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The Value of a Statistical Life

HENRIK ANDERSSON AND NICOLAS TREICH

Ecole d'économie de Toulouse (TSE) - Manufacture des Tabacs
Aile Jean-Jacques Laffont - 21, allée de Brienne - 31000 TOULOUSE
Tél : +33 (0) 5 61 12 85 89 - Fax : +33 (0) 5 61 12 86 37 - **www.TSE-fr.eu** - contact@TSE-fr.eu

Toulouse School of Economics

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Henrik Andersson
Department of Transport Economics,
Swedish National Road & Transport Research Institute (VTI), Sweden

Nicolas Treich
Toulouse School of Economics (INRA, LERNA), France

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1 Introduction

Modern societies rely on a well functioning transportation infrastructure. Policies taken to maintain and/or improve an infrastructure come at a cost; and the scarcity of resources forces policy makers to prioritize between policies. The use of a common metric for benefits and costs may facilitate the evaluation of different policies, which in turn, enables policy makers to allocate resources more efficiently. Monetary values often act as this common metric. Another good reason for monetizing non-marketed goods is that this common ground for comparisons makes the prioritization process more transparent to those not directly involved in the process (e.g. the public).

Many of the benefits and costs induced by policies within the transport sector have monetary values. Material expenditures, e.g., for road improvements in order to increase safety and reduce travel time, are easily obtainable since the materials are traded on markets and have market prices. However, many of the costs are not "construction costs" and do not have monetary market prices. For instance, road improvements might increase road traffic, resulting in increased noise and emission levels; in addition, when a new road is constructed recreation areas may be lost, wild life may be adversely affected, etc. Similarly, whereas expected benefits from avoided material damage caused by crashes can be calculated using available market prices, the benefits from a reduced risk exposure and/or a reduced travel time have no market prices.

In this paper we are interested in the monetary value of increased safety, and more specifically, in the value of reducing the risk of mortality. Economists often refer to the monetary value of reducing mortality risks as the "value of life". For those initiated in the vocabulary, this expression has a clear and precise meaning and is quite uncontroversial. For others it may be controversial since it seems to imply that human life can be valued while it should be "priceless".[1] The expression "value of life" is an unfortunate reduced form of the *the value of a statistical life* (VSL),[2] which defines the monetary value of a (small and similar among the population) mortality risk reduction that would prevent one *statistical* death and, therefore, should not be interpreted as how much individuals are willing to pay to save an *identified* life.[3]

A procedure often used to estimate benefits from reduced mortality is the human capital approach, in

[1]For a critical discussion, see e.g. Ackerman and Heinzerling (2004).

[2]Alternative terms for VSL used in the literature include micromorts (Howard, 1984), value per statistical life (Hammitt, 2000b), value per life saved (Jones-Lee, 1976), and value of prevented fatality (Jones-Lee, 2004).

[3]This difference between identified and statistical lives has been illustrated by how easy it is to collect money for the treatment of a young girl, who needs expensive care to prolong her life by a short time period, once the public is aware of her condition, compared with how hard it can be to get acceptance for, e.g., a tax-rise to finance health-care expenditures that would reduce the mortality risk for many, but unidentified, individuals (Schelling, 1968; Josefsson et al., 1994; Pratt and Zeckhauser, 1996). Whereas the girl constitutes an identified life, the small risk reductions enjoyed by unidentified individuals can be converted into statistical lives.

which the value of a person's life is determined by this person's market productivity. For several reasons, this approach is no longer popular. The dominant approach nowadays is based on individuals' willingness to pay (WTP). This approach assumes that individuals' preferences are the basis for economic welfare. The WTP-approach to value mortality risk reductions was introduced by Drèze (1962). Drèze's paper was written in French and the concept became widely known only after Schelling (1968)'s seminal paper. The theoretical foundation of the concept was further developed within the expected utility framework by Mishan (1971) and Jones-Lee (1974). A key contributor to the empirical literature on VSL is Viscusi, in particular for his analysis of compensating wage differentials (Viscusi, 1993; Viscusi and Aldy, 2003).[4]

To understand the VSL concept, it may be useful to take an example. Suppose that in a city composed of 100,000 identical individuals, there is an investment project that will make the city's roads safer. It is known that on average 5 individuals die every year on these roads, and the project is expected to reduce from 5 to 2 the number of expected fatalities per year. Suppose now that each member of the city is willing to pay \$150 annually to benefit from this reduction in mortality risk induced by the project. Then the corresponding VSL would be $\$150 \times 100,000/3 = \$5$ million. Indeed \$15 million could be collected in this city to save 3 statistical lives, and so the value of a statistical life could be established at \$5 million. This example also illustrates why estimates about individuals' VSL can be useful. Suppose indeed that one ignores the WTP of city members from this specific project; but one has some information about money/risk tradeoffs observed from the city members' choices (or from survey studies) concerning other mortality risks. Then it can be useful to compute an average implicit VSL in this city based on these choice data, and use this VSL to estimate the benefits of this specific risk-reduction road safety project that one wants to evaluate.

If individuals treat longevity, or small changes in mortality risk, like any other consumption good, there should be no or little controversy to use the concept of WTP to value a reduction in the probability of death (Freeman, 2003).[5] A source of controversy may arise, however, as there is evidence that individuals misperceive mortality risks and thus may give inconsistent WTP (Hammitt and Graham, 1999). Also, while standard preferences assume self-interested behavior, individuals may care about the risks to life of others (e.g., relatives or identified victims). Thus, altruistic concerns may matter in the WTP for reduction in mortality risks. Another and more classical issue is linked to the distributional effects of the WTP approach, that may for instance give disproportionate weight to wealthier individuals

[4]In compensating wage differential studies, researchers estimate additional wages paid to worker in riskier jobs, using econometric methods to control for other factors (such as education or the activity sector). The idea of compensating wage differentials dates back to Adam Smith, who noted in *The Wealth of Nations*, "The wages of labour vary with the ease or hardship, the cleanliness or dirtiness, the honourableness or dishonourableness of the employment." (Smith, 1776, p. 112).

[5]In Ezra Mishan's words, "...there is no call for evaluating loss of life on a criterion different from that which is basic to the economist's calculation of all the other effects comprehended in cost-benefit analysis." (Mishan, 1982, p. 324).

in the society. The heterogeneity of population risk-exposure is a sensitive topic. A challenge faced by policy-makers consists in determining whether and how the VSL should be adjusted to account for the differences in the types of risks and in individuals' characteristics.

The paper's first objective is to survey some classical theoretical and empirical findings on the VSL literature; but it also attempts to clarify some of these issues often raised by the application of the WTP approach to study of mortality risks. The paper is divided into two main sections, one theoretical and one empirical. In the following section, we outline the standard VSL model, describe how VSL is influenced by different factors and discuss some welfare implications. In the empirical part, we briefly discuss estimation approaches, as well as empirical findings and the use of the VSL in transport. The paper ends with some conclusions.

2 Theoretical Insights

In this section, we first introduce the VSL concept using a standard economic model and present some common extensions of the basic framework initially introduced. We then justify the policy use of the average VSL across individuals using a public goods model, and discuss some distributional implications of the economic approach. We finally present some comparative statics results.

2.1 The VSL model

2.1.1 The standard model

We consider a standard single-period VSL model. The individual maximizes his (state-dependent) expected indirect utility which is given by

$$V \equiv pu(w) + (1-p)v(w) \tag{1}$$

where p is the probability of surviving the period, $u(w)$ is the utility of wealth w if he survives the period, and $v(w)$ is the utility of wealth w if he dies (typically, the utility of a bequest). This model was introduced by Drèze (1962) and Jones-Lee (1974) and has been commonly used in the VSL literature.[6]

We adopt the standard assumptions that u and v are twice differentiable with

$$u > v, \ u' > v' \geq 0, \ u'' \leq 0 \text{ and } v'' \leq 0. \tag{2}$$

That is, state-dependent utilities are increasing and weakly concave. At any wealth level, both utility and marginal utility are larger if alive than dead. Under these standard assumptions, indifference curves over (w, p) are decreasing and strictly convex, as illustrated in Figure 1 .

[6]See for example the following significant contributions: Weinstein et al. (1980), Bergstrom (1982), Viscusi (1993) and Viscusi and Aldy (2003).

[Figure 1 about here.]

The willingness to pay (WTP) for a mortality risk reduction $\Delta p \equiv \varepsilon$ is denoted $C(\varepsilon)$ and is given by the following equation

$$(p+\varepsilon)u(w-C(\varepsilon))+(1-p-\varepsilon)v(w-C(\varepsilon))=V \tag{3}$$

where V is defined in (1). Similarly, the willingness to accept (WTA) for a mortality risk increase $\Delta p \equiv \varepsilon$ is denoted $P(\varepsilon)$ and is given by the following equation

$$(p-\varepsilon)u(w+P(\varepsilon))+(1-p+\varepsilon)v(w+P(\varepsilon))=V. \tag{4}$$

The WTP and WTA are represented in Figure 1. From Eqs. (3) and (4) it is obvious that WTP and WTA should be sensitive to the size of ε. For small ε it is important to stress, however, that we also expect that WTP and WTA should be nearly equal in magnitude and near-proportional to ε (Hammitt, 2000a).[7]

The VSL does not measure what an individual is willing to pay to avoid death with certainty, nor what he is willing to accept to face death with certainty. It measures the WTP or the WTA for an *infinitesimal* change in risk. It can be obtained by taking the limit of the WTP or the WTA when the change in risk is infinitely small, that is when $\varepsilon \simeq 0$.[8] In other words, the VSL is the marginal rate of substitution (MRS) between wealth and survival probability, that is, (the negative of) the slope of the indifference curve at (w, p). It is defined as follows

$$\text{VSL} \equiv \frac{-dw}{dp} = \frac{u(w)-v(w)}{pu'(w)+(1-p)v'(w)}. \tag{5}$$

The VSL thus depends separately on the characteristics of the baseline risk through p and on those of the individual through u, v and w. Notice that the properties exhibited in (2) imply that the VSL is always strictly positive.

2.1.2 The dead-anyway effect and the wealth effect

The expression obtained for the VSL in (5) is useful for identifying two standard effects. First, the dead-anyway effect (Pratt and Zeckhauser, 1996) describes how VSL increases with baseline risk $(1-p)$, i.e., how VSL decreases with survival probability p. Intuitively, an individual facing a large probability of death has little incentive to limit his spending on risk reduction since he is unlikely to survive. In (5)

[7] For large changes in risk or when the risk change has no close substitutes (Hanemann, 1991) differences between WTP and WTA can arise.

[8] The VSL can be obtained using first-order approximations of the WTP and WTA, that is by computing $C'(0)$ and $P'(0)$. We notice here that two other expressions - using equivalent variations instead of compensating variations - could also be used: i) the WTA for not implementing a risk-decreasing project and ii) the WTP for not implementing a risk-increasing project.

the value of the numerator is independent of p and a decrease in p reduces the value of the denominator (since $u' > v'$).[9]

Second, the wealth effect describes how VSL increases with wealth w. The intuition for the wealth effect is two-fold. First, wealthier people have more to lose if they die, i.e. the numerator in (5) increases with w (since $u' > v'$). Second, the utility cost of spending is smaller due to weakly diminishing marginal utility (risk aversion) with respect to wealth, i.e. the denominator in (5) does not increase (because $u'' \leq 0$ and $v'' \leq 0$). As a consequence, due to these two effects, the VSL increases as one moves upward and leftward along an indifference curve such as the one depicted in Figure 1.

To illustrate the two effects, it can be useful to consider specific functional forms. Assume that the (marginal) utility of bequest is zero, $v(w) = 0$, and that the utility function is isoelastic, $u(w) = w^{1-\gamma}/(1-\gamma)$ with $\gamma \in [0, 1[$. Then we get

$$\mathrm{VSL} = \frac{w}{p(1-\gamma)} \tag{6}$$

which increases in wealth w, and decreases in the survival probability p.

2.1.3 Risk aversion and background risks

It is often suggested that the VSL obtained from compensating wage differential studies underestimates the average VSL in the population because those who choose to work in hazardous industries are less risk averse. This suggestion, however, requires a more precise specification about what we mean by "less risk averse". For state-independent utility functions, it is usual to define risk aversion by the coefficient of curvature of the utility function introduced by Pratt (1964) and Arrow (1971, ch. 3). Yet, the above framework considers the case of state-dependent utility functions, that is, a case in which the utility assigned to any given level of wealth w varies with the state of nature (being alive or dead). And how to characterize risk aversion is not clear in the case of state-dependent utility functions (Karni, 1983).[10]

Eeckhoudt and Hammitt (2004) consider the standard model (1) and examine the effect of an increase in risk aversion in the sense of Arrow-Pratt of the utility contingent on being alive, that is of u. They show that more risk aversion increases the VSL when the marginal utility of bequest is zero and in a few other situations.[11] But in general, Eeckhoudt and Hammitt (2004) show that the effect of risk aversion on the VSL, or on the WTP/WTA for a risk change, is ambiguous. Moreover, Eeckhoudt and Hammitt (2001) and Kaplow (2005) show in model (1) that a high coefficient of relative risk aversion,

[9] Breyer and Felder (2005) show that the dead-anyway effect does not hold anymore when annuity markets are introduced. (See section 2.1.5.)

[10] Karni (1983) introduces such a general characterization, based on the equality of the marginal utility of wealth across states.

[11] Also, observe in (6) that VSL increases in the constant relative risk aversion parameter γ.

$-wu''(w)/u'(w)$, usually implies high values for the income elasticity of the VSL.

Eeckhoudt and Hammitt (2001) examine the effect of background financial and mortality risks on the VSL. Under reasonable assumptions about risk preferences with respect to wealth in the event of survival and death, they show that background mortality and financial risks decrease VSL. Andersson (2008) extends their analysis on background mortality risk and shows, that when individuals perceive the risks to be mutually exclusive, the background risk increases VSL.

2.1.4 Multiperiod models

We have presented so far a single-period model. In more realistic multiperiod models, individuals have preferences over probability distributions of the length of life and over consumption levels at each period of life. We illustrate this using the simplest two-period model

$$J \equiv \max_c u(c) + \beta p u(r(w-c)) \tag{7}$$

where β is a discount factor, r the interest factor, c consumption in period 1 and p the survival probability from period 1 to period 2. Observe that there is no bequest motive, and that an individual surviving period 1 will die for sure in period 2. The VSL, as defined as the MRS between wealth w and survival probability p, then equals

$$\text{VSL} = \frac{-dw}{dp} = \frac{\partial J/\partial p}{\partial J/\partial w} = \frac{u(r(w-c^*))}{pru'(r(w-c^*))} \tag{8}$$

in which c^* is optimal consumption. Observe that the obtained formulae for the VSL is not much different from the one of the single-period model (5) (assuming no bequest).

Several authors have used multiperiod life-cycle consumption models to derive an expression for the VSL (Conley, 1976; Bergstrom, 1982; Shepard and Zeckhauser, 1984; Garber and Phelps, 1997).[12] A recurrent problem overlooked in the formulation (7) is that future earnings may stop when the consumer dies, and so the wealth constraint should be carefully specified. Following Yaari (1965), two cases are often considered. In one case, the individual can purchase actuarially fair annuities. In the other case, the individual can borrow and lend at the riskless rate $r-1$, but can never be a net borrower. The results of each case differ, as illustrated by Shepard and Zeckhauser (1984) for instance.

One advantage of multiperiod models is that the effect of age can be studied. Although there is a widespread belief that VSL should decline with age (e.g., European Commission, 2000), there is no theoretical support for this belief. In particular, Johansson (2002) suggests that VSL should track the life-cycle pattern of consumption. Therefore, the relationship between age and VSL need not be

[12] The multiperiod model has also been used to examine how VSL is related to latent health risks, i.e. when there is a time lag between a change in exposure and a change in health risk (e.g. air pollution) (Hammitt and Liu, 2004; Johannesson and Johansson, 1996; Alberini et al., 2006a). Since the risk reduction usually is immediate in transport, this topic is not discussed in this paper.

monotonic. Some theoretical as well as some numerical results have suggested that there should be an inverted-U relationship between VSL and age (Aldy and Viscusi, 2007).

2.1.5 Human capital and annuities

Before the concept of WTP became widely accepted among economists as the appropriate evaluation method, the human capital (HC) approach was the dominant procedure to appraise the social value of a lost life. According to the HC approach the "value of life" is the value of the individual's market productivity, a value assumed to be reflected by the individual's earnings (Mishan, 1982). The HC is calculated as the individual's present value of future expected earnings and the approach has two major drawbacks: i) it assigns a zero value to non-market production implying that, e.g., unemployed and retired persons have a value equal to zero, and ii) it does not reflect individual preferences for safety. Attempts to also incorporate non-market earnings have been made by imputing, e.g., earnings to services carried out in the household (Max et al., 2004), or as in Keeler (2001) where leisure was given a monetary value. However, the main objection against HC is that it does not reflect individual preferences for safety, a problem which cannot be solved by assigning monetary values to non-market production or leisure.

To compare the VSL and the HC approach consider the following example. Assume a population of n identical people, in which $n(1-p)$ are expected to die. Consider a project that may save $n\varepsilon$ statistical lives. Using the WTP approach, one collects ex ante $n \times C(\varepsilon)$ - see (3) - which represents the monetary-equivalent benefits of the life savings project. In contrast, using the HC approach, one collects $n\varepsilon w$. That is, the monetary-equivalent benefits of the project is obtained by multiplying number of people who may be saved by their HC w (i.e., we interpret w as the discounted lifetime labor income). Notice then that comparing $n \times C(\varepsilon)$ to $n\varepsilon w$ amounts to compare $C(\varepsilon)/\varepsilon$ to w, which for small ε, amounts to compare VSL to w. However, notice that the VSL is usually larger than w, as illustrated by (6). The general idea that we want to put forward is that the HC approach may underestimate the value of preventing death.

Conley (1976), Cook (1978), Bergstrom (1982) and Rosen (1988) examine the relationship between the HC and VSL approach in a model with fair annuities. An annuity contract leads to specify ex ante how survivors will share ex post the wealth of those who will die. Overall, these papers suggest that HC may serve as a lower bound for the VSL under some (fairly plausible) restrictions on the utility functions. These restrictions usually include the concavity of u and a low bequest motive expressed through v.

2.2 VSL and welfare economics

2.2.1 Public provision of safety

We now introduce a model of public provision of safety (e.g., public investments in road safety) in a society with heterogenous individuals. We consider a particular case of the textbook model of provision of a public good (Samuelson, 1954) in order to underline the links between this textbook model and the VSL concept, as introduced above.

The economy is composed of n individuals. The level of safety expenditure z is a public good. Safety expenditure increases each individual i's survival probability $p_i(z)$, that is $p_i'(z) > 0$. Individual i's expected utility is given by

$$V_i \equiv p_i(z)u_i(w_i) + [1 - p_i(z)]v_i(w_i) \tag{9}$$

The objective of the benevolent social planner is to choose the level of public safety expenditure z together with the level of individual tax t_i in order to maximize

$$\sum_{i=1}^{n} \lambda_i \{p_i(z)u_i(w_i - t_i) + [1 - p_i(z)]v_i(w_i - t_i)\} \tag{10}$$

under the budget constraint

$$\sum_{i=1}^{n} t_i = z \tag{11}$$

Notice that λ_i is the Pareto weight associated with each individual i in the social planner's objective.

The first order conditions of this optimization program are given by

$$\begin{aligned} \sum_{i=1}^{n} \lambda_i p_i'(z)[u_i(w_i - t_i) - v_i(w_i - t_i)] &= \mu \quad (12) \\ \lambda_i\{p_i(z)u_i'(w_i - t_i) + [1 - p_i(z)]v_i'(w_i - t_i)\} &= \mu, \text{ for all } i \quad (13) \end{aligned}$$

where μ is the Lagrange multiplier associated to the constraint (11). Equation (12) is the social marginal benefit condition while equation (13) is the individual equalized marginal costs condition. Eliminating λ_is and μ in the $n + 1$ first order conditions above, we obtain

$$\sum_{i=1}^{n} p_i'(z)\text{VSL}_i = 1 \tag{14}$$

where VSL_i is the value of a statistical life corresponding to each individual i:

$$\text{VSL}_i \equiv \frac{u_i(w_i - t_i) - v_i(w_i - t_i)}{p_i(z)u_i'(w_i - t_i) + (1 - p_i(z)v_i'(w_i - t_i)}. \tag{15}$$

The equality (14) is therefore the efficiency condition that characterizes the optimal public provision of safety in this economy. It corresponds to the Samuelson's condition that the sum of MRSs equals the marginal rate of transformation (which is equal to one here).

Observe that if individual increases in survival probability $p_i'(z)$ are uncorrelated with VSL_i then the efficiency condition becomes

$$1/\left(\sum_{i=1}^{n} p_i'(z)\right) = \frac{1}{n}\sum_{i=1}^{n} \text{VSL}_i \tag{16}$$

that is, the marginal cost to save a life in the society should be equal to the overall population arithmetic mean of VSL. Therefore, this efficiency condition justifies the use of the average VSL as the economic criterion to determine the value of a social life when public projects affecting mortality risks in the society are implemented.

2.2.2 Distributional effects

The efficiency condition (16) relies on two critical assumptions: i) there are no restrictions on the tax levied on individuals, ii) the individual risk reductions are uncorrelated with individuals' VSLs.

Assumption i) relies on the possibility for the social planner to implement individualized lump-sum transfers t_i that are given by (12) and (13). However, governments usually do not have the information, nor possess the power to implement such optimal lump-sum transfers. Assumption i) is thus difficult to justify empirically. It is no surprise that it has been extensively discussed in the public economics literature (see, e.g., Drèze and Stern, 1987). If this assumption is relaxed, the efficiency rule is different, and therefore the efficient level of public safety should be different as well (see, e.g., Ballard and Fullerton, 1992).[13] Moreover, notice that assumption i) implies that the tax levied is such that all individuals end up with the same marginal utility of income, see (13). Hence the notion of equality that is put forward in economic analysis is that of marginal utility, and not a notion based on equal levels of risks to life for instance (Sen, 1973) or equal levels of differences in risks to life (Somanathan, 2006).[14]

It is unlikely that individual risk reductions are uncorrelated with individual VSL, as assumption ii) requires. Suppose indeed that a program principally affects a higher (lower) income group. Since VSL is expected to increase with wealth, individual risk reductions are positively (negatively) correlated with individual VSL. The same observation holds if the program principally affects high risk (low risk) people, due to the dead anyway effect.

These observations suggest that the use of the average VSL may lead to bias in risk policies that may disproportionately favor the rich, or the most exposed individuals for instance. One solution to "debias" risk policies is to weight individual VSL (for a general argument, see, e.g., Blackorby and Donaldson, 1990). The well-known problem is that there is no evident choice for the weights, as it has been discussed

[13] Armantier and Treich (2004) examine the social value of a project affecting mortality risks and that is financed by distortionary taxation, *but* assume that this project is evaluated by the average VSL rule (as if there were optimal lump-sum transfers). They exhibit some conditions such that the project will be overestimated or underestimated, and thus leads to a too high or too low level of safety provision.

[14] See Viscusi (2000) for an extensive discussion.

at length in the literature, and most economists prefer not to use weights at all (Harberger, 1971).[15] Baker et al. (2008) recently re-examine these arguments using the same framework that we introduced above. Specifically, they "adjust" the underlying social welfare function, in particular by adapting the Pareto-weights λ_is, so that the welfare function justifies the use of a "common" VSL.

2.2.3 Statistical vs. identified lives

Economists make clear that the VSL approach applies only when changes in risk are small and similar among the affected population (e.g., Viscusi, 1992, ch. 2).[16] Therefore, the focus on statistical lives leaves open the question of how to evaluate a project that may instead save, or threaten, the lives of identified people. It also meets a well-known conceptual issue, "Broome's paradox". Assume that a project may kill one person from a population of similar individuals. If the identity of the victim was unknown, the project may be adopted. Yet, if the victim's identity was known, the potential victim might require infinite compensation for the loss of his life and the project would be rejected.[17]

Hammitt and Treich (2007) examine formally the Broome's paradox in the framework introduced above. They explain that the paradox is related to the distributional effect discussed above, and arises because adding monetary compensations is only a good proxy for welfare if marginal utilities are equal across individuals. Along the same lines, Hammitt and Treich study the effect of information about the heterogeneity of risk in the population - that is, the effect of individual identifiability - on the average WTP or WTA for a mortality risk change. They show that the average WTA is usually larger with more information about how the project affects individuals' risks. Hence individual-specific information may lead to rejecting a risk-increasing project that would have been accepted without information, as in Broome's paradox. In contrast, they show that average WTP is usually smaller with more information about heterogeneity of the risk change. Hammitt and Treich (2007) thus conclude that there is no necessary relationship between the extent to which risk changes are statistical or identifiable and the level of safety endorsed by an economic analysis.

[15] As Arnold Harberger (1971) put it in one of his three postulates for applied welfare economics: "[C]osts and benefits accruing to each member of the relevant group (e.g. a nation) should normally be added without regard to the individual(s) to whom they accrue" (p. 785).

[16] This observation is reminiscent to the first sentence of the Thomas Schelling's seminal paper: "It is not the worth of human life that I shall discuss, but of 'life-saving', of preventing death. And it is not a particular death, but a statistical death." (Schelling, 1968).

[17] This is a paradox in the sense that the only difference between the two situations is knowing the identity of the victim. This, it may be argued (Broome, 1978), should not ultimately affect the social decision rule. Broome (1978)'s provocative paper raises a number of other conceptual issues for the application of the VSL framework. Most of these issues are discussed in a set of critical papers (Buchanan and Faith, 1979; Jones-Lee, 1979; Williams, 1979).

2.2.4 Altruism

The relationship between altruism and life-savings has been discussed in the early stage of the economic literature on VSL (Schelling, 1968; Mishan, 1971; Jones-Lee, 1976; Needleman, 1976) and has been more recently addressed in the psychology literature (see, e.g., Jenni and Loewenstein, 1997).

The benchmark economic result dates back to a point initially raised by Bergstrom (1982). Consider an altruistic economy in which individual i's utility $U_i \equiv U_i(V_1, ..., V_n)$ increases in each of its arguments and strictly increases in V_i, as defined in (9). This is the case of pure altruism. Bergstrom's point is that since preferences in this altruistic economy increase in everyone's utilities, every Pareto optimum in the altruistic economy must also be a Pareto optimum in the selfish economy described above. As a consequence, the necessary conditions (12) and (13) for an optimum in the altruistic economy are identical to those in the selfish economy.

The important implication of this point is that the presence of altruism should not lead to any adjustment upward or downward of the VSL but should be kept the same as if individuals were selfish. The intuitive argument is simple. A pure altruist benefits when another person's risk is reduced but is harmed when one imposes a financial cost on this person. The sign of one person's altruistic valuation for another is thus the same as the sign of the net private benefits to the other and so pure altruism cannot alter the sign of the social net benefits. This argument was recently generalized by Bergstrom (2006). Jones-Lee (1991) extended Bergstrom's analysis and showed that people's WTP for others' safety should only be taken account of when the altruism is "exclusively focused upon other people's safety" (p. 217). Individuals with this form of altruism are defined as safety paternalists, and disregard all factors besides safety that contribute to the utility of other people.[18]

We must finally notice that the above arguments do not exhaust the rich set of research questions that pose relations to others for VSL. These questions include those related to the modelling of intra-households interactions (e.g., patriarchal vs. bargaining models), to whether and how the relative position (with respect to utility, income, safety, etc.) of an individual compared to others matters for welfare and to the various pecuniary effects posed by mortality risks in our societies (life insurance, externalities due to increased longevity).

[18] Also, Jones-Lee (1992) proves that the benchmark result of Bergstrom also holds in an economy with "pure paternalism". An individual i is a pure paternalist if his "marginal rate of substitution of j's wealth for j's survival probability is the same as i's marginal rate of substitution of own wealth for own survival probability" (Jones-Lee, 1992, p. 86).

3 Empirical Aspects

In the following sections we first briefly describe preference elicitation of non-marketed goods, followed by a presentation of results from the empirical literature. This presentation contains: i) empirical estimates of VSL in transport, ii) findings from the VSL literature in general, and iii) a discussion of individuals' risk perception and how it relates to VSL. We finally discuss how VSL is used in policy-making.

3.1 Preference elicitation

Since the concept of WTP was developed forty years ago, the VSL has been estimated in a number of studies, and in a variety of areas. As mortality risk reductions *per se* are non-marketed goods, we have to rely on non-market valuation methods in order to estimate VSL.[19] These methods can be classified into two types, revealed- and stated-preferences methods. Both approaches have their strengths and weaknesses. Revealed preference (RP) methods use the information from choices made by individuals in existing markets, whereas stated preference (SP) methods employ hypothetical market scenarios.[20]

3.1.1 Revealed Preferences

In RP studies information is obtained from situations where individuals make actual tradeoff decisions, either implicitly or explicitly, between wealth (foregone consumption) and physical risk. Economists usually prefer RP to SP methods when non-marketed amenities are to be evaluated. With actual (and often repeated) choices, individuals have incentives to identify and understand the choice alternatives. Hence, preferences elicited in RP studies are not only based on actual behavior and thus are expected to be more consistent, but are also assumed, compared to hypothetical choices made by respondents in SP studies, to be made on a more informed basis.

Many RP studies to estimate VSL have used compensating wage differentials but individual consumption decisions have been employed as well (for a review, see Viscusi and Aldy, 2003). In transport, consumers' decisions on, e.g., the purchase of car models (Atkinson and Halvorsen, 1990), safety products such as bicycle helmets (Jenkins et al., 2001), and car drivers' decision whether to use a seat-belt or not (Blomquist, 1979; Hakes and Viscusi, 2007) have been used to estimate VSL.

A common problem of using consumption data on safety equipment, e.g. airbags or bicycle helmets,

[19] This paper only gives an introduction and brief overview of non-market valuation. We do not discuss the econometric aspects of preference elicitation. Instead we refer to the references provided in this section, in which many econometric aspects are discussed, together with other literature on non-market valuation (e.g., Bateman et al., 2002; Haab and McDonnel, 2003) as well as textbooks on econometrics (e.g., Wooldridge, 2002, 2003).

[20] An alternative to derive society's WTP for a mortality risk reduction is "implicit valuation" (Schelling, 1987), where social policy is assumed to express the value for the society to save "lives". The critique against using "implicit valuation" to estimate VSL is that "public tradeoffs do not directly inform about individual WTP" (Blomquist, 2004, p. 95). An interesting example of "implicit valuation" is Ashenfelter and Greenstone (2004a,b). Ashenfelter and Greenstone use speed legislation to derive VSL. They estimated a value approximately equal to US$ 1.5 million (in 1997 prices).

is that it provides a lower bound of consumers' WTP for safety, i.e. a lower bound for those who decide to buy the safety equipment. Since the consumers are faced with a binary decision, the decision to buy or not the safety device can only reveal whether the benefit from the product is at least as large as the cost of the product (Viscusi, 1993). The use of the car market with a wide variety of different models therefore provides an advantage compared with the use of most safety products, since it reveals the consumers' total WTP for safety (see below). The technique that has been used to estimate VSL in the car market is the hedonic regression technique (Atkinson and Halvorsen, 1990; Dreyfus and Viscusi, 1995; Andersson, 2005a).

The hedonic regression technique was formalized in a seminal paper by Rosen (Rosen, 1974). According to this technique, the price (P) of a composite good, defined as a vector of its attributes $\mathbf{A} = [a_1, \ldots, a_n]$, is a function of its utility-bearing characteristics, i.e. $P(\mathbf{A})$. The relationship between the price of the composite good and its characteristics is illustrated in Figure 2 (a) in the P-a_1 plane. Let θ^i and ϕ^i in Figure 2 (a) denote individual i's bid function (indifference curve) and firm i's offer function (isoprofit curve), and let a_1 denote survival probability. The market equilibria, observable by the analyst, are characterized by tangency between the bid and offer functions, where marginal valuation equals marginal cost. Since the bid function is equivalent to the indifference curve, the marginal WTP for a utility maximizing individual is proportional to the MRS between survival probability and other consumption. Since the hedonic price function (HPF) is derived from these equilibria, we can use it to estimate the population mean MRS(P,a_1), i.e. VSL. Deriving the HPF and estimating marginal WTP is sometimes referred to as the *first step* of the hedonic regression technique.

[Figure 2 about here.]

The HPF does not, as illustrated in Figure 2 (a), contain any information concerning the shape of the underlying bid and offer functions, however. Thus, in order to estimate non-marginal WTP using the hedonic regression technique, we need to derive the individuals' marginal bid functions, $\theta^i_{a_1}$, which are drawn in Figure 2 (b) for two individuals, together with the marginal price locus, P_{a_1}, and two marginal offer functions, $\phi^i_{a_1}$.[21] Rosen (1974) proposed that a *second step* should be carried out in order to identify these marginal bid and offer functions, where the results from step one, together with information on consumer and firm attributes, should be used.[22]

[21]Subscripts in Figure 2 (b) denote derivatives of functions with respect to the argument in the subscript.

[22]Whether the demand function can be identified using single market data in Rosen's two-step procedure has been under considerable debate (Brown and Rosen, 1982; Ekeland et al., 2002). One of two approaches can be followed to recover the preference parameters: i) impose a structure of non-linearity of the system (Ekeland et al., 2002, 2004), or ii) use multi market data where the HPFs differ between the markets (Brown and Rosen, 1982; Palmquist, 1991). Both approaches have been criticized, the former since often restrictions on the model are imposed that are unjustified from an economic perspective (Ohsfeldt and Smith, 1985; Epple, 1987), and the latter since the identification strategy often is "logically inconsistent" (Ekeland et al., 2002, p. 307).

The fact that RP methods rely on the existence of markets where individuals are assumed to make informed decisions about alternatives that differ in risk levels is also its potential weakness. Moreover, RP methods also require that the analyst is able to identify the alternatives identified by the consumers. For instance, if consumers base their decision on subjective risks, this is the information that should be used in principle by the analyst. Further, since real market situations are required: i) estimates are based on the market population (e.g. car owners) and not the general population, and ii) it limits the applicability to specific situations that analysts and policymakers are interested in.

3.1.2 Stated Preferences

SP methods have an important role to play when knowledge among analysts about the decision alternatives, the beliefs and consequences individuals face is limited, or when market data does not exist for the amenity of interest. SP methods are also more flexible than RP which allows the analyst to tailor the surveys to elicit the desired information, and they have, therefore, been employed in a wide variety of areas to estimate VSL (see e.g., Hammitt and Graham, 1999). There exists a wide range of techniques to elicit preferences using hypothetical market scenarios. Some recent studies in traffic safety have used a stated-choice approach to estimate VSL (e.g. Rizzi and Ortúzar, 2006a,b), but the method that dominates in the evaluation literature on VSL in traffic is the contingent valuation method (CVM) (Mitchell and Carson, 1989; Bateman et al., 2002).

The CVM is a SP method where individuals are asked directly how much they are willing to pay (or are willing to accept) for a change in the quantity of a good, or alternatively, how much they would require in compensation for a change that was not carried out. There are several CVM-formats for eliciting respondents' preferences. These can be divided into two subgroups, "open-ended" and the referendum format (see e.g. Bateman et al., 2002). In open-ended questions the respondents are asked to state their maximum WTP for the good, without being provided any choice alternatives. This provides the analyst with a continuous data on WTP, as illustrated in Figure 3 (a). In the referendum format the respondents are asked to answer *yes* or *no* to questions on whether or not they are willing to pay a certain amount for a specific good. Figure 3 (b) shows the data from a dichotomous single-bounded WTP question, where the analyst only knows whether the true WTP is above or below the asked bid level. The analyst also has the option to collect interval data, Figure 3 (c). This can be done using either follow-up questions to a dichotomous choice question, or to provide the respondents with series of bid levels.

[Figure 3 about here.]

The major drawback of the SP methods is that they are based on hypothetical choices. In a hypothetical setting respondents may have little incentives to truthfully state their preferences. Results from experiments suggest that respondents overstate their WTP (or WTA), i.e. SP studies are plagued by what is often referred to as "hypothetical bias". It has been suggested that the hypothetical bias can be related to unfamiliarity with the good and preference uncertainty among the respondents (List and Gallet, 2001; Blumenschein et al., 2008). To mitigate this bias, it is common practice to include questions about preference certainty, either as a quantitative or a qualitative measure, and to restrict the sample to those who are certain about their answer (Blumenschein et al., 1998, 2001, 2008; Champ et al., 1997; Champ and Bishop, 2001; Hultkrantz et al., 2006).[23]

In order to receive answers in CVM-studies that reflect the respondents' "true" preferences, the hypothetical market scenario should be meaningful and understandable for the respondents (Carson et al., 2001). Empirical evidence suggest that people are imprecise when stating their preferences in studies on safety (Dubourg et al., 1997), and Carson et al. (2001) conclude that preference elicitation of small changes of probability using CVM is particulary problematic. This may be due to peoples difficulties in understanding small (changes in) probabilities, for which there is a wealth of evidence (see section 3.2.3). It has been examined whether the problem of insensitivity to scale found in CVM studies (Hammitt and Graham, 1999) could be linked to the lack of understanding. Corso et al. (2001) and Alberini et al. (2004) find that by using proper visual aids and by training the respondents in trading wealth for safety, scale sensitivity in line with the theoretical predictions could be reached.[24] Moreover, Andersson and Svensson (2008) examine the correlation between cognitive ability among respondents and scale sensitivity. They find that respondents with a higher cognitive ability were more likely to state a WTP more in line with the theoretical predictions.

3.2 Results from the literature

3.2.1 Empirical estimates of VSL

Most studies that have elicited individuals' preferences for transport safety, have done so for road fatality risk. This attention towards road risk is not surprising considering it is by far the transport mode that causes most fatalities (see, e.g., Evans, 2003). Table 1 shows an overview of estimates of VSL, all related to road traffic.[25] As shown in the table, the magnitude of the estimates are vastly different, ranging from 150,000 (Bhattacharya et al., 2007) to ca. 36 million (McDaniels, 1992), in US$ 2005 price level.

[23] The hypothetical nature of preference elicitation also gives rise to other types of bias (see e.g., Bateman et al., 2002, pp. 302-303).

[24] The visual aid that worked the best in Corso et al. (2001) was an array of dots. The same aid has been used in other studies with less success (Jones-Lee et al., 1985; Persson et al., 2001; Andersson, 2007).

[25] The inclusion of VSL only for road traffic was a result of our literature review and was not intentional. We make no claim that the list of VSL studies in transport is complete, though.

[Table 1 about here.]

VSL is intended to reflect an affected population's preferences for a reduction in its mortality risk. Values might therefore differ, since there are "no a priori grounds for supposing these preferences, perceptions, and attitudes need necessarily be the same" (Jones-Lee and Loomes, 1995, p. 184) across populations. For instance, Carlsson et al. (2004) examine respondents' WTP for two transport modes (without estimating VSL, therefore not included in Table 1), travelling by air or taxi. For the same baseline and reduction in risk, they find that WTP is significantly higher when travelling by air compared with by taxi. One explanation for their result is that respondents perceived travelling by air to be riskier, even though the risks were the same size in the survey. This could be related to how travellers perceive the controllability, voluntariness and responsibility of a risk of a specific mode. If travellers perceive risks in surface transport to be less dreadful than other transport modes (air, underground, etc.), we expect WTP to be greater for the latter which was the finding in Carlsson et al. (2004).[26]

In Table 1 all studies have been conducted on road safety, but since the studies have been conducted under different contexts (e.g. in different locations or point of time) and for different populations, we can still expect the values to differ. For instance, the range of values in Blomquist et al. (1996) depends on transport modes (lowest value is for motorcyclists) and who benefits from the safety measure (highest value is parents' WTP for child safety). However, values are usually more sensitive to the context, the affected population, the survey design, etc., than predicted by theory. For instance, the large interval in: i) Andersson (2007) is due to insensitive to scale (see section 3.2.2), ii) Hultkrantz et al. (2006) whether the good is a public (lower value) or private safety measure, and iii) McDaniels (1992) if WTP (lower value) or WTA is estimated. The findings in these three studies are representative of the WTP literature on fatality risk, as well as other non-marketed amenities (Hammitt and Graham, 1999; Miller, 2000; Horowitz and McConnell, 2002; de Blaeij et al., 2003; Plott and Zeiler, 2005). Moreover, in their meta-analyzes on VSL in road safety, Miller (2000) and de Blaeij et al. (2003) found that estimates from SP studies were significantly higher than estimates from RP studies.

3.2.2 Miscellaneous empirical findings

How VSL is influenced by different factors is important not only to examine how values may differ between socio-economic or demographic groups. The analysis also plays an important role for validity testing. The list below contains a brief review of the empirical literature on how different attributes have been found to affect the VSL.

[26] Jones-Lee and Loomes (1995), using an implicit valuation approach, found that a WTP based VSL for Underground (Subway) risk should be approximately 50 percent higher compared with its road counterpart.

Wealth level From section 2.1.2 we know that VSL is predicted to increase with the wealth level. Even if RP and "CVM studies do not always find a statistically significant relationship with income..." (Hammitt, 2000a, p. 15), the evidence that VSL increases with wealth is quite strong (de Blaeij et al., 2003; Liu et al., 1997; Miller, 2000; Mrozek and Taylor, 2002; Viscusi and Aldy, 2003). Moreover, the evidence from the RP and SP literature suggests that the income elasticity is between zero and one (Viscusi, 1993; Hammitt et al., 2006).

Baseline risk We also know from section 2.1.2 that VSL should increase with the level of the baseline risk. Here the empirical evidence is mixed, with, e.g., the relationship found to be: i) positive in de Blaeij et al. (2003) and Persson et al. (2001), ii) negative in Andersson (2007) and Viscusi and Aldy (2003), and iii) non-monotonic and concave in Mrozek and Taylor (2002). Explanations why baseline risk does not always affect VSL according to theory could be sorting in the market and a difference between the perceived (i.e. the risk the consumer/respondent bases his decision on) and the objective (i.e. observed by the analyst) risk.

Background risk As described above, the effect of a physical background risk depends on how individuals regard it to be related to the specific risk, i.e. the risk for which VSL is estimated. The empirical evidence is limited; results from a Swedish SP study suggest that the risks are perceived to be independent, i.e. VSL decreases with the background risk (Andersson, 2007), whereas a Swedish RP study using the car market does not find any statistically significant correlation between the VSL and the background risk (Andersson, 2008).

Age As we outlined in section 2.1.4, the theoretical prediction of the effect of age on VSL is indeterminate, since the relationship is determined by the optimal consumption path which depends on assumptions on discount factors, saving opportunities, etc. Regarding empirical evidence, the findings in most studies support that VSL follows an inverted U-shape, is declining, or is independent of age (Alberini et al., 2004, 2006b; Andersson, 2007; Hammitt and Liu, 2004; Johannesson et al., 1999; Jones-Lee et al., 1985; Viscusi and Aldy, 2007; Krupnick, 2007).[27]

Health status It is intuitive to expect that people in good health should be willing to pay more to reduce the risk of fatality, since they in a sense have more to lose. However, health may also affect the marginal utility of wealth, which may potentially have some offsetting effects (Hammitt, 2002; Strand, 2006). Moreover, health is expected to affect negatively the VSL through its positive effect on survival probabilities (the dead anyway effect) and to affect positively the VSL through its

[27]VSL is sometimes converted to the value per statistical life-year (VSLY) (Alberini and Krupnick, 2002). This conversion relies on the assumption that VSL declines with age (Hammitt, 2007).

positive effect on the future flow of incomes and from reduced health care expenditures (the wealth effect). The effect of health status on VSL is ambiguous, and the empirical evidence suggests that VSL does not vary with health status (Alberini et al., 2004, 2006b; Andersson, 2007; Smith et al., 2004).

Altruism Regarding individuals' WTP for others' safety (health), the overall evidence seems inconclusive. Several studies have found evidence which implies that individuals are safety-paternalistic (Vázquez Rodríguez and León, 2004; Jacobsson et al., 2007; Holmes, 1990; Andersson and Lindberg, 2007). Others have found that WTP is higher among parents for their children than for themselves (Liu et al., 2000; Dickie and Messman, 2004; Chanel et al., 2005), and that WTP is higher for a safety measure for the entire household than for a measure which can only be used individually (Bateman and Brouwer, 2006; Chanel et al., 2005). However, it also seems that individuals are not willing to pay as much for others' safety as they are for their own safety, which is manifested by the empirical evidence which shows that individuals are not prepared to pay as much for a public safety measure as for a private measure (Johannesson et al., 1996; de Blaeij et al., 2003; Hultkrantz et al., 2006).

Scale sensitivity A necessary (but not sufficient) condition for WTP answers in SP studies to be valid estimates of individuals' preferences for small mortality risk reductions is that WTP is near-proportional (increasing and slightly concave) to the size of the risk reduction (Hammitt, 2000a).[28] Corso et al. (2001) distinguish between weak and strong scale sensitivity, where weak and strong refer to an increasing and near-proportional WTP to the magnitude of the risk reduction, respectively. A consequence of a rejection of near-proportionality is that the VSL is sensitive to the change in the mortality risk (Andersson, 2007). Whereas there is often support for weak sensitivity in the empirical literature, strong sensitivity is often rejected, even though there have been some recent promising results regarding the latter (Hammitt and Graham, 1999; Corso et al., 2001; Alberini et al., 2004; Andersson and Svensson, 2008).

3.2.3 Mortality risk perceptions

The VSL depends on how individuals perceive mortality risks, in particular it depends on their perception of baseline risks and of probability changes. If, for instance, they perceive risks to be higher than they actually are, monetary estimates of the value of risk reductions are expected to be higher than if the public was better informed (Gayer et al., 2000; Bleichrodt and Eeckhoudt, 2006).

[28] Note that in the first step of the hedonic technique, marginal WTP is estimated and therefore scale sensitivity is not an issue.

There is extensive, and "strong and quite diverse" (Viscusi, 1992, p. 108) evidence that individuals are rational in their decision-making involving risks in the market (Viscusi and Aldy, 2003; Blomquist, 2004), but there are also results which imply that the estimated "risk-dollar" tradeoffs may not always be accurate (Viscusi and Magat, 1987). When hypothetical markets are used to elicit individuals' WTP, there is evidence of ordinal but not cardinal risk comprehension (Hammitt and Graham, 1999). Hence, individuals seem to respond in a correct way to risks, both in hypothetical and market scenarios, but "their ability to perceive risk in a cardinally correct way is questioned" (Blomquist, 2004, p. 99).

Lichtenstein et al. (1978) showed that individuals overassess small fatality risks and underassess large fatality risks, a pattern confirmed by the results in several other studies and today regarded as an established fact (Morgan et al., 1983; Benjamin and Dougan, 1997; Viscusi et al., 1997; Hakes and Viscusi, 2004; Armantier, 2006). Studies on risk perception have, however, used automobile risk as the "standard anchor" (Hakes and Viscusi, 2007, p. 668). We, therefore, need to turn to the literature that has specifically examined respondents' perception of road-traffic risks to be able to draw any conclusions whether road users underassess or overassess their risk exposure from road-traffic. For instance, Hammerton et al. (1982) find evidence that "...on average subjective assessments are of a broadly similar order of magnitude to the objective ratio" (p. 192), and Persson and Cedervall (1991) that the median of the respondents' perceived risk is equal to the calculated objective risk. Andersson and Lundborg (2007) who examined respondents' perception of their own risk, find that the respondents underassess their risk, which is a result of men underassessing their fatality risk. In their study: i) the risk perception among females is not statistically significantly different from the objective risk, and ii) a similar pattern to Lichtenstein et al. (1978) is observed with only those with the lowest objective risk level (women aged 25-54) overassessing their risk.[29]

RP studies only observe individuals' choices and do not observe individuals' risk perceptions. Analysts thus need to make some assumptions about individuals' risk perceptions. They usually assume that individuals hold unbiased beliefs about mortality risks. When examining which car attributes are important for car consumers, Johansson-Stenman and Martinsson (2006) find that nearly all car consumers considered safety to be very (ca. 85 %) or fairly (ca. 15 %) important. When car dealers were asked how important car attributes were for the consumers, they stated that safety was very (ca. 54 %) or fairly (ca. 37 %) important for more than 90 percent. If this translates into consumers seeking information, they will become well-informed and any potential bias from RP studies could be small.

[29]The pattern of overassessment of small risks and underassessment of large risks may follow the prediction that individuals update their risk perceptions in a Bayesian fashion (Smith and Johnson, 1988; Viscusi, 1989; Dickie and Gerking, 1996; Hakes and Viscusi, 1997; Gayer et al., 2000). This updating process is of interest to SP studies on mortality risk, since respondents might combine their prior beliefs with the values in the survey and state their WTP for this updated risk reduction (instead of the one presented in the survey) (Hammitt and Graham, 1999; Corso et al., 2001).

3.3 Policy use of VSL in transport

Benefit-cost analysis (BCA) of road safety projects goes back at least thirty years (Elvik and Vaa, 2004). Early monetary values of preventing a fatality were commonly based on the HC approach (Abraham and Thedie, 1960; Persson, 2004; US DoT, 2004) and many countries still use values based on this approach (Trawén et al., 2002; Bristow and Nellthorp, 2000). Other countries adopted the concept of WTP in the early 1990s; Sweden 1990 (Persson, 2004), New Zealand 1991 (Guria et al., 2005), followed by the UK and the US in 1993 when the Department of Transport in each country decided to replace their previous policy value by preference based values (US DoT, 2004; UK DoT, 2007).

Table 2 shows policy VSL used in New Zealand, Norway, Sweden, UK and US.[30] For ease of comparison between countries and to the estimated values in Table 1, values have been converted to US$ 2005 price level. The table reveals that the values are based on relatively old studies, i.e. from the early 1990s.[31] Values have been revised since they were implemented, and new research have on those occasions been considered (SIKA, 2005; Robinson, 2007). However, policy makers have been reluctant to revise the values on grounds other than price and real income changes, which is probably a result of the uncertainty still surrounding VSL estimates.

[Table 2 about here.]

It is important to recognize that individual WTP may not fully reflect the social value of traffic safety. The individual WTP may not reflect a reduction in costs to society such as medical, police surveillance, damage, and lost productivity. Jones-Lee et al. (1985) found evidence that the respondents did not take account of such other effects of the safety improvements. Therefore, in, e.g., Sweden, the UK and the US the VSL is augmented by a value that reflects these other effects (SIKA, 2005; Robinson, 2007; UK DoT, 2007). For instance, the Swedish value in Table 2 consists of two components: i) marginal WTP to reduce fatality risk, and ii) what is referred to as "material costs" and consists of net loss production, other costs and medical costs (Trawén et al., 2002). Material costs are only a fraction of the total value, seven percent, though.

The VSL has been mostly developed and used by policy makers in the US. The major impetus for this may be related to the US executive order which imposed almost thirty years ago the use of BCA. We, therefore use the US to relate the policy values in Table 2 to other areas where policy values are also used. The Office and Management Budget (OMB) has primary responsibility for writing guidelines

[30] We again make no claim that the list of values is complete.

[31] After the Exxon Valdez oil spill the NOAA (National Oceanic and Atmospheric Administration) panel was formed to examine issues in damage compensation (NOAA, 1993). The NOAA Panel's recommendations of preference elicitation using SP techniques have had a major impact on later studies and contributed to more precise SP estimates, which is why studies conducted prior to NOAA can be considered relatively old.

to assist regulatory assessment and for coordinating and reviewing analyses across US federal agencies (Robinson, 2007). The OMB Circular A-4 (US OMB, 2004) reports that the range of VSL estimates is usually between US$ 1 and 10 million, and agencies generally use values in this range. The Environmental Protection Agency (EPA) (which is responsible for more costly federal policies and has played a significant role in the increasing use of VSL) depending on context, use values within the range US$ 1 to 10 million, with a mean estimate of US$ 5.5 million, whereas the Food and Drug Administration (FDA) uses a slightly lower value, US$ 5 million (EPA 1999 prices, FDA no price year reported, Robinson, 2007). These values are, thus, higher than the value used by the Department of Transportation as reported in Table 2.[32]

Based on theoretical and empirical evidence there may sometimes be a motivation to use different VSLs for different populations. However, this suggestion is controversial since it raises issues about the equitable treatment of different segments of the population. Therefore, the adjustment of VSL made by regulatory agencies is very modest, and does not reflect the large WTP differences observed in individuals' choices. In the United Kingdom for instance, the value in Table 2 is used for all causes of death except cancer, where a value twice this size is applied (Baker et al., 2008). Regarding wealth levels, adjustments are made longitudinally (over time) but not cross-sectionally (across populations) since the latter is considered controversial from an ethical perspective (European Commission, 2000; Robinson, 2007). Moreover, it is noticeable that public recommendations may openly prohibit the used of differentiated VSL. OMB for instance issued a memorandum advising agencies against adjusting VSL for age (Robinson, 2007). Similarly, the European Commission states that "it is not recommended that [VSL] values be changed according to the income of the population affected" (European Commission, 2000).

4 Conclusions

In this paper we have described from a theoretical and empirical perspective how to estimate monetary values of reducing the mortality risk in transport. We presented the standard theoretical expected utility model in a static framework, which we then extended to a multiperiod model and how different attributes affect VSL, and issues related to public provision of safety. In the empirical part we described how preferences can be elicited, showed empirical results, and discussed how the values are used in policy making. Since the VSL concept is based on preference elicitation, it adopts the standard economic concept that individuals are the best judges of their own interests (i.e. individual sovereignty). Preference

[32] As a comparison, recommended policy value for EU is € 1.0 million with a range of € 0.65 to 2.5 million (2000 prices) (European Commission, 2000).

elicitation requires not only good econometric practice but also a solid theoretical foundation.

The elicitation of preferences for safety has come a long way since it was introduced about four decades ago. However, old findings can be improved and new questions are raised continuously. For instance, in section 2.2.1 the decision problem is that of a social planner who must select optimal public safety expenditures. In this framework, individuals make no decisions. However, in reality, individuals make decisions that may directly interact with the public decision. It has been argued for instance that road safety measures or automobile safety standards (e.g., seat belts) may fail to save lives because safer roads or safer cars induce more dangerous driving (Peltzman, 1975). Thus the behavioral response of individuals to public action should not be ignored.[33]

Model (1) is based on the expected utility model. Although this model is still the dominant model in the theory of choice under risk, many alternative models have been proposed. These alternative models may better account for empirical or experimental evidence that is often inconsistent with the theoretical predictions based on expected utility. However, few studies have studied VSL using these alternative models. An exception is Bleichrodt and Eeckhoudt (2006) who assume that individuals do not evaluate probabilities linearly (Quiggin, 1982) and show that this may affect the WTP for reduction in mortality risks.[34]

Finally, it is important to remember that model (1) relies on a state-dependent utility framework. The comparative statics results that we have presented depend on the assumptions in (2), in particular on those on the utility of death, i.e., on the bequest utility. But we observe that we have little sense of what should be the sensible properties on the bequest utility, and how it should vary across the population and time. Presumably, it may vary with family structure. Moreover, there is a well known identification problem here because the subjective probabilities and the relative units of scales and origins of the state-dependent utility cannot usually be separately identified (Drèze and Rustichini, 2004; Karni, 1985), unlike within the state-independent framework.

These questions were raised more or less recently in the VSL literature, and may be the object of future research efforts. There are obviously many factors that may influence VSL, and we have considered just a few of them.

[33]See Viscusi (1994) and Gossner and Picard (2005) for some early studies on the interaction of private and public protection measures.

[34]See also Treich (2007) who shows that VSL is always higher under ambiguity aversion (Klibanoff et al., 2005). Other models that could potentially be applied to VSL may include the prospect theory model (Kahneman and Tversky, 1979), regret/disappointment models (Loomes and Sugden, 1982; Bell, 1985) and the more recent reference-dependent models (see, e.g., Köszegi and Rabin, 2007).

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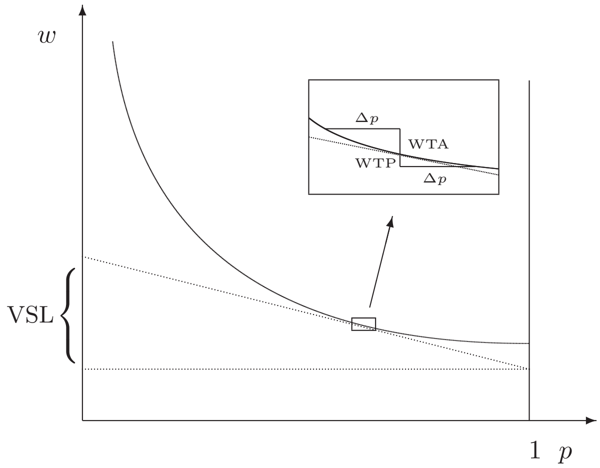
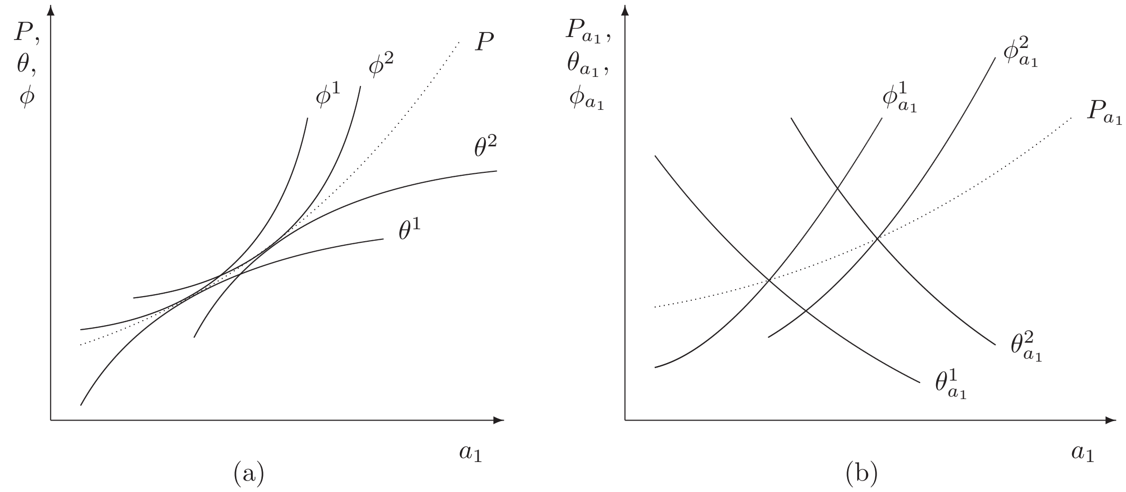
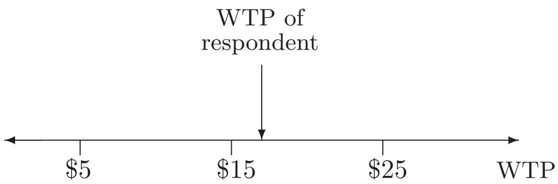


Figure 1: The value of a statistical life: Indifference curve over survival probability (p) and wealth (w). The slope of the curve represents the marginal rate of substitution between p and w. The WTP (WTA) represents the maximal amount that an individual is willing to pay (accept) for a mortality risk reduction (Δp) (increase). (Source: James Hammitt, Lecture notes, School of Public Health, Harvard University.)

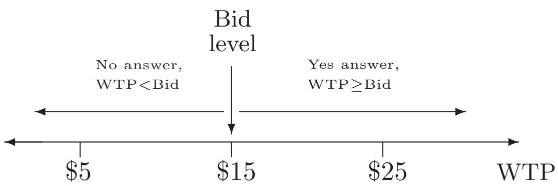


(a) (b)

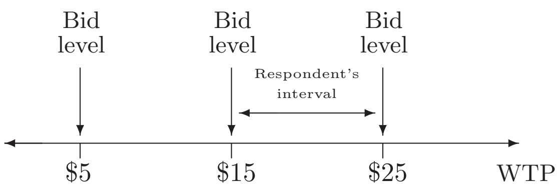
Figure 2: (a) The hedonic price function (P) and the bid (θ^i) and offer functions (ϕ^i) for two utility- and profit-maximizing consumers and firms, respectively. Tangency between a bid and an offer function denotes a market equilibrium. (b) The marginal price locus (P_{a_1}) and two marginal bid ($\theta^i_{a_1}$) and offer functions ($\phi^i_{a_1}$), respectively. Marginal WTP equals marginal cost at intersections between the marginal bid and offer functions. Source: Andersson (2005b)



(a) Continuous data on WTP



(b) Binary data on WTP



(c) Interval data on WTP

Figure 3: Data on WTP from CVM surveys

Table 1: Empirical estimates of the value of a statistical life in road traffic, in US$ 2005 ($\times$1000)[a]

		Year of data,	No. of	Range of VSL estimates		
Authors	Country	Study type	estimates[b]	Single	Lowest	Highest
Andersson (2005a)	Sweden	1998, RP	1	1,425		
Andersson (2007)	Sweden	1998, SP	8		3,017	15,297
Atkinson and Halvorsen (1990)	US	1986, RP	1	5,521		
Beattie et al. (1998)	UK	1996, SP	4		1,510	17,060
Bhattacharya et al. (2007)	India	2005, SP	1	150		
Blomquist (1979)	US	1972, RP	1	1,832		
Blomquist et al. (1996)	US	1991, RP	4		1,434	7,170
Carthy et al. (1999)	UK	1997, SP	4		4,528	5,893
Corso et al. (2001)	US	1999, SP	2		3,517	4,690
Desaigues and Rabl (1995)	France	1994, SP	6		1,031	23,984
Dreyfus and Viscusi (1995)	US	1987, RP	1	4,935		
Ghosh et al. (1975)	UK	1973, RP	1	1,901		
Hakes and Viscusi (2007)	US	1998, SP	5		2,396	6,404
	US	1998, RP	6		2,288	10,016
Hojman et al. (2005)	Chile	2005[c], SP	1	541		
Hultkrantz et al. (2006)	Sweden	2004, SP	2		2,192	5,781
Iragüen and Ortúzar (2004)	Chile	2002, SP	1	261		
Jara-Diaz et al. (2000)	Chile	1999, SP	1	4,555		
Jenkins et al. (2001)	US	1997, RP	9		1,350	4,867
Johannesson et al. (1996)	Sweden	1995, SP	4		5,798	6,981
Jones-Lee et al. (1985)	UK	1982, SP	1	4,981		
Kidholm (1995)	Denmark	1993, SP	3		898	1,338
Lanoie et al. (1995)	Canada	1986, SP	2		1,989	3,558
Maier et al. (1989)	Australia	1989[c], SP	6		1,853	5,114
McDaniels (1992)	US	1986, SP	3		10,131	36,418
Melinek (1974)	UK	1974[c], RP	1	881		
Persson et al. (2001)	Sweden	1998, SP	1	2,551		
Rizzi and Ortúzar (2003)	Chile	2000, SP	1	486		
Schwab Christe (1995)	Switzerland	1993, SP	1	1,094		
Vassanadumrongdee and Matsuoka (2005)	Thailand	2003, SP	2		3,208	5,458
Viscusi et al. (1990)	US	1991[c], SP	1	11,091		
Winston and Mannering (1984)	US	1980, RP	1	2,315		

VSL estimates in US$ 2005. Values transformed using purchasing power parities (PPP) and consumer price indices (CPI) from http://stats.oecd.org, 09/02/07. (For Chile and Thailand PPP and CPI from http://www.imf.org/external/data.htm were used.)
a: Many of the VSL estimates are from de Blaeij et al. (2003).
b: Several studies contain more estimates than stated here. When available, "preferred" values have been used.
c: Refers to year of study rather than data, since the latter not available.

Table 2: Policy VSL in use, in US$ 2005 ($\times$1000)[a]

Country	Source	Official value based on...	VSL
New Zealand	Trawén et al. (2002)	SP study (Miller and Guria, 1991).	1,790
Norway	Trawén et al. (2002)	meta-analysis (Elvik, 1993).	2,051
Sweden	SIKA (2005)	SP study (Persson and Cedervall, 1991).	1,996
United Kingdom	UK DoT (2007)	multi-stage approach (Carthy et al., 2000).	2,308
United States	US DoT (2002)	meta-analysis (Miller, 1990).	3,309

VSL estimates in US$ 2005. Values transformed using purchasing power parities (PPP) and consumer price indices (CPI) from http://stats.oecd.org, 09/02/07.
a: In this table we only show examples of VSL used in policy. For other policy values in use of preventing a fatality see Trawén et al. (2002), Bristow and Nellthorp (2000), and Boiteux and Baumstark (2001).