surveys for policy: for if small changes in task or wording can prompt wide and systematic variation in elicited values and their implications, the dilemma remains where should the "true" value for policy lie?" p 142-143 (Chilton, Codey, Hopkins, Jones-Lee, Loomes, Pidgeon, Robinson, & Spencer 2004a)

4.5 Concluding remarks.

This chapter has outlined different empirical possibilities for applying the theoretical model from Chapter 3. Methods to derive WTP from stated preferences and from revealed preferences have been discussed and a number of estimates found by use of the CVM have been listed. In addition, various determinants of the value of a change in the probability of dying have been discussed and, from Appendix B, it can be seen that the values vary a great deal, which in part can be explained by the influence of different determinants. However, some of the studies raise some concerns regarding the validity of CVM.

Some general concerns regarding the validity of CVM have been raised in this chapter. However, these issues are particularly serious when valuing a change in the probability of dying, due to the following two factors: 1) the difficulties with valuing a change in probabilities and 2) the unwillingness to make a trade-off between life and money.

Another more positive observation found in this chapter is that the various stated preference techniques reveal that people actually value a change in the probability of dying. Moreover, even though the values found by means of stated preferences are not always comparable with the values found by use of the CVM, it is clear that individuals actually do make trade-offs as suggested in the model by Jones-Lee in Chapter 3.

Finally, as stated in Chapter 3 it is important to emphasise that the problems outlined here are results of the axioms underlying the expected utility theory. Accordingly if one finds that the behaviour described above is more in accordance with the "typical individual" then the expected utility theory needs to be reformulated (for instance with the contribution from prospect theory).

5 Life-cycle consumption models.

The main focus of Chapter 3 and 4 was a derivation of the value of a change in the probability of dying in a single-period discrete time-static setting and some empirical estimates. However, as mentioned this approach was primarily developed and used within the areas of transportation and occupational safety, and the static period model has limitations as it cannot incorporate the fact that an individual would presumably prefer to die later rather than sooner. Many environmental policies (including air pollution) involve actions today whose effects on the probability of dying are realised at some time in the future.

As already mentioned, age and latency are two of the parameters one would expect to influence the valuation of a change in the probability of dying. In order to be able to analyse these parameters properly, one would have to consider the valuation in a multi-period setting and, therefore, this chapter will introduce the time dimension to valuing a change in the probability of dying.

At first, a model in a continuous time-setting will be presented with utility depending only on initial wealth and time (Jones-Lee 1976). This model is in a continuous time-setting, but does not take into account how value varies with consumption throughout a life. However, it does illustrate the association between the one period model treated in Chapter 3 and the models treated in this chapter.

The origin of the life-cycle consumption models is found in (Yaari 1965) and (Usher 1973). However, the main contributions were published in the 1980s and little work has been published on these models since. The common framework for these models is based on a utility function depending only on consumption and on whether or not the individual is alive. The analysis, in most cases, consists of 2 steps:
1) Solving the model to find the optimal pattern of consumption.
2) Calculating the willingness to pay, i.e. sacrificed consumption for improved survival, by assuming that the individuals follow this pattern.

The analysis can be carried out in different settings, depending on different assumptions regarding the market and the time-frame (whether the survival probabilities are exogenous or can be influenced by protective behaviour).

Even though most of the life-cycle consumption models have some very restrictive assumptions, e.g. that utility depends only on consumption and whether or not an individual is alive, the literature focusing on the models will nevertheless receive considerable attention in this paper due to following factors:

Firstly, life-cycle consumption models view life utility as consisting of different periods of utility and, thereby, create a framework for the discussion on valuing a change in life expectancy instead of valuing a change in the probability of dying.

Secondly in contrast to the static one-period approach, life-cycle consumption models incorporates the very important element that wealth and a change in the probability of dying are complements, by which is meant that the expected value of consumption changes when the probability of dying changes (refer to Chapter 3).

Finally, it must be kept in mind that utility in basic welfare functions only depends on consumption. However, this assumption seems even more restrictive when dealing with matters as life and death.

This chapter will be based on the approach developed by (Cropper 1990b), (Cropper 1990a;Freeman III 2003). However, different extensions of this model will be discussed as well and the main results will be presented.

5.1 The continuous problem.

The problem of extending the single-period discrete-time framework to a continuous-time case is analysed by Jones-Lee (Jones-Lee 1976).

In his framework the individual's expected utility can be written:

$$E(U) = \int_0^T U(\overline{w},t)\bar{l}(t)dt \qquad \text{[EQ 5.1]}$$

where

t = time of death

$\overline{w}$ = initial wealth

U(w,t) = utility function

$\bar{l}$ = initial subjective probability density function for time of death

By the same reasoning as in Chapter 3.2, V can be described in the following way:

$$\int_0^T U(\bar{w}-V,t)l(t)dt = \int_0^T U(\bar{w},t)\bar{l}(t)dt \qquad \text{[EQ 5.2]}$$

At this point one must remember that different changes in the probability density function can give rise to identical changes in life expectancy. Jones-Lee considers the change in the mean of $\bar{l}$ (t).

The following analysis in the continuous-time model follows the same steps as the analysis in the discrete-time framework. The results are listed below.

The marginal value of life expectancy evaluated at the initial level of life expectancy is an increasing function of initial wealth, and life expectancy is a non-inferior good. This corresponds to the findings from the discrete-time model and a change in probability being a normal good.

The analysis by Jones-Lee is concerned both with insured and uninsured individuals. Regardless of whether or not the individual purchases life insurance, the marginal value of life expectancy is a decreasing function of initial life expectancy. Again this corresponds to the discrete-time approach. The reasoning is that a high initial life expectancy means a low initial probability of dying and in Section 3.2 it was found that the value of a change in the probability of dying is an increasing function of initial risk.

A conventional CBA, therefore, seems to tend to direct scarce safety improvement resources towards relatively high-income individuals with a low initial life expectancy. Refer to section 5.2.1.2 for a discussion of this result.

5.2 The life-cycle consumption models.

In order to illustrate the difference between the Jones-Lee model and the life-cycle consumption models, the following model by (Shepard & Zeckhauser 1984) is presented:

$$Z_j = \int_t^T e^{-r(\tau - t)} l(\tau) u(c(\tau)) d\tau \qquad \text{[EQ 5.3]}$$

Z_j is an individual's utility at time t of his remaining life after age t (that is his expected discounted utility of consumption for each year in which he is alive from tine t on. l(t) is a survival function with l(0) =1 and $0 \leq l(t) \leq 1$. T is the maximum possible survival time so l(t) = 0 for t>T and c(t) is the rate of consumption at time t. The assumption underlying this formulation will be discussed in the next section.

By comparing EQ 5.3 with the Jones-Lee model, many similarities can be seen. However, in the Jones-Lee model utility depends on initial wealth, whereas utility in the life-cycle consumption models depends on consumption, with consumption, in turn, being dependent on time. This represents the main difference between the two approaches and accordingly, the life-cycle consumption model can be described as a joint utility function for a consumption trajectory and a survival function. This enables us, as mentioned earlier, to find the optimal consumption stream and, subsequently, the willingness to pay, under the assumption that the individual follows this consumption path. By multiplication of the consumption trajectory with the survival function, more weight is given to consumption in years with a higher probability of surviving. In this way, the complementarities of consumption and survival probability are taken into account.

5.2.1 The Cropper and Sussman approach.

The model corresponds to the above, but for reasons of simplicity a discrete-time model is used.

Assuming that $p_{j,t}$ is the probability that the individual dies at age t (just before t+1) ($\sum_{t=j}^{T} p_{j,t} = 1$) and $u_t(\ )$ is the utility of consumption in years j through t, expected utility at age j is then the utility of living exactly t-j more years times the probability of doing so:

$$Z_j = \sum_{t=j}^{T} p_{j,t} u_t(c_j, c_{j+1}, .., c_t) \qquad \text{[EQ 5.4]}$$

However EQ 5.4 can be rephrased if u_t is assumed additively separable and time independent and $q_{j,t} = \sum_{s=t}^{T} p_{j,s}$ is the probability that the individual survives to his t^{th} birthday given he is alive at age j:

$$Z_j = \sum_{t=j}^{T} (1+\rho)^{j-t} q_{j,t} U(c_t) \qquad \text{[EQ 5.5]}$$

where ρ is the rate of individual time preference. $U(c_t)$ is the period utility function and is assumed to be increasing in c_t and to be strictly concave.

The model is based on some assumptions which will be listed here.

- The analysis is carried out within the welfare economic framework. In accordance with this, the assumptions outlined in Chapter 2 also apply here and, hence, the utility of living is dependent only on consumption.
- An individual's utility over life spans of different lengths can be represented as a weighted sum of period utilities.
- The utility of consumption at one time is independent of past consumption (marginality assumption).
- The utility function is only a utility function for small perturbations in the survival function.[34]
- The survival probabilities are exogenous. (Refer to Chapter 5.2.2 for a discussion).
- Death has a utility of zero. (Refer to Chapter 5.2.3 for a discussion)

[34] The reason being that the decisions must be made before the uncertainty is resolved, so that utility on consumption in one period depends on the probability distribution of the likely amount of consumption in a future period. The effect of large changes must be obtained by solving a complex problem in the calculus of variations (Shepard & Zeckhauser 1982).

Besides the above-mentioned assumptions, the model is based on the existence of a perfect market with fair annuities[35]. Therefore, the following must be satisfied:

$(1+R_j)(1-D_j) = 1+r$

with r being the risk-less rate of interest and D_j being the conditional probability of dying at age j $(1-D_k) = \frac{q_{j,k+1}}{q_{j,k}}$ [EQ 5.6]

Hence, an individual who invests 1 DKK at the beginning of the j^{th} year will receive (1+R) DKK at the end of the year with probability $(1-D_j)$ and nothing with probability D_j. In addition, it is assumed that the individual must borrow at R_j. In order to prevent unlimited borrowing, the individual's budget constraint can be expressed by the requirement that the present value of consumption equals the present value of lifetime earning plus initial wealth:

$$\sum_{t=j}^{T} q_{j,t}(1+r)^{j-t} c_t = \sum_{t=j}^{T} q_{j,t}(1+r)^{j-t} y_t + W_j \qquad \text{[EQ 5.7]}$$

The optimal pattern of consumption over the life-cycle is determined by maximising EQ 5.5 s.t EQ 5.7. This is the first step mentioned.

Now consider a regulation that can alter the probability of a person dying in any year k. The regulation can only alter the probability of a person dying in any year if that person is alive at the beginning of that year. Hence in the next derivations, a regulation that reduces the conditional probability of dying at age k, D_k will be considered – using the definition in EQ 5.6.

$q_{j,k} = (1-D_j)(1-D_{j+1})..(1-D_{k-1})$

$q_{j,k+1} = (1-D_j)(1-D_{j+1})..(1-D_k)$

[35] The setting below is based on a market with actuarially fair annuities. Refer to (Cropper 1990b) for a discussion of the effect of capital market imperfections on discount rates.

Consequently, when the conditional probability of dying is changed at age k (D_k), it affects the probabilities of surviving to age k+1 ($q_{j,k+1}$) and beyond.
It must be emphasised (as in the Jones-Lee model) that there are many changes in D_k that result in equivalent changes in life expectancy. Accordingly, the derivation of the marginal rate of substitution which follows actually requires extending the concept of differentiation to variation in the total survival function l(t). Refer to the approach used by (Rosen 1988) and (Arthur 1981).

In Chapter 3, the willingness to pay for a change in the probability of dying was derived as the marginal rate of substitution between risk and wealth. This result is used in this chapter as well and a change is considered that keeps utility unchanged (refer to (Varian 1999)).

$$dZj = \frac{\partial Zj}{\partial D_k} dD_k + \frac{\partial Zj}{\partial Wj} dWj = 0$$

$$\frac{dW_j}{dD_k} = -\frac{\partial Z_j / \partial D_k}{\partial Zj / \partial W_j}$$

From the marginal rate of substitution between wealth and a change in the probability of dying, it follows that the individual's willingness to pay at age j for a change in D_k is

$$WTP_{j,k} = -\frac{\partial Z_j / \partial D_k}{\partial Zj / \partial W_j} dD_k \qquad \text{[EQ 5.8]}$$

By applying the Lagrange function to EQ 5.5 and EQ 5.7:

$$L = \sum_{t=k}^{T} (1+\rho)^{j-t} q_{j,t} U(c_t) - \lambda_j \left(\sum_{t=k}^{T} q_{j,t} (1+r)^{j-t} (c_t - y_t) - W_j\right)$$

$$= \sum_{t=k}^{T} (1+\rho)^{j-t} q_{j,t} U(c_t) + \lambda_j \left(\sum_{t=k}^{T} q_{j,t} (1+r)^{j-t} (y_t - c_t) + W_j\right)$$

The envelope theorem tells us that (Sydsæter & Hammond 1995)

$$\frac{\partial Z_j / \partial D_k}{\partial Z_j / \partial W_j} = \frac{\partial L \ / \partial D_k}{\partial L_j / \partial W_j}$$

And to follow:

$$\frac{\partial Z_j}{\partial D_k} = 0 + -\frac{1}{(1-D_k)} \sum_{t=k}^{T} [\ q_{j,t+1}(1+\rho)^{j-t-1} U(c_{k+1}) + \lambda_j (1+r)^{j-t-1} (y_{t+1} - c_{t+1})\ ]$$

$$= -\frac{1}{(1-D_k)} \sum_{t=k+1}^{T} [\ q_{j,t}(1+\rho)^{j-t} U(c_t) + \lambda_j (1+r)^{j-t} (y_t - c_1)\ ]$$

$$\frac{\partial Z_j}{\partial W_j} = \lambda_j \quad \text{(the marginal value of wealth)}$$

By applying EQ 5.6 the following appears:

$$WTP_{j,k} = \left[(1-D_k)^{-1} \sum_{t=k+1}^{T} q_{j,t} \left[(1+\rho)^{j-t} U(c_t) \lambda^{-1}{}_j + (1+r)^{j-t} (y_t - c_t) \right] \right] \mathrm{dD_k} \quad \text{[EQ 5.9]}$$

The willingness to pay[36] at age j for a reduction in the conditional probability of death at age k consists of the sum of two parts:

1) The gain in expected utility from age k+1 onward, converted to DKK by dividing by the marginal utility of wealth in year j λ_j (represented in the first part of the bracket).

2) The effect on the budget constraint which is determined by two different factors. On the one hand, a reduction in D_k makes the individual wealthier by increasing the value of the expected earnings from age k+1 and onwards. On the other hand, a reduction in the conditional probability of death also decreases the consumption the person can afford in each of the years k+1 through T. Accordingly, the effect on the budget constraint is the present value of the difference between the earnings and the value of the consumption stream,

[36] It must be pointed out that for a policy that affects the conditional probability of dying over a number of years, the total WTP is the sum of WTP for the changes in each of the D_k.

Another way of considering WTP in the life-cycle consumption model is by means of the inter-temporal substitution possibilities, which refer to substitution between quantity (life-years) and quality (consumption per year). The intuition is that a greater inter-temporal substitution reduces the willingness to pay for life extensions, because quantity and quality are better substitutes (Rosen 1988).

5.2.1.1 Latency

In the air pollution context, issues of latency arise as it is often the case that an individual affected by air pollution experiences the impact several years after the event. Hence, it is very important for decision-makers to be informed about how latency affects the value of a change in the probability of dying.

From the first order condition for utility maximisation (refer to appendix B for a calculation) EQ 5.9 can be rephrased:

$$WTP_{j,k} = \left[(1 - D_k)^{-1} \sum_{t=k+1}^{T} q_{j,t} (1+r)^{j-t} \left[U(c_t)/U'(c_t) + y_t - c_t \right] \right] dD_k \quad \text{[EQ 5.10]}$$

Using the fact that $q_{j+1,t} = q_{j,t}/(1-D_j)$ and $1+R_j = \frac{(1+r)}{(1-D_j)}$, it is then apparent that the following relationship exists:

$$WTP_{j+1,k} = (1+R_j) WTP_{j,k} \Leftrightarrow WTP_{j+1,k} / WTP_{j,k} = 1 + R_j$$

and accordingly:

$$WTP_{j,k} = \Gamma_{j,k} WTP_{k,k} \quad , \quad \Gamma_{j,k} = \prod_{t=j}^{k-1} (1+R_t)^{-1}$$

The importance of this result is that if estimates of WTP can be found for a change in conditional probability of death in the future ($WTP_{k,k}$), these can be discounted to estimate WTP today for a future risk change. Refer to (Alberini et al. 2004) for an empirical application.

According to Cropper, the theoretical expectation of this model is that the presence of a latency period reduces willingness to pay. The reasoning is that WTP is lower at a higher age due to two things; 1) the discounting of WTP to the present, and 2) there being fewer expected life-years at risk (Cropper 1990b).

However, in my opinion, the conclusion that WTP decreases with age is not unambiguous, and this will be expanded upon in the next section.

At first, the discount factor $(1+R_t)^{-1}$ deserves some attention. D_j is the probability of dying at age j and must be presumed to be an increasing function of age. Hence $(1-D_j)^{-1}$ increases with age, and as r is assumed to be constant, $(1+R_j)$ also increases with age. The intuitive explanation is that the effective rate of time preference is increased by the force of mortality. Hence, the future is discounted more heavily with age due to the probability that the person may not be around to enjoy it (Rosen 1988). This is in accordance with the prediction that the latency period reduces the WTP.

It is evident that the issue of latency is closely related to the issue of the relationship between age and the valuation of a change in the probability of dying. This relationship will be given even more attention in the next section where the above-mentioned ambiguity will also be described.

5.2.1.2 Age

As mentioned in Chapter 4, it has been claimed that a change in the risk of dying in relation to a change in air pollution mainly affects the elderly.[37] For this reason it very important to investigate whether the value of a statistical life varies with age.

When taking a close look at formula EQ 5.10, it is reasonable to assume that y_t and c_t follow some kind of inverse u-form (refer to the empirical analysis in (Shepard & Zeckhauser 1982)). With $c_t>y_t$ at "high" ages and $c_t<y_t$ at lower ages, the input from this factor is negative for high level of ages and positive for lower level of ages.

The relation $(U(c_t)/U'(c_t))$ is positive. If the utility of consumption is time-invariant, this relationship is constant and accepting the assumptions about c_t and y_t from above, it is reasonable to assume that the relationship between the WTP for a risk reduction and the age of the individual follows an inverse U-form. This has been found in some empirical analyses using the static model (refer to Chapter 4) and in some life-cycle consumption analyses as well (refer to (Shepard & Zeckhauser 1982;Shepard & Zeckhauser 1984). However, it is important to emphasise that the inverse U-form found in the life-cycle models is partly based on *empirical analysis* of life-time earnings in the U.S. and partly on assumptions concerning the utility functions. Accordingly, the result is not a theoretical result. Regarding the assumptions about the utility function in the analysis in (Shepard & Zeckhauser 1982), the utility and marginal utility of consumption are defined as $U(c) = c^{0.2}$ resulting in $U'(c) = 0.2c^{-0.8}$. However, $(U(c_t)/U'(c_t))$ constitutes a linear relationship in c. $(U(c_t)/U'(c_t))=5c$). The point worth emphasising here is that the utility function is *time-invariant.*

However, if the utility of some given level of consumption depends on age or time, the sign of the expression $(U(c_t)/U'(c_t))$ differentiated with respect to time (age) is ambiguous. Even though it is reasonable to assume that consumption and utility of consumption decreases with age (after a certain age), this could very well be outweighed by an even faster decrease in the marginal utility of consumption. Accordingly, $(U(c_t)/U'(c_t))$ could decrease or increase with age. It is not possible to say whether this out-weights the input from $(y_t - c_t)$ and, hence, WTP could be constant, decrease or increase with age. This observation corresponds to the results of the theoretical analysis made in (Johansson 2002). The conclusion of this study is that there is no theoretical support for the idea that the value of statistical life should decline as a function of age.

The relationship between marginal utility, utility and the dollar value represents the cornerstone in the analysis made by Ng, (Ng 1992). The reasoning in this article is that the marginal utility of a dollar when young is much higher as it can be compounded longer, whereas the value of life in utility terms may decrease as one ages. However, when combined the dollar value of life $(U(c)/U'(c))$ may increase dramatically with age, since the marginal utility of a dollar may decrease faster. This illustrates the point made earlier on the ambiguity of the relation between the utility of consumption and the marginal utility of consumption when time (age) is taken into consideration.

At this point, it is interesting to recall the theoretical results found in the Jones-Lee model, refer to Section 5.1 and Chapter 3. One result was that the marginal value of life expectancy is a decreasing function of initial life expectancy. Accordingly, the prediction from this model is that an elderly person with a lower life expectancy will value a marginal change in life expectancy higher than a younger person. This unambiguous result illustrates the difference between taking the life-cycle consumption into account and only considering the initial wealth as in the Jones-Lee model. The intuitive explanation is that given two persons with the same initial wealth, one will expect the elder individual to value a change in life expectancy higher than the younger, because the marginal value of money is low in the state of death. However in the life-cycle consumption models it is taking into account that earnings and consumption (and thereby wealth) changes with age, which results in the formulas discussed in this section.

5.2.2 The survival probabilities.

In the Jones-Lee framework, the probabilities of dying are considered given and interpreted as the individual's subjective probability of dying. The Cropper model does not explicitly discuss whether the probabilities should be interpreted as subjective or objective probabilities. However, it is reasonable to assume that the model is based on objective probabilities because the empirical work (refer to Shepard) has been performed with factual information and, thereby, objective measures of probabilities.

The survival probabilities are taken for given and are therefore described as exogenous. However, the analysis found in (Ehrlich 2000) is an extension of the Cropper model and opens up for the possibility that the incidence of mortality can be controlled at the margin, through health and safety-enhancing choices. Choosing an optimal amount of these efforts can be referred to as the protection problem, with self-protection services produced through inputs of time, market goods and an

efficiency parameter as education or age. The analysis presents a closed-form solution for individuals' private value on saving lives and, besides the factors already mentioned (age and wealth), family status, occupation, education and sex are also determinants due to the effect they have on the value of life protection.
By incorporating a stochastic time horizon, the model becomes very complex, but it does allow for a distinction between *actual life span* and *planning horizon*. The value of life and health protection is seen to be rising over a good part of the life-cycle, because ageing raises the benefits from protection. However, since the actual life-span of most is shorter than the planned horizon, the value of life can be seen also to rise in the last part of the actual life span.

5.2.3 Preferences for bequest.

The Cropper model ignored the preferences for bequest, whereas the Jones-Lee model assumed that the value of wealth has a higher value in the state of being alive as compared to a "state of death". However, the models of Ehrlich (1990, 2000), among other factors, incorporate preferences for bequest (refer to Chapter 5.2.3).

The preference for bequest is defined as the relationship between the utility of one unit of capital to be bequeathed at t and the marginal expected utility of a unit of wealth while one is alive. In the rare case where a dollar bequeathed yields the same utility as a dollar enjoyed while alive, a person derives equal satisfaction from a given amount of financial wealth either directly or through survivors. Optimal bequest will exhaust the individual's wealth constraint and the foregone benefits of expected future income represent the value of life which corresponds to the value of a "wage-earner" in the terminology by Dublin (Dublin & Lotka 1930;Ehrlich 2000) (refer to Chapter 3). Besides, the amount any individual would pay for a given reduction in risk would be independent of base probability (Weinstein, Shepard, & Pliskin 1980), and money and survival probabilities would not be complements.

However, a more general result is presented in the situation where a unit of wealth bequeathed has a lower marginal expected utility than a unit of wealth while alive (in accordance with the Jones-Lee framework). Not surprisingly, the private value of life protection is then inversely related to one's relative bequest preferences. The intuitive explanation could be that by leaving a large bequest the individual "lives on" through descendants.

To analyse the bequest values fully, the model instead ought to incorporate the utility the person receives from dependents when alive (Rosen 1988). However, it is not an easy task to find some empirical estimates of the relative bequest preferences. One possibility is according to Ehrlich to assume, as Becker (Becker G.S, Murphy, & Tamura 1990), that the intensity of the current generation's bequest motive is directly related to family size. It follows that a reduction in average family size will be associated with a higher demand for life expectancy. This assumption represents, of course, a rather rough simplification of reality.

5.3 Health.

In the original life-cycle consumption models, inter-temporal substitution is, as mentioned above, understood as the substitution between quality and quantity, with quantity being measured as the amount of consumption available. However, in later applications of the life cycle consumption models, the relationship between utility and the health status of the individuals in the life cycle consumption models has been given some attention in the literature. I will consider two different approaches to combine some measure of the health status of the individual with the life cycle consumption models:

1) Linking QALY maximisation with the life cycle consumption models. (Bleichrodt & Quiggin 1999)

2) Incorporating the Grossman model into the life cycle consumption models. (Ehrlich & Chuma 1990)

The models will not be examined in detail here. However, some important results are worth mentioning. To begin with, further analysis of the Cropper model will be made in order to establish if the model can tell us anything about the influence of health status on the valuation in the life-cycle consumption models.

5.3.1 Expectations from the Cropper model.

Taking a closer look at EQ 5.10 again one can make a similar analysis as in Chapter 3.2.3.1. If poor health limits the individual's opportunity to consume, the marginal utility of consumption may be smaller if survival will mean poor health. However if the utility of being alive when being in poor health is smaller as well, then the direction of the influence turns out to have an ambiguous sign. This is similar to the result derived in Chapter 3 in the static model.

5.3.2 Life-cycle consumption models and QALY maximisation.

In the health economics literature, much work has been carried out on the concept of a Quality Adjusted Life Year (QALY). QALYs are used as an outcome measure in cost-utility analysis. A QALY is calculated by adjusting life years for the health status in which they are spent. Each health state is assigned a quality weight with a value between 0 and 1 and, hence, a year in bad health will weigh less than a year in good health. See e.g (Bleichrodt & Johannesson 1997) for a discussion of QALYs. By accepting this assumption and transferring it to the valuation of a risk reduction, this should mean that the value of a risk reduction would be given a lower value if a respondent is in bad health and, thereby, the value of a risk reduction would be increasing in health.

The objective of the study by (Bleichrodt & Quiggin 1999) is to show when the outcome side of a cost-benefit analysis (represented by the life-cycle consumption models) is consistent with the cost-effectiveness studies (represented by the QALY maximisation). By assuming no bequest motive and a utility function which strictly increases with consumption, the authors derive a model which basically multiplies the utility of the health status with the utility of the consumption at any given time. Accordingly, larger welfare gains can be obtained by devoting resources to individuals with a high level of consumption and a high QALY score. This corresponds to the result found in Chapter 3 that the marginal value of a decrease in risk is a non-decreasing function of initial wealth.

However, in deriving the model above by combining QALY with the life-cycle consumption models, the following assumptions are needed, according to (Bleichrodt & Quiggin 1999):

1. Utility must be additive over time (the marginality assumption implying that all complementarities between time periods are excluded).
2. It must be possible to multiplicatively decompose the one-period utility function into a utility function for consumption and a utility function for health status (and hence independence is assumed between the utility of health status and the utility of consumption).
3. The utility of consumption (and the marginal utility) must be constant over time (due to the strictly increasing utility of consumption, this means constant consumption).

However, some of these assumptions are alleviated in the following approach.

5.3.3 Life-cycle consumption models and the Grossman model

The assumptions from the model above are, to a certain extent, not necessary in the model by (Ehrlich & Chuma 1990) as the demand for health is determined jointly with that for longevity[38]. The utility function is still specified as being separable over time (assumption no. 1). However, the maximising objective is to choose an optimal time horizon in conjunction with both the consumption and the health path. The framework is based on the theoretical model by Grossman (Grossman 1972). In the Grossman model, health capital is seen as having two different functions; 1) it augments the amount of health time available by reducing the fraction of sick time, and 2) delays the approach of death. By combining the life-cycle consumption model with the Grossman model, individual longevity can be linked with the force of economic incentive from endowed wealth, health education, medical cost, age and time preference.

[38] This article assumes that the health path is known with certainty, meaning that the time of death is an event occurring at some certain time in the future and not a possible event occurring tomorrow. This assumption is alleviated in (Ehrlich 2000).

This methodology has been further developed in work by Cameron & DeShazo[39] by characterising how the value of avoiding a variety of different illness profiles varies across each year of an individual's remaining life-time.

5.4 Critique of the life-cycle consumption models.

The life-cycle framework described above can, in my opinion, be very informative when a theoretical analysis of the effect of age and latency is required. The models can provide analysis in a way that is not possible within the static one-period model. However, the model framework has some serious limitations. Some of them are grounded in the basic welfare economic framework and some of them have been discussed and relaxed.

An important thing to stress is that in models which solely depend on consumption, the derived value is actually the willingness to pay for the opportunity to consume (Freeman III 2003). Even though this is a basic assumption behind welfare theory, it seems even more restrictive when dealing with matters such as life and death. It seems unlikely that individuals are indifferent to time remaining and, according to Bergstrom (Bergstrom 1982), the models should include a valuation of life *per se*. If this is increasing with the $q_{j,t}$ (the probability that the individual survives to his t^{th} birthday given he is alive at age j), then EQ 5.9 must be regarded as a lower bond on the WTP.

In Figure 5.1, the model, some essential assumptions and the results are illustrated. The yellow-coloured boxes are the essential assumptions made and below these, some relaxations of these assumptions are given.

It is apparent from the figure that the fundamental assumption that utility is a weighted sum of period utilities underlies all the models and many other models that take the time dimension into account.

[39] This work has not been published yet, but some papers can be seen on the webpage of DeShazo. http://www.sppsr.ucla.edu/dept.cfm?d=ps&s=faculty&f=faculty1.cfm&id=57 (15/3 2006)

However, as with most other assumptions within the welfare economic framework, when applied to the value of life, they seem rather extreme. This is because one is caused to consider whether it is reasonable to assume that individuals perceive their life as consisting of different periods, weighted with the survival probability of the given period.

The additive property of the utility function is crucial for the QALY framework as well, and the underlying assumptions behind this property have been investigated theoretically within this framework. Refer to (Pliskin, Shepard, & Weinstein 1980). However this discussion has not been extended to the life-cycle consumption models. The reasons are, most likely, grounded in some technical limitations of the life-cycle consumption framework, which could become extremely complex when relaxing the assumption about the additive utility function. [40].

[40] Still a relatively obviously extension would be to incorporate another utility discounting procedure than the conventional used (e.g. hyperbolic discounting)

The model by (Ehrlich 2000) is a good example of a complex model incorporating many factors. However, the empirical use of this model has yet still to be demonstrated. Yet the empirical use of the life-cycle consumption models has in overall been limited. This is due to the massive data requirements and the difficulties with estimating the utility function. Obviously, the functional form of the utility function can be assumed to follow some mathematical form, however in order to verify this form empirical, perfect foresight of the individual is required.

Still, in my opinion, it is necessary to develop the models further, as they provide tools for analysing very important determinants for the value of life. This could very well be done by extending the model in (Bleichrodt & Johannesson 1997), relaxing some of the assumptions and by for example using another discounting procedure (e.g. hyperbolic discounting.[41])

[41] This was suggested by Per Andersen, SDU

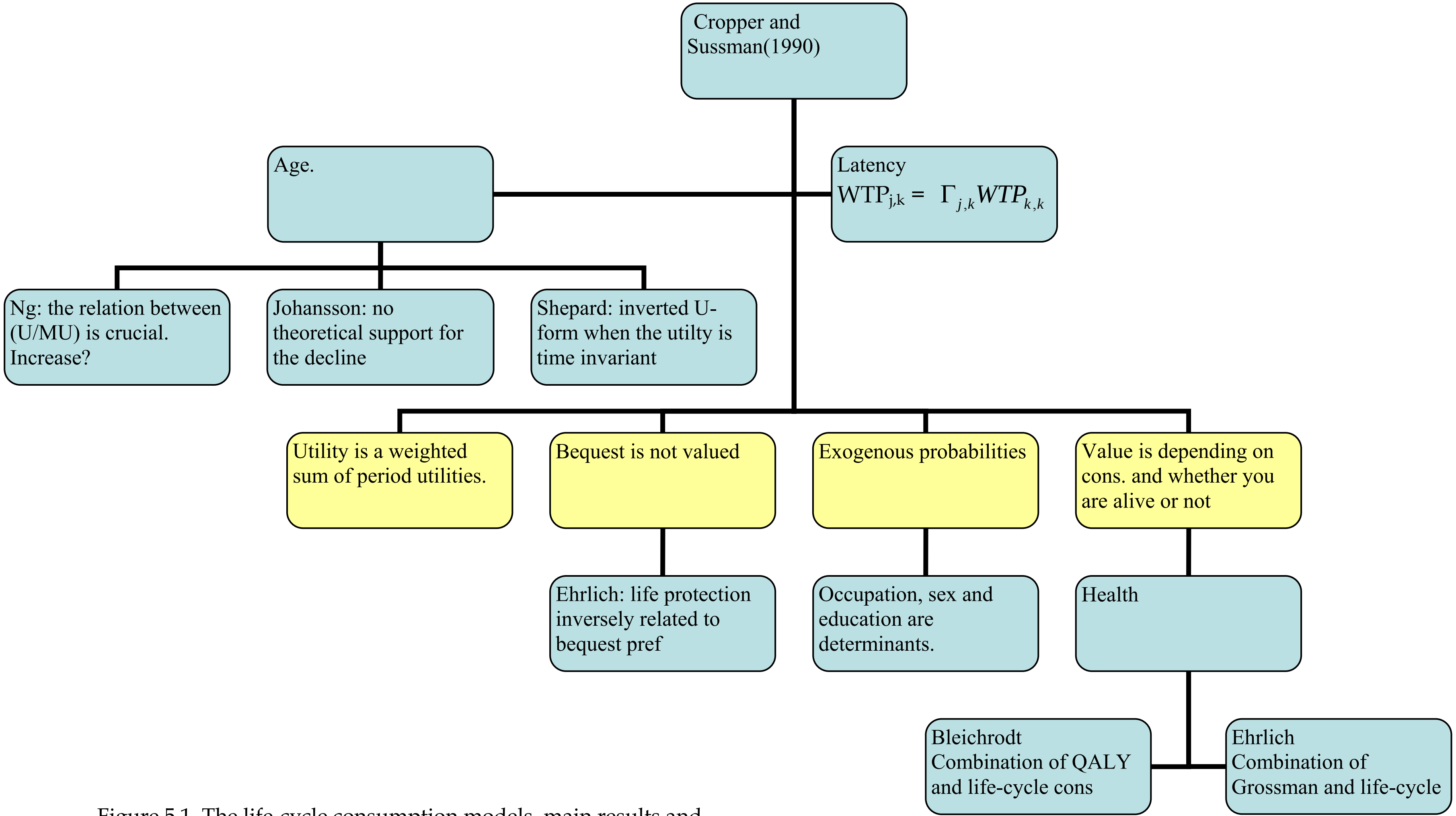


Figure 5.1. The life-cycle consumption models, main results and assumptions.

5.5 Concluding remarks.

In this chapter the life-cycle consumption models have been investigated. The Cropper and Sussman model has been presented and, in addition, some extensions of the model have been discussed. When studying the life-cycle consumption models, it is apparent that the main work was carried out during the 1980s. Since, there have only been a few attempts to investigate and extend the models. It is also noticeable that work on the models basically builds on an identical framework, with the notable exception of (Ng 1992), who chooses a slightly different direction.

First of all, it must be stressed that if decision-makers feel that "a life is a life whatever the age" then the use of a life-cycle criterion will no longer be appropriate. In this case, each life should be given the same value, no matter the age of the individual at risk (Arthur 1981). This question turns out to be a moral discussion of the significance of age and leads to the question of whether to minimise numbers of life-years lost or number of lives lost (Harris 1985). As described in (Harris 1985), focusing on the number of years can mean that one can become involved in a number of absurd weighting exercises on whether it is better to save one month for 121,000 people than to save 1,000 people every 10 years. The discussion on prioritising between different people poses the question of why age should determine the differentiation Harris (1985). One consequence of this is that it would be more desirable to rescue the life of a 15-year old to that of a 45-year old (if the "cut-off" were 70 years). Harris gives a discussion of the "*anti-ageist view*", which involves that an individual values life just as highly if they have 2 months left to live or 50 years, and the "*fair-innings*" view, where a certain number of life-years is regarded as "fair", and everyone should have identical chances in relation to achieving these years.

However, both the anti-ageist view and, in part, the fair-innings view can be questioned by the following quote:

"Those interested merely in numbers of lives saved, but not at all in time-span, think that there is as much value in postponing a death for ten minutes as in postponing it for ten years. This seems absurd." ((Glover 1977) quote p. 220)

In view of this different empirical attempts with regard to how a change in life expectancy should be valued will be investigated in Chapter 6, together with a discussion on whether there is a theoretical rationale.

6 The value of a life-year lost.

Within the field of empirical estimation of the value of a life year lost, three different approaches have evolved. With a theoretical reference to the life-cycle consumption models, one method converts VSL into Value of Life Years Lost (VOLY). Another approach recalculates the answers given in a "conventional CVM survey on VSL" into values of changes in life expectancy. A third method directly asks respondents to value life-expectancy in a CVM study.

In this chapter the three different approaches will be outlined and the theoretical justification discussed.

However, before studying the different methods it is appropriate to consider the technical relation between a change in the probability of dying and a change in life expectancy.

The life expectancy of an individual at age 20 is the sum of the probability of the individual surviving to age 21 plus the conditional probability of the individual surviving to age 22 and so on. This is illustrated by:

$$LE = \sum_{t=j}^{T} {}_{j}q_{t+1} \qquad \text{[EQ 6.1]}$$

A change in the survival curve is a change in one or more of ${}_{j}q_{t+1}$ as will be discussed later on, it is important to emphasise that different changes in the survival curve could result in the same change in LE (e.g. a change at different ages, a change in one period versus a permanent change). This is important to keep in mind when valuing a change in life expectancy. At first it seems like a static one-period measure, but it actually covers a sum of changes in probabilities over a longer time period.

6.1 The VOLY approach.

6.1.1 Description.

This approach has evolved in connection with the ExternE framework. The starting point is an empirical estimate of the VSL for an individual at age a (VSL(a)). This value is converted to a VOLY following the approach below.

$$VSL(a) = VOLY_r \sum_{i=a+1}^{i=T} {}_aP_i (1+r)^{-(i-a-1)}$$ (Holland, Berry, & Forster 1998)

${}_aP_i$ is the conditional probability of surviving from age a to age i, conditional on surviving to age a and r being the utility discount rate.

Accordingly, the age-specific VSL is divided into (T-a-1) life-years and in this approach each life-year has been given a constant value. The various life-years are weighted with the conditional probability of surviving until this specific year and are discounted.

6.1.2 Discussion of the theoretical foundation.

By comparing the VOLY expression with the expression for the WTP derived in the life-cycle consumption framework EQ 5.7, some differences and similarities are apparent.

First of all, it is noticeable that the effect on the budget constraint (second part of the bracket in EQ5.9 – preceding chapter) is not included in the VOLY approach (or more likely, it is assumed that this is a part of the VOLY and r = ρ .). By assuming that the VOLY represents ($U(c_t)/\lambda_j$) and r= ρ , the remainder of the two formulae look very similar. However, besides the assumptions given in Chapter 5, additional assumptions are required in order to justify giving each life-year an equal value. A requirement for using the VOLY approach is constant utility of consumption and constant marginal utility of consumption for all t (Krupnick et al. 1999).

The implicit implications of using this formula and a constant VOLY is that VSL for an individual will decrease monotonically with age. This is a result of that the age-related VSL as one ages will be consisting of fewer life years which all have been assigned the same value. When remembering the mixed results about the relation between age and WTP, this monotonical way of representing the relation is a very simplistic way of expressing reality.

However, an even more crucial concern about this method arises when bearing in mind the way in which the VSL is derived as an aggregation of the different individuals' valuations of a specific change in the probability of dying at a specific time in life. In Chapter 4, it was argued that the value does not symbolise the value of a person. By splitting this value into life–years, this specific change in the probability of dying is altered to denote a value for a life-year for one single individual, instead.

6.2 A value for life expectancy derived from a survey on VSL.

6.2.1 Description

Another approach exists which is not based on life–cycle consumption models, but on the static model developed in Chapter 3. The approach was developed in relation to the follow-up of the ExternE project, the EU project named NewExt (Friedrich 2006).In this project, the questionnaire developed by (Krupnick, Alberini, Cropper, Simon, O'Brien, Goeree, & Heintzelman 2002) is used (the survey is included in the table in Appendix B). In the questionnaire, the respondents, value a change in the probability of dying. Based on the age of the respondents, it is possible to calculate what change in life expectancy the respondents, hereby, have implicitly valued (the average being 1.23 months in the sample). Hence, it is assumed that this is part of the individual's calculation. Finally, the values are aggregated to the value of a life-year lost.

6.2.2 Discussion of the theoretical foundation.

This method, at first, seems very elegant as it uses an existing questionnaire approach to find a value for a change in life expectancy. However, there are some implicit assumptions contained in this approach towards finding a value of a life-year lost. Firstly, the method assumes comparability of the scale used to value a change in the probability of dying and a change in life expectancy (a summation of probabilities). This is a very heroic assumption bearing in mind the issues on scope in the CVM discussed in Chapter 3, as well as issues to be mentioned further on in this chapter. Secondly, there are some reservations regarding the generalisation of a change in the survival curve into changes in life expectancy because as mentioned different changes in the survival curve can results in the same change in life expectancy. Thirdly, it is assumed that individuals value a life-year as the sum of months, each allocated the same value. It is thereby assumed, using the terminology of the life-cycle consumption models, that the utility and the marginal utility of consumption is kept constant over a lifetime.

6.3 Directly asking for a value for a change in life expectancy.

When asking directly about the value of a change in life expectancy (LE), two different groups of concern arise: 1) the theoretical foundation behind valuing a change in life expectancy instead of a change in the probability of dying 2) issues concerning validity and how well the respondents understand the concept of LE in a CVM. In this section, both 1) and 2) will be discussed.

6.3.1 Discussion of the theoretical foundation.

As described, the life expectancy of an individual is the summation of changes in the conditional survival probabilities. Hence, as described, one change in life expectancy could actually reflect many different changes in the survival curve and, in turn, a valuation of a change in life expectancy could correspond to a valuation of many different changes in the survival curve.

With reference to EQ 5.9 in the preceding chapter, valuing a change in life expectancy corresponds to a valuation of the aggregation $\sum_{t=k+1}^{T} q_{j,t}$ dD_k. It is, therefore, impossible, afterwards, to divide this value into the value of the different life-years which could be influenced by this change in probability. Hence, it is not possible to tell anything about how the value of a life year for an individual changes with age,

health and so on. Of course, one can make cross-sectional comparisons between individuals' valuations – however, this was not the intention with the life-cycle consumption models. Accordingly, with knowledge of the value of a change in life expectancy alone, it would be problematic to predict how the value of a life varies throughout life, which is the intention with the life-cycle consumption framework.
Still, the theoretical foundation for valuing a change in life expectancy exists qua the life-cycle consumption models, even though it is not possible to incorporate the dynamic properties of the life-cycle consumption models in the valuation. The model used is actually transformed into a model within a static framework, which is very much the same as the Jones-Lee approach in Chapter 3.

$$E(U(\sum_{t=k+1}^{T} q_{j,t}\, dD_k)) = E(U(\sum_{t=k+1}^{T} q_{j,t} - V_j)) \text{ or}$$

$$E(U(LE\ \Delta D)) = E(U(LE - V))$$

with V_j being a one-time payment made at age j corresponding to the terminology in Chapter 3.
This method does not reveal any more information than the Jones-Lee model and the remaining question regards the plausibility of the assumption that a life can be divided into life-years, refer to Chapter 5.

6.3.2 Description of different surveys.

Very few studies have estimated the value of a change in life expectancy directly. The few studies undertaken are summarised in the table below, but some of them require additional comments[42].

[42] Another empirical analysis of the value of a life-year is found in (Johnson et al. 1998). However this study measures *a certain* increase in longevity and will, therefore, not be given any more attention in this paper. However, the particularly interesting part of this study is actually the arguments for choosing certainty. A certain increase in longevity has been used as a compromise in relation to what the authors call the dilemma between the ex-ante valuation approach (of which the reliability can be questioned due to the difficulties for the respondents in understanding probabilities) and the ex-post approach that invites respondents' refusal (and with no theoretical justification).

Author	Context	Risk Reduction	Means	Median	Data-collecting	n	Country
Johannsesson(1996)	private	1 year	1350		Telephone	2013	Sweden
Morris2001	private	11 months		418	Telephone	332	
		5 months		270			
Chilton2004	public	1month (normal health)	68	28	Personal	517	UK
		3 months (normal health)	77	34	Personal		
		6 months	92	45	Personal		
Desaigues(2004)	No	LE correspondning to 5/1000 in 10 years	228		Personal	59	France
		1 month	128		Personal	61	
		3 months	215		Personal		
		12 months	346		Personal		
		as the first one- but with the probability mentioned as well	193		Personal	52	

Table 6.1. Values of life expectancy. The values reflect the risk reduction valued without any aggregation. The values are stated in Euro(2000) corrected for PPs.

The first empirical estimate of the value of a change in life expectancy is found in (Johannesson & Johansson 1996). The following question was used in the questionnaire:

The chance for a man/woman of your age to become at least 75 years old is x percent. On average, a 75 year-old lives for another ten years. Assume that if you survive to the age of 75 years you are given the possibility to undergo a medical treatment. The treatment is expected to increase your expected remaining length of life to 11 years.
Would you choose to buy this treatment if it costs SEK C and has to be paid for this year?
yes
no

Quote p 168 (Johannesson & Johansson 1996)

The good in question is a change in a conditional probability and, hence, corresponds to the life-cycle consumption models presented in the last chapter. In addition to the WTP for a change in life expectancy, the study by (Johannesson & Johansson 1997) considers the relationship between self-assessed health and WTP in the same study. There is a strong positive correlation between the expected quality of health and the willingness to pay,

Another very interesting study uses the CVM on two different sub-samples, with respondents in one of the sub-samples being asked to value a change in the *probability of dying* and in a change in *life expectancy*. To value a change in life expectancy, the following question was asked:

On average, a person aged 60 (70) has a life expectancy of 21 (14) years. That is, the average 60 years-old (70-year-old) will live to age 81 (84). Suppose that a pneumonia vaccine will be available to you when you reach age 60 (70). The vaccine is perfectly safe and if you get vaccinated when you are 60 (70), your life expectancy will increase from 21 years to 21 years and 11 months (from 14 years to 14 years and 5 months). Would you consider getting a vaccine at age 60 (70)?
(Morris & Hammit 2001) p. 477)

The corresponding change in the probability of dying was from 4.8% to 4.6% (from 7 % to 6.8%). If the respondent answered yes to the question above, he or she was asked to state the willingness to pay in the current year by responding to a double-bounded dichotomous choice question. The two surveys seem very similar with regard to the framing of the questions. However, some differences are apparent. Besides the different changes in life expectancy, it is more explicitly stated in the Johannesson survey that the change in life expectancy is conditional upon turning 60, whereas in the Morris study an 18-year old respondent could consider answering "no" to the question, because they do not expect to turn 60(70).

Another approach was applied in a recent study in the UK in the context of air pollution. A "package" of four benefits was valued (X months more life expectancy in normal health, X months more life expectancy in poor health when elderly, respiratory hospital admission and avoiding days of breathing discomfort). The respondents were asked what the household was willing to pay each year for the rest of their life to benefit from this "package" (a random card sorting procedure was used). Afterwards, they were asked to divide this total WTP between the four benefits (Chilton et al. 2004b).

This perhaps represents a more realistic scenario, because the respondents are asked to value a bundle of goods all related to a change in air pollution, but the task is also quite challenging for the respondents.

At the moment a survey is carried out in 8 countries (including Denmark) regarding an air pollution related change in life expectancy. The survey uses identical questionnaires and 3 and 6 months differences in life expectancy are valued. The results are not available at this time, but will be published in a report in connection with the EU project, NEEDS.[43]

6.3.2.1 Communicating a change in life expectancy in the CVM.

It has been suggested that a change in life expectancy is easier for respondents in a CVM study to understand than a change in the probability of dying. Accordingly, valuing this good instead could make the conducting of a valid survey with CVM less demanding.

In (Morris & Hammit 2001), it was demonstrated empirically that valuing a change in life expectancy performed better in the test of scope than the valuation of a change on the probability of dying. However, in this particular survey it is questionable whether a change in 11 months, or 5 months, and the changes in probabilities used can be regarded as marginal changes. However, the same can be said for the study by Johannesson where a change in life expectancy of 1 year was valued.

In the study (Chilton, Covey, Jones-Lee, Loomes, & Metcalf 2004b), changes in life expectancy of 1, 3 and 6 months were valued (6 months is an increase of just over 1.5% and the question if this is marginal is raised). According to the authors, one would expect the values from this study to be smaller than those from other studies, where only a single good is valued. This argument is based on that the contingent valuation method is hypothetical and that the potential for over-valuation of a good is reduced when more than one good is being valued at the same time. Relatively low values were placed on extending life for short periods where that time was to be spent in poor health compared with time spent in normal health. However,

[43] NEEDS (New Energy Externalities Development for Sustainability) http://www.needs-project.org/

sensitivity to scope in the study is limited, which is explained either by 1) the a change of 6 months not being marginal and accordingly affecting the budget constraint or 2) that individuals are not capable of discriminating between the different changes.

Still, the question remains whether individuals are more capable of relating to changes in the life expectancy rather than changes in the probability of dying.
Kahneman noticed in his Nobel prize lecture (Kahneman D. 2002) that when studying the preferences for different therapies, it appears that 90% short-term survival is less threatening than 10% immediate mortality (and this being no less pronounced among experienced physicians than among patients) (refer to (McNeil et al. 1982) for the empirical analysis). One explanation of this deviation could be that anxiety is explicitly present in one case (mortality risk), whereas it is more implicit in the other (survival probabilities or life expectancy). The study demonstrates that to present an effect of a treatment as a change in life expectancy is not perceived as equivalent to the corresponding change in the cumulative probabilities. Anxiety could explain part of this, but another explanation could be that a change in life expectancy is perceived as if the change is received for certain, whereas it is uncertainty which is emphasised in the change in probabilities.

Theoretically, the value of a change in the probability of dying and the corresponding probability of surviving should result in identical values. However, when this is not the case, the question remains of what the correct measure should be. There is no clear-cut answer to this question, because while the original model of VSL was derived in the framework of a change in the probability of dying, the good in question in the life-cycle consumption models is a change in the survival curve and the corresponding survival probabilities.

6.4 Value of a life-year lost.

The natural question is now whether it is possible to aggregate the value of a change in life expectancy found by either method 2) or 3) into a value of a life- year lost. This actually parallels the discussion in Chapter 3 on the aggregation of probabilities into VSL. As in the Jones-Lee analysis, it is not realistic to assume that an individual will value a change in life expectancy of 12 months as for instance 12 * (the value of 1 months change in life expectancy). Hence the value of a life-year for an individual can only be found if the respondents are asked for their valuation of a full year (which one cannot assume is a marginal change). However, one can find the value of a "statistical life-year" by aggregating across individuals. This is not the value of one specific individual's year. Instead, it is, for instance, 12 individuals' valuation of a change in their life expectancy of 1 month.

6.5 Concluding remarks.

In this chapter, three different methods for valuing a change in life expectancy have been discussed. Regarding the first method, this seems to be a very convenient way to find a value for a life year on the basis of an already existing VSL. However, besides being based on very restrictive assumptions regarding the life-cycle consumption model, it is also, as mentioned, misleading to interpret the VSL as the value of the life of an individual.

Both the second and third methods calculate the change in life expectancy without a multi-period model. In a multi-period model, changes in the survival curve can be valued. However, in the applications, the valuation procedure is reduced to a one-period static setting which is comparable with the Jones-Lee model. Yet, the Jones-Lee model actually provides a more precise definition of the good being valued, because a change in the probability of dying at any given time constitutes a more precise description of the good than a change in life expectancy does.

At this point, it could seem paradoxical to value a change in life expectancy instead of a change in the probability of dying. However, several arguments must be kept in mind:

1) In the static one-period framework it is not possible to incorporate latency. This can be done by valuing the change in life expectancy, even though this is at an aggregate level.

2) The static one-period model cannot take into account that a change in the survival probability one year changes the survival curve as a whole. Again, this can be taken into account at an aggregate level when valuing a change in life expectancy.

3) The epidemiological estimating procedure prefers to estimate the number of years lost and not the number of lives lost. The underlying reasoning is that life is extended and not permanently saved (Moore & Viscusi 1988).

Another reason for calculating the value of a change in life expectancy could be motivated by empirical data-collecting issues. However, in my opinion it is not obvious that an individual is more capable of valuing small changes in life expectancy than small changes in the probability of dying. The two concepts are, in all cases, perceived differently as illustrated by the study by (McNeil, Pauker, Sox, & Tversky 1982) and it could be reasonable to doubt that respondents are capable of valuing a change in summation of probabilities (e.g. a change in life expectancy) if they are not capable of valuing a change in the probability of dying.

The reasons for valuing a change in life expectancy instead of a change in probabilities should be found in the three points listed above. Still, it would be appropriate to attempt to answer the following questions: Why should life-years be a measure of the change in the mortality? Why not value different stages of life? The answer is most likely found in convenience reasons, but it is important to give some consideration to these fundamental questions.

7 Conclusion.

In Chapter 1 it was declared that the answers to three related question were sought. The questions were as follows:

1. What is a possible economic foundation behind valuing a change in the probability of dying?
2. What is a possible economic foundation behind valuing a change in life expectancy?
3. What are the possible empirical perspectives of 1) and 2)?

This paper has established a theoretical rationale for a valuation of change in the probability of dying. The relationship with a theoretical valuation of a change in the survival curve has been established as well as the subsequent valuation of the aggregated change in life expectancy. Hereby, this paper has responded to question 1) and 2).

From the static one-period analysis, it follows that the marginal value of a decrease in risk is an increasing function of **initial risk** and an increasing function of **initial wealth**. In order to analyse the influence of latency and age on the valuation of a change in mortality, the analysis has been extended to an analysis in life-cycle consumption models. A theoretical result has been arrived at with regard to how to value a change in mortality which occurs after a latency period. The theoretical result on the influence of age has been of an ambiguous sign.

However, when analysing the empirical perspectives of the frameworks (Q3) some matters of concern arise. These have been dealt with in the paper and can be summarised as three main issues:

1) Problems implied by the expected utility framework.
2) Specific problems arising when the good in question is a change in mortality.
3) Aggregation procedures.

7.1 Problems implied by the expected utility framework in general.

In Chapter 2, the underpinning foundations of CBA were analysed and it was demonstrated that the theory of consumer surplus and the potential compensation principle, together, provide a conceptual framework in which proposed policy changes can be analysed. Some of the underlying assumptions behind the utilitarian framework, however, give cause for great concern about the usefulness of the analysis. The greatest concern focuses on the empirical estimation of probabilities and whether the individuals act in accordance with the NM axioms.

In this paper, this is of special importance when moving from the static one-period model to the multidimensional model, because then the valuation changes from valuing a change in the probability of dying to valuing change in the survival curve. And as mentioned, people do not value corresponding changes in survival probabilities and probabilities of dying equally.

Another concern is that the framework outlined in Chapter 2 assumes that utility is dependent only on consumption. As can be seen from the analysis in both the one-period framework and the life-cycle consumption models, other determinants influence the value as well (the health status of the individual, for example).

7.2 Specific problems.

The finding that money and changes in the probability of dying are complements makes valuation of a change in the probability of dying complicated. However, one could argue that this is not a problem when only looking at marginal changes, which is the purpose of a CBA.

Another very important implication of the method is how to deal with the reality that some individuals are simply unwilling to make a trade-off between life and money. In other words, how to deal with "protected values". A related concern is whether people, in reality, value anxiety and not the value of a change in the probability of dying.

Another concern relates to that the models take time into consideration and the division of a life into different independent periods. Even though individuals do not think that "a life is a life whatever the age" there is no clear-cut evidence that individuals view their lifetime as the summation of different periods, as implied by the life-cycle consumption models.

7.3 Aggregation procedures.

Different aggregation procedures have been derived in order to be able to obtain values at a more aggregated level for use in CBA.

First, the term "value of a statistical life" has been criticised. This aggregation should, in my opinion, be avoided because VSL is a confusing name and does not clearly say what is being valued. However, I realise that aggregation can sometimes be necessary in CBA – but, in these cases, the VSL should at least be labelled VSL(risk change, initial risk), and I would prefer the VPF term to be used instead.
Secondly, it has be mentioned that when aggregating different variations in the survival curve into changes in life expectancy, information from the life-cycle consumption models is lost and the subsequent model has many similarities with a one-period static setting.
Thirdly, the natural question is whether it is possible to aggregate the values assigned to a change in life expectancy into the value of a life-year lost The value of a life-year for an individual can only be found if the respondents are asked for their valuation of a full year (which one cannot assume is a marginal change). However, one can find the value of a "statistical life-year" by aggregating across individuals, but this is not the value of one specific individual's year.

7.4 Consequences and wider perspectives.

When investigating all the problems and limitations with the outlined framework, the obvious question that comes into mind is whether it makes any sense trying to value a change in mortality?

This question can be investigated from different perspectives:

1) If the expected utility framework cannot be accepted, one can choose not to use any form of economic evaluation in a prioritising situation. However, given the

scarcity of resources, it in is my opinion a very complex task to prioritise without input from any economic valuation.

Given the limitations of the expected utility theory, it would be very useful to try to "rethink" the expected utility framework with a contribution from behavioural economics (e.g. the prospect theory).
The empirical solution has been to incorporate findings from sociology and psychology into empirical estimations techniques (stated preferences). In this way, it is recognised that people do not react in accordance with the underlying axioms. However, the welfare economic framework is still the theoretical starting point for CVM. Still, this collaboration between fields could, hopefully, in time result in a reformulation of the expected utility framework with input from behavioural economics.

2) This said, the intent of this paper was to establish a framework for valuing a change in mortality in the expected utility sense. If policy-makers accept the expected utility framework, solutions need to be found with regard to how to deal with the specific problems related to valuation of mortality (anxiety, complementarity, etc.)[44]
If we cannot value a change in mortality in the expected utility sense, it then makes no sense to evaluate policy decisions that, among other things, affect the mortality rate. By not setting a value for a change in mortality in a CBA, a change in mortality is either assigned a value of zero or the value of a change in mortality turns into the numeraire against which the value of all other interventions must be compared. However, in my opinion the description of the good needs further sophistication. "A change in the probability of dying" or a "change in the survival-curve" are rather vague descriptions of a good, when taking into account how the value of a change in mortality can vary with e.g. the health status of the individual. Further development of a model within the expected utility framework to value a change in mortality while taking health status into consideration must be a priority for future research.

[44] I have already mentioned that it is arbitrary to stress some problems as specific to the valuation of mortality, because it is an assumption in the welfare economic framework that we have consistent well-established preferences, no matter the good in question.

References

Acton, J. P. 1976, "Measuring the Monetary Value of Lifesaving Programs", *Law and contemporary Problems*, vol. 40, no. 4, pp. 46-72.

Alberini, A., Cropper, M. L., Krupnick, A., & Simon, N. Willingness to pay for mortality Risk Reductions: Does Latency Matter? Working Paper 04-04 US.EPA 2004 . 2004.
Ref Type: Generic

Alberini, A. 2004, *Robustness of VSL Values from contingent Valuation Surveys*, Fondazione Eni Enrico Mattei.

Allais, M. & Hagen, O. 1979, *Expected utility hypothesis and the Allais Paradox* D. Reidel Publishing Company, Dordrecht, Holland.

Andersen, M. S., Frohn, L. M., Jensen, S. S., Nielsen, J. S., Sørensen, P. B., Hertel, O., Brandt, J., & Christensen, J. 2004, *Sundhedseffekter af luftforurening-beregningspriser* Faglig rapport fra DMU nr. 507.

Anderson, R. J. 1981, "A Note on option Value and the Expected Value of Consumer's Surplus", *Journal of Environmental Economics and Management*, vol. 8, pp. 187-191.

Andersson, H. 2005, "The value of safety as revealed in the Swedish car market: An application of the hedonic pricing approach", *Journal of Risk and Uncertainty*, vol. 30, no. 3, pp. 211-239.

Arrow, K., Solow, R., Portney, P. R., Leamer, E. E., Radner, R., & Haward Schuman 1993, *Report of the NOAA Panel on Contingent Valuation*.

Arthur, W. B. 1981, "The Economics of Risks to Life", *The American Economic Review*, vol. 71, no. 1, pp. 54-66.

Bach, H., Andersen, M.S:, Illerup, J. B., Møller, F., Birr-Pdersen, K., Brandt, J., Ellerman T, Frohn, L. M., Hansen, K. M., Jensen, F. P., & Nielsen, J. S. 2006, *Vurdering af de samfundsøkonomiske konsekvenser af Kommissionens temastrategi om luftforurening* DMU Faglig Raport - forthcoming.

Baron, J. 1997a, "Biases in the Quantitative Measurement of Values for Public Decisions", *Psychological Bulletin*, vol. 122, no. 1, pp. 72-88.

Baron, J. 1997b, "Protected Values", *Organizational Behavior and Human Decision Processes*, vol. 70, no. 1, pp. 1-16.

Bateman, I. J., CArson, R. T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M. W., Loomes, G., Mourato, S., Özdemiroglu, E., Pearce, D. W., Sugden, R., & Swanson, J. 2002, *Economic Valuation with Stated Prefernce Techniques. A Manual.* Edward Elgar, Cheltenham.

Baumol, W. 1958, "The Cardinal Utility Which is Ordinal", *The Economic Journal*, vol. 68, no. 272, pp. 665-672.

Becker G.S, Murphy, K. M., & Tamura, R. 1990, "Human Capital, Fertility, and economic Growth", *The Journal of Political Economy*, vol. 98, no. 5(2), pp. S12-37.

Bergstrom 1982, "When is a man's life worth more than his human capital?," in *The Value of Life and Safety. Proceedings of a Conference held by the 'Geneva Association'. Collection of Papers presented at the Geneva conference on The Value of Life and Safety held at the University of Geneva 30th, 31st March and 1st April, 1981*, The Value of Life and Safety. Proceedings of a Conference held by the 'Geneva Association'. Collection of Papers presented at the Geneva conference on The Value of Life and Safety held at the University of Geneva 30th, 31st March and 1st April, 1981 edn, M. W. Jones-Lee, ed., NORTH-HOLLAND PUBLISHING COMPANY, pp. 3-26.

Bernoulli, D. 1954, "Exposition of a New Theory on the Measurement of Risk", *Econometrica*, vol. 22, no. 1, pp. 23-36.

Bishop, R. C. 1982, "Option Value: An exposition and Extension", *Land Economics*, vol. 58, no. 1, pp. 1-15.

Bleichrodt, H. & Johannesson, M. 1997, "Standard gamble, time trade-off and rating scale: experimental results on the ranking properties of QALYs", *Journal of Health Economics*, vol. 16, pp. 155-175.

Bleichrodt, H. & Quiggin, J. 1999, "Life-cycle preferences over consumption and health: when is cost-effectiveness analysis equivalent to cost-benefit analysis?", *Journal of Health Economics*, vol. 18, pp. 681-708.

Blomqusit, G. C. 2004, "Self-Protection and Averting Behavior, Values of Statistical Lives, and Benefit Cost Analysis of Environmental Policy", *Review of Economics of the Household*, vol. 2, pp. 89-110.

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. 2001, *Cost-Benefit Analysis. Concepts and Practice.*, Second Edition edn, Prentice Hall, Inc, New Jersey.

Broome, J. 1978, "Trying to value a life.", *Journal of Public Economics*, vol. 9, pp. 91-100.

Brunekreed, B. 1997, "Air pollution and life expectancy: is there a relation?", *Occupational and environmental medicine*, vol. 54, pp. 781-784.

CArson, R. T. 1997, "Contingent Valuation Surveys and Tests of Insensivity to Scope," in *Determining the Value of Non-Marketed Goods: Economic, psychological, and Policy Relevant Aspects of Contingent VAluation Methods.*, R. J. Kopp, W. Pommerhene, & N. Schwartz, eds., Kluwer, Boston.

CArson, R. T. 2000, "Contingent Valuation: A User's Guide", *Environmental Science and Technology*, vol. 34, pp. 1413-1418.

CArson, R. T., Flores, N. E., & Meade, N. F. 2001, "Contingent Valuation: Controversies and Evidence", *Environmental and Resource Economics.*, vol. 19, pp. 173-210.

Chanel.O., Faugere, E., Geniauz, G., Kast, R., Luchini, S., & Scapecchi, P. 2003, *Economic valuation of air pollution effects: evidence from a contextual CV survey*, GREQAM, Document de Travail n 03B09.

Chilton, S., Covey, J., Hopkins, L., Jones-Lee, M. W., Loomes, G., & Spencer, A. 2002, "Public perceptions of Risk and Preference-Based Values of safety", *Journal of Risk and Uncertainty*, vol. 25, no. 3, pp. 211-232.

Chilton, S., Jones-Lee, M. W., Loomes, G., Robinson, A., Cookson, R., Covey, J., Spencer, A., Hopkins, L., Pidgeon, N., & Beattie, J. 1997, *Valuing health and safety controls. A literature review*, The Health and Safety Executive, Contract Research Report 171/1998.

Chilton, S., Codey, J., Hopkins, L., Jones-Lee, M. W., Loomes, G., Pidgeon, N., Robinson, A., & Spencer, A. 2004a, "Valuing the "value of life". A case of constructed preferences?," in *Mixing Methods in Psychology. The Integration of Qualitative and Quantitative Methods in theory and Practice*, Z. Todd et al., eds., Psychology Press, East Sussex.

Chilton, S., Covey, J., Jones-Lee, M. W., Loomes, G., & Metcalf, H. 2004b, *Valuation of health benefits associated with reductions in air pollution.*

Cicchetti, C. J. & Freeman III, A. M. 1971, "Option Demand and Consumer Surplus: Further Comment", *Quaterly Journal of economics*, vol. 85, no. 3, pp. 528-539.

Ciriacy-Wanstrup, S. V. 1947, "Capital Returns from Soil Conservation Practices.", *Journal of Farm Economics*, vol. 29, pp. 1181-1196.

Corso, P. S., Hammit, J. K., & Graham, J. D. 2001, "Valuing Mortality-Risk reduction: Using Visual Aids to Improve the Validity of Contingent Valuation.", *Journal of Risk and Uncertainty*, vol. 23, no. 2, pp. 165-184.

COWI 2004, *External Costs of Transport. Report no. 1-3*, Dansik Ministry of Transport.

Cropper, M. 2001, *Outline paper. DG environment workshop on mortality valuation*.

Cropper, M. L. & Arriaga-Salinas, A. S. 1980, "Inter-city Wage Differentials and the Vakue of Air Quality", *Journal of Urban Economics.*, vol. 8, pp. 236-254.

Cropper, M., Aydede, S. K., & Portney, P. R. 1994, "Preferences for Life Saving Programs: How the Public Discount Time and Age.", *Journal of Risk and Uncertainty*, vol. 8, pp. 243-265.

Cropper, M. & Freeman III, A. M. 1991, "Environmental health effects.," in *Measuring the Demand for Environmental Quality.*, J. B. Braden & C. D. Kolstad, eds., North-Holland, Amsterdam, pp. 165-211.

Cropper, M. L. P. P. R. 1990a, "Discounting and the Evaluation of Lifesaving Programs.", *Journal of Risk and Uncertainty*, vol. 3, pp. 369-379.

Cropper, M. S. F. G. 1990b, "Valuing future risks to life", *Journal of Environmental Economics and Management* pp. 160-174.

Dalvi, M. Q. 1988, *The value of life and safety: A search for a consensus estimate.* Department of Transport., London.

Diamond, P. A. & Hausman, J. A. 1994, "Contingent valuation: Is Some Number better than No Number?", *The Journal of Economic Perspectives*, vol. 8, no. 4, pp. 45-64.

Drèze, J. H. 1962, "L'Utilite Sociale D'une vie Humaine", *Revue francaise de recherche opérationnelle*, vol. 6, pp. 93-118.

Dublin, L. I. & Lotka, A. J. 1930, *The Money Value of a Man* The Ronald Press Company., New York.

Dwyer, L. 1986, "Environmental Policy and the Economic Value of Human Life.", *Journal of Environmental Management*, vol. 22, pp. 229-243.

Ehrlich, I. 2000, "Uncertain lifetime, life protection, and the value of life saving.", *Journal of Health Economics*, vol. 19, pp. 341-367.

Ehrlich, I. & Chuma, H. 1990, "A Model of the Damand for Longevity and the Value of Life Extension.", *The Journal of Political Economy*, vol. 98, no. 4, pp. 761-782.

European Commission 2001, *Recommended Interim Values for the Value of Preventing a Fatality in DG Environment Cost Benefit Analysis.*

Folland, S., Goodman, A., & Stano, M. 2004, *The economics of health and health care*, Fourth edn, Prentice Hall, New Jersey.

Freeman III, A. M. 1985, "Supply Uncertainty, Option Price, and Option Value", *Land Economics*, vol. 61, no. 2, pp. 176-181.

Freeman III, A. M. 1989, "Ex Ante and Ex Post Values for Changes in Risks", *Risk Analysis*, vol. 9, no. 3, pp. 309-317.

Freeman III, A. M. 1993, *The Measurement of Environmental and Resource Values. Theory and Methods* Resources for the Future, Washington.

Freeman III, A. M. 2003, *The Measurement of Environmental and Resource Values. Theory and Methods* Resources for the Future, Washington.

Friedrich, R. 2006, *New Elements for the Assessment of External Costs from Energy Technologies (NEWEXT),* Stuttgart: IER..

Gayer, T., Hamilton, J. T., & Viscusi, W. K. 2000, "Private values of risk tradeoffs at Superfund Sites: Housing market evidence on learning about risk", *The Review of Economics and Statistics*, vol. 82, no. 3, pp. 439-451.

Glover, J. 1977, "Choices Between People," in *Causing Death and Saving Lives*, Penguin Books, London, pp. 217-227.

Grossman, M. 1972, "On the concept of Health Capital and the Demand for Health", *Journal of Political Economy*, vol. 80, pp. 223-255.

Hammerton, M., Jones-Lee, M. W., & Abbott, V. 1982, "Equity and Public Risk: Some Empirical Results", *Operations Research*, vol. 30, no. 1, pp. 203-207.

Hammit, J. K. 2000, "Valuing mortality risk: Theory and practice", *Environmental Science and Technology*, vol. 34, no. 8, pp. 1396-1400.

Hammit, J. K. & Graham, J. D. 1999, "Willingness to Pay for Health Protection : Inadequate Sensivity to Probablility", *Journal of Risk and Uncertainty*, vol. 8, pp. 33-62.

Hanemann, M. W. 1994, "Valuing the Environment Through Contingent Valuation", *The Journal of Economic Perspectives*, vol. 8, no. 4, pp. 19-43.

Hansen, T. B. 1997, "The Willingness-to-PAy for the royal Theatre in Copenhagen as a Public Good", *Journal of Cultural Economics*, vol. 21, pp. 1-28.

Harbaugh, W. T. 1998, "Valuing children's health. What does economic theory say about including parental and societal willingness to pay?", US Environmental Protection Agency Office Of Children's Health Protection.

Harris, J. 1985, "5. The value of life.," in *The Value of Life*, J. Harris, ed., Routledge & Kegan Paul plc, London, pp. 87-110.

Herzog, H. W. & Schlottmann, A. M. 1990, "Valuinng Risk in the Workplace: Market Price, Willingness to Pay, and the Optimal Provision of Safety", *The Review of Economics and Statistics*, vol. 72, no. 3, pp. 463-470.

Holland, M., Berry, J., & Forster, D. 1998, *ExternE Externalties of Energy. Volume 7: Methodology 1998 Update*, European Commission Directorate-General XII Science, Research and Development.

Horowitz, J. K. & Carson, R. T. 1993, "Baseline Risk and Preference for Reductions in Risk-to-Life", *Risk Analysis*, vol. **13**, no. 4, p. 457.

Horowitz, J. K. & McConnell, K. E. 2002, "A review of WTA/WTP Studies", *Journal of Environmental Economics and Management*, vol. 44, no. 3, pp. 246-447.

Johannesson, M. & Johansson, P. O. 1996, "To Be, or Not to Be, that is the Question: An Empirical Study of the WTP for an increased Life Expectancy at an advanced Age.", *Journal of Risk and Uncertainty*, vol. 13, pp. 163-174.

Johannesson, M. & Johansson, P. O. 1997, "Quality of life and the WTP for an increased life expectancy at an advanced age.", *Journal of Public Economics*, vol. 65, pp. 219-228.

Johannesson, M., Johansson, P. O., & Löfgren, K.-G. 1997, "On the Value of Changes in Life Expectancy: Blips Versus Parametric Changes", *Journal of Risk and Uncertainty*, vol. 15, pp. 221-239.

Johannesson, M., Johansson, P. O., & O'Conor, R. M. 1996, "The Value of Private Safety versus the Value of Public Safety", *Journal of Risk and Uncertainty*, vol. 13, no. 3, pp. 263-275.

Johansson, P. O. 2002, "On the definition and Age-Dependency of the Value of a Statistical Life", *Journal of Risk and Uncertainty.*, vol. 25, no. 3, pp. 251-263.

Johnson, F. R., Desvousges, W. H., Ruby, M. C., Stieb, D., DeCivita, P., & Binghm, M. F. 1998, "Eliciting stated health preferences: an application to willingness to pay for longevity", *Medical Decision Making*, vol. 18, no. 2 Suppl, pp. S57-67.

Johnson, F. R., Fries, E. E., & Banzhaf, H. S. 1997, "An integration of the willingness-to-pay and health-status litteratures.", *Journal of Health Economics*, vol. 16, pp. 641-665.

Jones-Lee, M. W. 1969, "Valuation of reduction in probability of death by road accident.", *Journal of Transport Economics and Policy*, vol. 3, pp. 37-47.

Jones-Lee, M. W. 1979, "Trying to value a life. Why Broome does not sweep clean.", *Journal of Public Economics*, vol. 12, pp. 249-256.

Jones-Lee, M. W. 1980, "The Value of Non-Marginal Changes in Physical Risk," in *Microeconomic Analysis*, D. Currie, D. Peel, & Peters W, eds., Croom Helm, London.

Jones-Lee, M. W. 1982, *The Value of Life and Safety. Proceedings of a Conference held by the 'Geneva Association'* North-Holland Publishing Company, Amsterdam.

Jones-Lee, M. W. & Loomes, G. 1995, "Scale and Context Effects in the Valuation of Transport Safety", *Journal of Risk and Uncertainty*, vol. 11, no. 3, pp. 183-203.

Jones-Lee, M. W. 1974, "The Value of Changes in the Pobability of Death or Injury", *The Journal of Political Economy*, vol. 82, no. 4, pp. 835-849.

Jones-Lee, M. W. 1976, *The Value of Life. An economic analysis.* Martin Robertson & Co. Ltd, London.

Jones-Lee, M. W. 1987, "Evaluating Safety Benefits", *Transport UK an economic, social and policy audit*.

Jones-Lee, M. W. 1991, "Altruism and the Value of Other People' s Safety", *Journal of Risk and Uncertainty*, vol. 4, pp. 213-219.

Jones-Lee, M. W. 1992, "Paternalsitic altruism and the value of statistical life", *Economic Journal*, vol. 102, pp. 80-90.

Jones-Lee, M. W., Hammerton, M., & Phillips, P. R. 1985, "The Value of Safety: Results of a NAtional Sample Survey", *The Economic Journal*, vol. 95, no. 377, pp. 49-72.

Kahneman D. "Maps of bounded rationality: a perspective on intuitive judgment and choice".

Kahneman D. 2003, "Maps of Bounded Rationality: Psychology for Behaviorak Economics", *The American Economic Review*, vol. 93, no. 5, pp. 1449-1475.

Kahneman D. & Tversky, A. 1979, "Prospect theory:An Analysis of Decision under Risk.", *Econometrica*, vol. 47, no. 2, pp. 263-292.

Kahneman, D., Ritov, I., & Schkade, D. 1999, "Economic preferences or attitude expressions? An analysis of dollar responses to public issues", *Journal of Risk and Uncertainty*, vol. 19, no. 1-3, pp. 203-235.

Keeney, R. L. 1980, "Equity and Public Risk", *Operations Research*, vol. 28, no. 3, pp. 527-534.

Kidholm, K. 1992, "Værdisætning af trafiksikkerhed.", *Nationaløkonomisk Tidsskrift*, vol. 130, pp. 630-641.

Kidholm, K. 1995a, "Assesing the value of traffic safety using the contingent valuation technique: the danish survey," in *Contingent Valuation, transport Safety and the Value of Life*, N. G. S. Christie & N. C. Soguel, eds., Kluwer Academic Publishers, Boston, pp. 45-61.

Kidholm, K. 1995b, *Estimation af betalingsvilje for forebyggelse af personskader ved trafikulykker* Center for Helsetjenesteforskning og socialpolitik., Odense.

Kriström, B. 1990, *Valuing environmental benefits using the contingent valuation method.* Solfjädern Offset AB, Umeå.

Krupnick, A., Alberini, A., Cropper, M., Simon, N., Itaoka, K., & Akai, M. Mortality Risk Valuation for Environmental policy. Discussion Paper 99-47 . 1999. Resources for the Future.
Ref Type: Generic

Krupnick, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Goeree, R., & Heintzelman, M. 2002, "Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents.", *Journal of Risk and Uncertainty*, vol. 24, no. 2, pp. 161-186.

Lancaster, K. J. 1966, "New Approach to Consumer Theory", *Journal of Political Economy*, vol. 74, no. 2, pp. 132-157.

Lanoie, P., Pedro, P., & Latour, R. 1995, "The Value of a Statistical Life: A Comparison of Two Approaches", *Journal of Risk and Uncertainty*, vol. 10, pp. 235-257.

Linneroth & , J. 1982, " Murdering Statistical lives ..?," in *The Value of Life and Safety. Proceedings of a Conference held by the 'Geneva Association'. Collection of Papers presented at the Geneva conference on The Value of Life and Safety held at the University of Geneva 30th, 31st March and 1st April, 1981*, M.W.Jones-Lee, ed., NORTH-HOLLAND PUBLISHING COMPANY, pp. 229-265.

Litwin M.S 1995, *How to Measure Survey Reliability and Validity* Thousand Oaks, London.

Louviere, J. & Woodworth, G. 1983, "Design and analysis of simulated consumer choice or allocation experiments: an approach based on aggeagte data", *Jounal of Marketing Research*, vol. 20, pp. 350-67.

McNeil, B. J., Pauker, S. G., Sox, H. C., & Tversky, A. 1982, "On the elicitation of preferences for alternative therapies", *New England Journal of Medicine*, vol. 306, pp. 1259-1262.

Mishan E.J 1971, "Evaluation of Life and Limb: A Theoretical Approach", *The Journal of Political Economy*, vol. 79, no. 4, pp. 687-705.

Mitchell, R. C. & CArson, R. T. 1989, *Using Surveys to Value Public Goods: The Contingent Valuation Method* Resources for the Future, Washington.

Møller, F. 1996, *Værdisætning af miljøgoder* Økonomiforbundets Forlag.

Mooney, G. H. 1977, *The Valuation of Human Life.* The Macmillan Press LTD, London.

Moore, M. J. & Viscusi, W. K. 1988, "The Quantity-Adjusted Value of Life", *Economic Inquiry*, vol. 26, pp. 369-388.

Morris, J. & Hammit, J. K. 2001, "Using Life Expectancy to Communicate Benefits of Health Care Programs in Contingent Valuation Studies", *Medical Decision Making*, vol. 21, no. 6, pp. 468-478.

Ng, Y.-K. 1992, "The Older the More Valuable. Divergence Between Utilty and Dollar Values of LIfe as One Ages.", *Journal of Economics*, vol. 55, pp. 1-16.

Payne, J. W., Bettman, J. R., & Schkade, D. A. 1999, "Measuring constructed preferences: Towards a building code", *Journal of Risk and Uncertainty*, vol. 19, no. 1-3, pp. 243-270.

Pearce, D. 1998, "Cost- benefit analysis and environmental policy", *Oxford Review of Economic Policy*, vol. 14, no. 4, pp. 84-100.

Pearce, D. 2000, *VALUING RISKS TO LIFE AND HEALTH Towards Consistent Transfer Estimates in the European Union and Accession State* University College London.

Pedersen, K. M. Compensating Wage Differentials: A Measure of Willingness to Pay? An Empirical Investigation of Labor Market Valuation of Life and Limb. 1983. Department of Public Finance and Policy, Odense university. Occasional Papers No 8.
Ref Type: Generic

Pedersen, K. M., Wittrup-Jensen, K., Brooks, R., & Gudex, C. 2003, *Værdisætning af sundhed. Teorien om kvalitetsjusterede leveår og en dansk anvendelse* Syddansk Universitetsforlag, Odense.

Pigou, A. C. 1932, *The Economics of Welfare*, Fourth edn, Macmmillian and Co, London.

Pliskin, J. S., Shepard, & Weinstein, M. C. 1980, "Utility Functions for Life Years and Health Status", *Operations Research*, vol. 28, no. 1, pp. 206-224.

Pope, C. A., Burnett, R. T., Thun, M. J., Calle, E. F., Krewski, D., Ito, K., & Thurston, G. D. 2002, "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution", *JAMA*, vol. 2002, no. 287, pp. 1132-1141.

Pope, C. A., Thun, M. J., Namboodiri, M. M., Dockery, D. W., Evans, J. S., Speizer, F. E., & Health, C. W. 1995, "Particulate air Pollution as a Predictor of mortality in a Prospective Studyof U.S. Adults", *Am J Respir Crit Care Med*, vol. 151, pp. 669-674.

Portney, P. R. 1981, "Housing Prices, Health Effects, and Valuing Reductions in Risk of Death", *Journal of Environmental Economics and Management*, vol. 8, pp. 72-78.

Reynolds, D. J. 1956, "The Cost of Road Accidents", *Journal of the Royal Statistical Society.Series A (General)*, vol. 119, no. 4, pp. 393-408.

Rosen, S. 1988, "The Value of Changes in Life Expectancy", *Journal of Risk and Uncertainty*, vol. 1, pp. 285-304.

Rottenstreich, Y. & Hsee, C. K. 2001, "Money, kisses, and electric shocks:On the affective Psychology of Risk.", *Psychological Science*, vol. 12, no. 3, pp. 185-190.

Schelling, T. C. 1968, "The Life You Save May Be Your Own," in *Problems in Public expenditure Analysis,* S. B. Chase, ed., The Brookings Institution, Washington D.C, pp. 127-166.

Schmalensee, R. 1972, "option Demand and Consumer's Surplus. Valuing Price Changes Under Uncertainty", *The American Economic Review*, vol. 62, no. 5, pp. 813-824.

Schoemaker, P. J. H. 1982, "The Expected Utility Model: Its Variants, Purposes, Evidence and Limitations.", *Journal of Economic Literature*, vol. 20, no. 2, pp. 529-563.

Sen, A. 1979, "Personal utilities and Public Judgements: or What's wrong With Welfare Economics", *The Economic Journal*, vol. 355, pp. 537-558.

Sen, S. K. 1977, "Rational Fools: A Critique of the Behavioral Foundations of Economic Theory", *Journal of Public Affairs*, vol. 6, no. 4, pp. 317-344.

Shepard & Zeckhauser 1982, "Life-cycle consumption and willingness to pay for increased survival," in ***The Value of Life and Safety. Proceedings of a Conference held by the 'Geneva Association'. Collection of Papers presented at the Geneva conference on The Value of Life and Safety held at the University of Geneva 30th, 31st March and 1st April, 1981***, M.W.Jones-Lee, ed., NORTH-HOLLAND PUBLISHING COMPANY, pp. 95-145.

Shepard, D. S. & Zeckhauser, R. 1984, "Survival versus consumption", *Management Science*, vol. 30, no. 4, pp. 423-439.

Shogren, J. F. & Stamland, T. 2005, "Self-Protection and Value of Statistical Life Estimation.", *Land Economics*, vol. 81, no. 1, pp. 100-113.

Smith, V. K. & Descouges, W. H. 1986, *Measuring Water Quality Benefits* Kluwer & Nijhoff, Boston.

Smith, V. K. & Desvouges, W. H. 1987, "An Empirical Analysis of the Economic Value of Risk Changes.", *The Journal of Political Economy*, vol. 95, no. 1, pp. 89-114.

Smith, V. K. & Huang, J. C. 1995, "Can Markets Value Air-Quality - A Metaanalysis of Hedonic Property Value Models", *Journal of Political Economy*, vol. 103, no. 1, pp. 209-227.

Sommer, H., Seethaler, R., Chanel, O., Herry, M., Masson, S., & Vergnaud, J.-C. 1999, *Health Costs due to Road Traffic-related Air Pollution. An impact assessment project of Austria, France and Switzerland* WHO report.

Strand, J. Public- and private-good values of statistical lives: Results from a combined choice-experiment and contingent-valuation surrvey. 2004. Department of Economics, University of Oslo.
Ref Type: Generic

Strand, J. 2005, "Individual and household values of mortality reductions with intrahousehold bargaining", *Journal of Risk and Uncertainty*, vol. 31, no. 2, pp. 217-236.

Sugden, R. 2003, *Coping with preference anomalies in cost-benefit analysis* CSERGE Working Paper EDM 03-03.

Sydsæter, K. & Hammond, P. J. 1995, *Mathematics for Economic Analysis* Prentice-Hall Intrnational, Inc., New Jersey.

Telser, H. & Zweifel, P. 2005, *Validity of Discrete-Choice Experiments Evidence for Health Risk Reduction*, University of Zurich, Socioeconomic Institue., Working Paper No. 0313.

Thaler.R. & Rosen, S. 1975, "The Value of Saving a Life: Evidence from the Labor Market," in *Household Production and Consumption*, N. E. Terleckyj, ed., National Bureau of Economic Research, New York, pp. 266-302.

Trafikministeriet 2004, *Nøgletalskatalog - til brug for samfundsøkonomiske analyser på transportområdet.*

Tsuge, T., Kishimoto, A., & Takeuchi, K. 2005, "A choice experiment approach to the valuation of mortality", *Journal of Risk and Uncertainty*, vol. 31, no. 1, pp. 73-95.

Tversky, A. & Kahneman D. 1981, "The framing of Decisions and the Psychology of Choice", *Science*, vol. 211, no. 4481, pp. 453-458.

Usher, D. 1973, "An Imputation to the Measure of Economic Growth for Changes in Life Expectancy," in *The Measurement of Economic and Social Performance*, M. Moss, ed., National Bureau of Economic Research, New York, pp. 193-232.

Varian, H. 1999, *Intermediate Microeconomics*, 5 edn, W.W. Norton & Company, Inc, New York.

Vassanadumrongdee, S. & Matsuoka, S. 2005, "Risk Perceptions and Value of a Statistical Life for Air Pollution and traffic Accidents: Evidence from Bangkok, Thailand.", *Journal of Risk and Uncertainty*, vol. 30, no. 3, pp. 261-287.

Vassanadumrongdee, S., Matsuoka, S., & Shirakawa, S. 2004, "Meta-analysis of contingent valuation studies on air pollution-related morbidity risks", *Environmental Economics and Policy Studies*, vol. 6, no. 1, pp. 11-47.

Venkatachalam, L. 2004, "The Contingent valuation method: a review.", *Environmental Impact Assessment Review*, vol. 24, pp. 89-124.

Viscusi, W. K. 1992, *FATAL TRADEOFFS* Oxford University Press, New York.

Viscusi, W. K. 1998, *Rational risk policy : the 1996 Arne Ryde memorial lectures* Clarendon Press.

Viscusi, W. K. & Aldy, J. E. 2003, "The value of a statistical life: A critical review of market estimates throughout the world", *Journal of Risk and Uncertainty*, vol. 27, no. 1, pp. 5-76.

Viscusi, W. K. & Evans, W. N. 1990, "Utility Functions That depend on Health Status: Estimates and Economic Implications", *The American Economic Review*, vol. 80, no. 3, pp. 353-374.

Viscusi, W. K., Magat, W. A., & Huber, J. 1987, "An investigation of the rationality of consumer valuations of multiple health risks", *RAND Journal of Economics*, vol. 18, no. 4, pp. 465-479.

von Neumann, J. & Morgenstern, O. 1944, *Theory of games and economic behavior.* John Wiley & Sons, Inc., New York.

Weinstein, M. C. & Quinn, R. J. 1983, "Psychological Considerations in Valuing Health Risk Reductions", *Natural Resources Journal*, vol. 23, pp. 659-674.

Weinstein, M., Shepard, D. S., & Pliskin, J. S. 1980, "The Economic Value of Changing Mortality Probabilities: A decision- Theoretic Approach", *The Quarterly Journal of Economics*, vol. 94, no. 2, pp. 373-396.

Weisbrod, B. A. 1964, "Collective-consumption sevices of individual-consumption goods", *Quaterly Journal of economics*, vol. 78, pp. 471-477.

Whitehead, J. W. 1991, "The Forfotten Limits: Reason and Regulation in Economic Theory," in *The economic approach to politics. A critical reassessment of the theory of rational action.*, K. R. Monroe, ed., HarperCollinsPublishers, New York, pp. 53-74.

Winch, D. M. 1971, *Analytical welfare economics* Penguin Books, Middlesex, England.

Wright, B. D. & Williams, J. C. 1988, "Measurement of Consumer Gains from Market Stabilization", *American Journal of Agricultural Economics*, vol. 70, pp. 616-627.

Yaari, M. E. 1965, "Uncertain Lifetime, Life Insurance, and the Theory of the Consumer,", *The Review of Economic Studies.*, vol. 32, no. 2, pp. 137-150.

APPENDIX A
BIASES IN A CONTINGENT VALUATION SURVEY

Type of bias	Description
General bias	
- strategic bias	
free-rider	- If a respondent underplays the value the assign to a public good due to the expectation that others will pay.
over-pledging	- When a respondent gives an inflated value in the belief that their WTP will have a positive influence in relation to protecting delivery of the good.
- information bias	- If the amount of information delivered disturbs the respondent. However, the question is the amount of information which is optimal.
- hypothetical bias	- The respondent is presented with a hypothetical situation.
Procedural bias	
- sampling and interviewer bias	- How representative is the random sample and to what degree does the interview affect the respondent?
Instrument-related bias	
- presentation of the payment	- If bias can arise from the method whereby the respondent is asked to give the sum they consider to be their WTP.

(Kriström 1990) and (Venkatachalam 2004)

Appendix B Summary of Contingent Valuation Estimates of the Value of Statistical Life (from 1985) n>100

Table 1 Characteristic of the good

Author	Context	Private/public	Risk Reduction	VSL (in 1000) Euro2000 PPs adjusted Mean	Median
Jones-Lee(1985)	"Safety feature"	private	X in 100.000	4093	2384
Viscusi(1991)	Automobile death	private	X/100.000	6645	1856
Kidholm(1995)	Airbag	private	20 % of initial	3830	1603
			30% of initial	6077	1841
Lanoie1995	Air bag		from 4 to 2 in 10.000	807	
Desaigues1995	Road safety	public	50 deaths p.a	21068	6958
	Road safety	public	500 deaths p.a	4935	1392
	Road safety	public	5000 deaths p.a	906	275
Jones-Lee(1995)	safety device	private	4 in 100,000	4947	2910
Johannesson(1996)	safety device	private	halves your risk	2819	
Johannesson(1996)	road	public	halves your risk	5349	
Johansseon, Johansson og Lofgren(1997)	medicine	private	X/10.000 in 1 year	2085	
Carthy(1999)	Road safety	private	X out of 10	2816	157
Persson(2001)	safety device	private	2,4/100000	2175	
Krupnick(1999)	Medicin	Private	5 in1000 in 10 years	865	469
			1 in 1000 in 10 years	3433	1216
Corso2001	Airbag	private	1,5/10.000	3058	
			1/10.000	4078	
Alberini(2002)	Medicin	Private	5 in1000 in 10 years	1328	604
			1 in 1000 in 10 years	4167	949
Strand(2004)	Heart disease	private	1% of extending ones life with one year	920	
Chanel(2003)	air pollution exposure	public	red of 25%/50%/100% of 2/100 deaths	782	596
Vassanadumrongdee(2005)	Road safety	Airbag	30 in 1.000.000	1232	637
			60 in 1.000.000	863	602
	Air Pollution	Medical check-up (private)	30 in 1.000.000	1132	616
			60 in 1.000.000	920	446
Newext(2005)	Medicin	Private (as Krupnick)	5 in 1000 in 10 years	1906	934
Alberini2005			X (1-12 depending on age) in 1000 in 10 years	1317	2857
Itaoka(2005)	Medicin	private	5 in1000 in 10 years	531	128
			1 in 1000 in 10 years	1516	329
Tsuge(2005)		private	1/1000 in 10 years	1400	

Table 2. The population

Author	VSL (in 1000) Euro2000 PPs adjusted		Characteristics of respondents	
	Mean	Median	Age	Health
Jones-Lee(1985)	4093	2384	Inv. U	Prefer to reduce cancer, to heart disease to motor accidents
Viscusi(1991)	6645	1856		
Kidholm(1995)	3830	1603	Declining	
	6077	1841		
Lanoie1995	807			
Desaigues1995	21068	6958	Declining	
	4935	1392	Declining	
	906	275	Declining	
Jones-Lee(1995)	4947	2910		
Johannesson(1996)	2819			
	5349			
Johansseon, Johansson og Lofgren(1997)	2085		Inverted U	
Carthy(1999)	2816	157		
Persson(2001)	2175		Inv u	
Krupnick(1999)	865	469	No up to 65 the declining	no except people with cancer - higher value (and family history except cancer)) and poor mental health lower
	3433	1216		
Corso2001	3058		Neg	
	4078			
Alberini(2002)	1328	604		chronic lung disease, high blood preasure and famly history (except cancer)
	4167	949		
Strand(2004)	920			
Chanel(2003)	782	596	Inv U-form	
Vassanadumrongdee(2005)	1232	637	Inverted U	
	863	602	Inverted U	
	1132	616	Inverted U	
	920	446	Inverted U	
Newext(2005)	1906	934	no sign relation	no sign relation
Alberini2005	1317	2857	Declining	no sign relation
Itaoka(2005)	531	128	Increases in age (40-69)	Cancer; lower heart diseases; higher, poor mental health; lower
	1516	329		
Tsuge(2005)	1400		Lower for persons >70	

Table 3. The survey

Author	Data-collecting	n	Country	Age group
Jones-Lee(1985)	Personal interviews	1103	England, Scotland and Wales	?
Viscusi(1991)	Interactive computer program	389	U.S North Carolina	33 mean
Kidholm(1995)	Personal interviews	945	Denmark	
				>18
Lanoie1995	Personal interviews	191	Montreal, Canada	?
Desaigues1995	Personal interviews	1000	France	
	Personal interviews			
	Personal interviews			?
Jones-Lee(1995)	Personal interviews	414	England, Scotland and Wales	
Johannesson(1996)	Telephone interviews		Sweden	>16
	Telephone interviews	1067		
Johansseon, Johansson og Lofgren(1997)	Telephone interviews	2029		18-74
Carthy(1999)	Personal interviews	167	England	
Persson(2001)	Postal	2884	Sweden	18-74
Krupnick(1999)	Self-adm. computer	930	Hamilton, Ontario Canada	
Corso2001	Telephone	1104	?	>18
Alberini(2002)	self adm computer	1200	U.S	
	self adm computer			
Strand(2004)	Personal interviews	1000	Norway	
Chanel(2003)	Telephone, self adm computer	923	Bouches-de-Rhône	>18
Vassanadumrongdee(2005)	Personal interviews	301	Bangkok, Thailand	43 average
	Personal interviews	301	Bangkok, Thailand	43
	Personal interviews	524	Bangkok, Thailand	37
	Personal interviews	524	Bangkok, Thailand	37
Newext(2005)	Self adm. computer	921	France, UK and Italy	
Alberini2005	Self adm computer	954	Czech republic	
Itaoka(2005)	self adm computer	677	Shizuoka, Japan	>40
	self adm computer			
Tsuge(2005)	Personal interviews	400	Tokyo, Japan	>30

References

Alberini, A., Krupnick, A., Cropper, M. L., Simon, N., & Cook, J. The Willingness to pay for mortality risk reductions: A comparison of the United States and Cananda. 2002. CESifo Working Paper No. 668 (8).
Ref Type: Generic

Alberini, A., Scasny, M., & Koholova, M. K. "THE VALUE OF A STATISTICAL LIFE IN THE CZECH REPUBLIC: EVIDENCE FROM A CONTINGENT VALUATION STUDY", Paper submitted for presentation at the EAERE annual meeting, Bremen 23-26 June.

Carthy, T., Chilton, S., Covey, J., Hopkins, L., Jones-Lee, M. W., Loomes, G., Pidgeon, N., & Spencer, A. 1999, "On the Contingent Valuation of Safety and the Safety of Contingent VAluation: Part 2 - The CV/SG "Charined" Approach", *Journal of Risk and Uncertainty*, vol. 17, no. 3, pp. 187-213.

Corso, P. S., Hammit, J. K., & Graham, J. D. 2001, "Valuing Mortality-Risk reduction: Using Visual Aids to Improve the Validity of Contingent Valuation.", *Journal of Risk and Uncertainty*, vol. 23, no. 2, pp. 165-184.

Desaigues, B. & Rabl, A. 1995, "Reference values for human life: an econometric analysis of a contingent valuation in France," in *Contingent Valuation, Transport Safety and the Value of Life*, N. G. S. Christie & N. C. Soguel, eds., Kluwer Academic Publishers, Boston, pp. 85-111.

Itaoka, K., Krupnick, A., Akai, M., Alberini, A., Cropper, M. L., & Simon, N. 2005, *Age, Health, and the Willingness to Pay for a Mortality risk Reduction. A Contingent Valuation Survey in Japan* Resources For the Future, RFF DP 05-34.

Johannesson, M., Johansson, P. O., & O'Conor, R. M. 1996, "The Value of Private Safety versus the Value of Public Safety", *Journal of Risk and Uncertainty*, vol. 13, no. 3, pp. 263-275.

Johannesson, M., Johansson, P. O., & Löfgren, K.-G. 1997, "On the Value of Changes in Life Expectancy: Blips Versus Parametric Changes", *Journal of Risk and Uncertainty*, vol. 15, pp. 221-239.

Jones-Lee, M. W. & Loomes, G. 1995, "Scale and Context Effects in the Valuation of Transport Safety", *Journal of Risk and Uncertainty*, vol. 11, no. 3, pp. 183-203.

Jones-Lee, M. W., Loomes, G., & Phillips, P. R. 1995, "Valuing the Prevention of Non-Fatal Road Injuries: Contingent Valuation vs. Standard Gambles", *Oxford Economic Papers*, vol. 47, no. 4, pp. 676-695.

Jones-Lee, M. W., Hammerton, M., & Phillips, P. R. 1985, "The Value of Safety: Results of a NAtional Sample Survey", *The Economic Journal*, vol. 95, no. 377, pp. 49-72.

Kidholm, K. 1995, "Assesing the value of traffic safety using the contingent valuation technique: the danish survey," in *Contingent Valuation, transport Safety and the Value of Life*, N. G. S. Christie & N. C. Soguel, eds., Kluwer Academic Publishers, Boston, pp. 45-61.

Krupnick, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Goeree, R., & Heintzelman, M. 2002, "Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents.", *Journal of Risk and Uncertainty*, vol. 24, no. 2, pp. 161-186.

Lanoie, P., Pedro, P., & Latour, R. 1995, "The Value of a Statistical Life: A Comparison of Two Approaches", *Journal of Risk and Uncertainty*, vol. 10, pp. 235-257.

NewExt 2004, *New Elements for the Assessment of External Costs from Energy Technologies: Final Report to the European Commission, DG Research, Technological Development and Demonstration (RTD).*

Persson, U., Norinder, A., Hjalte, K., & Gralen, K. 2001, "The Value of a Statistical Life in Transport: Findings from a New Contingent Valuation Study in Sweden", *Journal of Risk and Uncertainty*, vol. 23, no. 2, pp. 121-134.

Strand, J. Public- and private-good values of statistical lives: Results from a combined choice-experiment and contingent-valuation surrvey. 2004. Department of Economics, University of Oslo.
Ref Type: Generic

Tsuge, T., Kishimoto, A., & Takeuchi, K. 2005, "A choice experiment approach to the valuation of mortality", *Journal of Risk and Uncertainty*, vol. 31, no. 1, pp. 73-95.

Vassanadumrongdee, S. & Matsuoka, S. 2005, "Risk Perceptions and Value of a Statistical Life for Air Pollution and traffic Accidents: Evidence from Bangkok, Thailand.", *Journal of Risk and Uncertainty*, vol. 30, no. 3, pp. 261-287.

Viscusi, W. K., Magat, W. A., & Huber, J. 1991, "Pricing environmental health risk: survey assessments of risk-risk and risk-dollar trade-offs for chronic bronchitis.", *Journal of Environmental Economics and Management*, vol. 21, pp. 35-51.

Appendix C

A derivation of EQ 5.8

max $V(c_k, D_k) = \sum_{t=k}^{T} (1+\rho)^{j-t} q_{j,t} U(c_t)$

s.t $g(c_k, D_k) = \sum_{t=k}^{T} q_{j,t} (1+r)^{j-t} (c_t - y_t) - W$

F.O.C.

$$V'_{c_k}(c_k, D_k) = \lambda g'_{c_k}(c_k, D_k) \quad \Leftrightarrow \quad \sum_{t=k+1}^{T} q_{j,t} (1+\rho)^{j-t} U'(c_t) = \lambda \sum_{t=k+1}^{T} q_{j,t} (1+r)^{j-t}$$

$$V'_{D_k}(c_k, D_k) = \lambda g'_{D_k}(c_k, D_k) \quad \Leftrightarrow \quad \sum_{t=k+1}^{T} q_{j,t} (1+\rho)^{j-t} U(c_t) = \lambda \sum_{t=k+1}^{T} q_{j,t} (1+r)^{j-t} (y_t - c_t)$$

$$W = \sum_{t=k}^{T} q_{j,t} (1+r)^{j-t} (c_t - y_t)$$

From equation XX follows:

$$\lambda_j = \frac{\sum_{t=k+1}^{T} (1+\rho)^{j-t} q_{j,t} U'(c_t)}{\sum_{t=k+1}^{T} q_{j,t} (1+r)^{j-t}}$$

and by substituting λ_j euqation XX appears.

Appendix D. Variables and abbreviations.

Chapter 2.

W : wealth

CV : Hicks' Compensating Variation

EV : Hicks' Equivalent Variation

CS : Consumer Surplus

CVM : Contingent Valuation Method

L : lottery

OP : Option Price

Y : income

A* : adverse advent

D : the maximum sum of money the individual would give up to experience A* = 0 instead of A*

Chapter 3

L(W) : utility of wealth conditional on surviving

D(W) : utility of wealth conditional on dying.

$\overline{w}$: initial wealth

$\overline{p}$: initial probability of dying

V : the maximum sum that the individual is willing to give up to leave him with the same level of *expected* utility as in the initial situation.

QALY : Quality Adjusted Life Year

VSL : Value of a Statistical Life

WTP : Willingness-to-pay

Chapter 5

l(t) : initial survival function (continuous time)

Z_j : individual's utility at time t of hid remaining life after t

$p_{j,t}$: the probability that the individual dies at age t, just before t+1

ρ : rate if individual time preference

$q_{j,t} = \sum_{s=t}^{T} p_{j,s}$: the probability that the individual survives to his t^{th} birthday given he is alive at age j.

D_j : conditional probability of dying at age j $(1-D_k)=\frac{q_{j,k+1}}{q_{j,k}}$

R : risk-less rate of interest

$$\Gamma_{j,k}=\prod_{t=j}^{k-1}(1+R_t)^{-1}$$

Chapter 6

VOLY : Value of a Life Year

LE : Life expectancy

dD_k : change in the probability of dying at time k

Studies in Health Economics present the results of health economics research at Institute for Public Health, Health Economics, University of Southern Denmark.

Professor Terkel Christiansen is editor of the series. He is professor of health economics and head of the department of Health Economics (University of Southern Denmark.

Further information

Institute of Public Health
Department of Health Economics
University of Southern Denmark
J.B. Winsløwsvej 9, 1
DK-5000 Odense C
Denmark
Phone:+45 6550 3081
Fax: +45 6550 3880
email: hmj@sam.sdu.dk