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Statistical Analysis of Value-of Life Estimates Using Hedonic Wage Method

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Abstract

This research analyses the variability of value-of-life estimates. We find evidence that this variability may in large part be explained by differences in the methodologies used to estimate the value of life. Income elasticity for the value of life is found to be in the 1.07 to 1.72 interval, a result similar to that obtained by Miller (2000) and de Blaeij et al. (2000). We also analyze the relationship between the value of life and the initial probability of a fatal accident, often used in the literature as a proxy for the variation in the probability of death. We show that although the willingness to pay may increase with the probability of death, the value of life will decrease with this probability if the initial probability is less than one half. We draw conclusive evidence of such a relationship from a sample of 38 value-of-life estimates based on the hedonic-wage method.

Keywords: Value of life, willingness to pay, probability of death, estimate, methodology.

Résumé

Cette recherche analyse la variabilité des estimations de la valeur de la vie. Nous vérifions que cette variabilité peut être expliquée, en grande partie, par des différences dans les méthodologies utilisées dans l'estimation de la valeur de la vie. L'élasticité revenu de la valeur de la vie estimée se situe dans l'intervalle 1,07 et 1,73, un résultat similaire à ceux obtenus par Miller (2000) et Blaeij et al. (2000). Nous analysons également la relation entre la valeur de la vie et le niveau de la probabilité d'accident initiale, souvent utilisée comme approximation de la *variation* de la probabilité de décès. Nous montrons que même si la volonté à payer augmente avec la probabilité de décès, la valeur de la vie décroît en fonction de cette probabilité, si la probabilité initiale est inférieure à ½. Nous mettons en évidence une telle relation en utilisant un échantillon de 38 estimés de la valeur de la vie obtenus d'études utilisant la méthode hédonique d'estimation des salaires.

Mots clés : Valeur de la vie, volonté à payer, probabilité de décès, estimation, méthodologie.

1 Introduction

Of the many topics in cost-benefit analysis (CBA), no other is more controversial than the value to be placed on lives saved in assessing the economic viability of a project. The controversy has spawned an impressive volume of articles, both theoretical and empirical. How this value should be defined economically is still an open question and how it should be measured remains a real methodological problem. After approximately forty years of debate in the economic literature, a reasonable consensus has emerged that the willingness to pay for a reduction in the probability of death can be used to infer the value society places on saving one human life. However, it is too seldom pointed out that the concept needed is not the value placed on saving one's own life but rather that placed by society on saving one anonymous, statistical life. This somewhat subtle distinction sidesteps many ethical questions that would otherwise arise when evaluating a human life. As Drèze (1962), Schelling (1968) and Mishan (1971) noted, the monetary equivalent chosen must reflect the preferences of the individuals affected by the project being evaluated and will thus implicitly involve the trade-off between risk and wealth which is common in everyday life. Although the willingness-to-pay concept is well defined, its measurement poses some important empirical challenges that economists have tried to meet, albeit with limited success.

To our knowledge, 68 estimations of the value of life (VOL) have been performed in the economic literature's universe of 61 empirical studies.[1] The results obtained range from \$336,000 to \$33.6 million CAN.[2] More than ever, these results tend to diverge rather than converge. From a practitioner's standpoint, this frustrates any attempt to

[1] ECONLIT, PROQUEST and IDEAS databases were used to complement the estimations reported in Viscusi (1993) and Lanoie (1998). The period covered is from January 1973 to August 2001.

[2] All monetary values where actualized to 2000 Canadian dollars. The authors used the same procedure as Miller (2000), first converting these values to Canadian dollars using the exchange rate for the year of the experiment and then discounting these values back to the year 2000.

validate the desirability of projects, since many decisions depend crucially on the values used. Even if a sensitivity analysis is performed, it will, in many cases, fail to produce a clear-cut rank ordering of projects. Before settling for an educated-guess value to evaluate alternatives in practice, we should at least attempt to understand the source of this variability in results. As observed in Dionne and Lanoie (2002), government agencies around the world apply very different estimates in evaluating their projects.

In the introduction to his literature review, Viscusi (1993) discusses at length what factors, other than those arising from random sampling, might explain this variation. Viscusi points to a number of drawbacks in the methodologies employed in empirical experiments which might, in part, explain this variability. We propose to start by testing for these qualitative differences within a general statistical framework designed to identify accurately the sources giving rise to the variations observed in the literature. Positive results would be of great help to practitioners who turn to the literature in search of a standard value upon which to base their final decision. These results might also shed some light on the methodological framework to be preferred in assessing this value in future experiments. Our second objective is to verify how the properties of value-of-life and willingness-to-pay estimates relate to each other. This is of great importance, since this relationship may be one of the principal sources of the variability we observe when there is no detailed empirical analysis.

The usual technique used to infer the VOL is to estimate, in a first step, the willingness to pay (WTP) for marginal changes in the probability of death and next to find the value of one life saved in a homogenous group with this WTP.[3] The problem

[3] Often attributed to the empirical study of Thaler and Rosen (1976) but already discussed in theoretical papers by Drèze (1962), Schelling (1968) and Mishan (1971). It should be emphasized here that the probability of an accident is used to measure the level of risk. Of course, this is not a measure of pure risk in the sense of a mean preserving spread or of a variance, although the level of risk or the variance may be affected. In fact, we mainly refer to a first order stochastic dominance when p decreases (see Dachraoui et al [2000] for a longer discussion of this issue).

is that although the interpretation of the actual calculation is correct in terms of the CBA (albeit with tight restrictions on the WTP aggregation[4]), it might be that we are, in fact, estimating this value with a linear value-of-life approximation suitable only for small changes in probability levels. Since the willingness to pay is usually modeled as a non-linear function of the probability of death, one may wonder just how appropriate this estimation really is.

Another interesting question which has not yet been thoroughly explored concerns VOL properties as they relate to change in the initial level of probability of death. Indeed, we would expect that, since one individual is willing to pay more to reduce a probability when it is higher, then society as a whole should accept to place a higher value on saving a life when the initial probability is higher. As Viscusi (1993) noticed, empirical studies with a higher average probability of death in their sample seem to obtain lower value-of-life estimates. This factual observation may come from the heterogeneity of those studies; and countless more or less relevant reasons could be invoked to explain this heterogeneity unless we carefully tackle the question empirically as well as theoretically.

The paper is organized as follow. Section 2 presents the theoretical implications of moving from the WTP for a marginal reduction in the probability of death to the value of life using the common approximation applied in the literature. Section 3 presents a short discussion of the methods used to estimate the VOL, with particular attention to the hedonic-wage method pioneered by Thaler and Rosen (1976) and to the methodological drawbacks later discovered in the application of this method. Section 4 presents a statistical framework designed to pinpoint the factors affecting the value of life and to estimate the potential effect of methodological choices on the variability of the results obtained. Section 5 analyses the estimation results, and finally, Section 6 provides concluding remarks and suggestions for further research.

[4] See Drèze (1992) for a discussion of aggregation problems.

2 From WTP to Value of Life

Following the work of Drèze (1962) and Jones-Lee (1976), the WTP to reduce the probability of a fatal accident is derived by total differentiation of an expected state-dependent utility function (SDUF) of wealth, $EU_I(w)$ on two states of nature ($I = D, L$), namely death and life.[5] Keeping the level of expected utility constant, the total differentiation of EU_I with respect to initial wealth (w) and the initial probability of a fatal accident (p) yields $\phi(p, w)$, which is the marginal rate of substitution between wealth and the initial probability of death or the usual expression for the marginal WTP for a small variation in the probability of death:[6]

$$\phi(p,w) = \frac{dw}{dp}|_{dEU=0} = \frac{U_L(w) - U_D(w)}{EU_I'} > 0 \tag{1}$$

where $EU_I' = pU_D'(w) + (1-p)U_L'(w)$. Differentiating (1) with respect to p yields

$$\phi_p'(p,w) = \frac{d^2w}{dp^2}|_{dEU=0} = -\frac{[U_L(w) - U_D(w)]\,[U_D'(w) - U_L'(w)]}{\left(EU_I'\right)^2} \gtreqless 0 \tag{2}$$

given that $U_L'(w) \gtreqless U_D'(w)$. A similar relationship arises for the derivative of $\phi\,(p,w)$ with respect to wealth. The sign of $\phi_w'(p,w)$ will depend again on the marginal utilities in both states. No a priori conjecture can be made concerning the relative magnitude of these marginal utilities; and there can be no clear prediction of how the WTP will relate to either the level of the initial probability of death or the initial level of wealth. However,

[5] Here wealth is independent of both states. We make the assumption that individuals are fully insured against the loss of wealth. Alternative modelling, to allow for change in wealth would not alter the analysis undertaken here. The level of insurance coverage will be taken into account in the empirical analysis.

[6] See Linerooth (1979) and Beladhji (1994) for a discussion of this general theoretical model and the underlying sensitivity of the model's assumptions on its prediction.

it is often accepted in the literature that $U'_L(w) > U'_D(w)$ for all w, so WTP is claimed to be an increasing function of p and w . We must then estimate the value of a statistical life (VOL) from the marginal WTP estimates. Usually, the $VOL = WTP/\Delta p$, which means that the VOL must take into account the effect of the project on the variation of the probability of death (Persson et al., 2001). Consider the following example (Dionne and Lanoie, 2002). A society of 8 million citizens has a traffic fatality probability of 1/10,000. So, 800 persons, on average, die each year in road accidents. A new project that may reduce the number of persons killed by 160 is being considered. So, the probability of death would become 0.8/10,000 and the correponding variation would be 1/50,000. Suppose that the average WTP of the individuals in the population for this project is \$100; the implicit value of a statistical life would then be 5 million $\left(\frac{100}{1/50{,}000}\right)$ and not 1,000,000 $\left(\frac{100}{1/10{,}000}\right)$! In the literature and in practice, the common approach for deriving the statistical value of life from the marginal WTP is to use the approximation $\frac{1}{p}\phi(w,p)$ as a measurement of the value of life, assuming $(w,p) = (\overline{w},\overline{p})$, the average numbers in the population affected by the risky situation. The idea is, therefore, that they are considering a policy such that $\frac{1}{p}$ individuals are concerned about the risky situation and not the number of lives saved by the project[7].

So, empirically, particularly in labor studies, we often rely on the following expression of the VOL:

$$V(\overline{p},\overline{w}) = \frac{1}{\overline{p}}\phi(\overline{p},\overline{w}) \tag{3}$$

where $\overline{p}$ is the mean of the probability of death, $\overline{w}$ is the mean of wealth estimated by income in a given population for which we are seeking to estimate value for saving one life, and $\phi(\overline{p},\overline{w})$ is accordingly the estimated marginal WTP.

[7]However, another roughly equivalent interpretation is that an individual facing probability p is willing to pay approximately $\frac{1}{p}\phi(w,p)$ to reduce his probability of death to 0, which is rarely the output of a project.

To look at the effect of a variation in the initial level of the probability of death on the VOL and to understand certain results in the literature, we differentiate (3) with respect to $\overline{p}$ and evaluate the derivative at the mean probability of death:

$$V'(\overline{p},\overline{w}) = \frac{1}{\overline{p}}\phi'(\overline{p},\overline{w}) - \frac{1}{\overline{p}^2}\phi(\overline{p},\overline{w}) \tag{4}$$

where $\phi'(\overline{p},\overline{w}) \equiv \frac{\partial\phi}{\partial\overline{p}}$.

In order to characterize the sign of this derivative, given that the second part on the r.h.s. of (4) is negative and the first part is ambiguous and depends on the magnitude of the marginal utilities of wealth in each state, we need to find a condition such that, for example,

$$\frac{1}{\overline{p}}\phi'(\overline{p},\overline{w}) - \frac{1}{\overline{p}^2}\phi(\overline{p},\overline{w}) < 0 \tag{5}$$

without having to make an assumption about marginal utilities in each state. We first rewrite the above inequality as:

$$\overline{p}\frac{\phi'(\overline{p},\overline{w})}{\phi(\overline{p},\overline{w})} \gtreqqless 1$$

and therefore we have as an intermediary result that if and only if the elasticity of the WTP for change in the initial probability is greater (smaller) than one, then the value of life is increasing (decreasing) in the probability of death. We may look further to find a sufficient condition for (5) to be true. Substituting the general expression of $\phi'(\overline{p},\overline{w})$ and $\phi(\overline{p},\overline{w})$ from (1) and (2) to further investigate this inequality gives

$$-\frac{\frac{[U_L(w)-U_D(w)]\left[U_D'(w)-U_L'(w)\right]}{EU_I^2}}{\frac{U_L(w)-U_D(w)}{EU_I'}} \gtreqless \frac{1}{p} \tag{6}$$

$$\frac{[U_L'(w)-U_D'(w)]}{EU_I'} \gtreqless \frac{1}{\overline{p}}. \tag{7}$$

Using $EU_I' = \overline{p}U_D'(w) + (1-\overline{p})U_L'(w)$ and substituting in (7) yields

$$\frac{[U_L'(w)-U_D'(w)]}{\overline{p}U_D'(w)+(1-\overline{p})U_L'(w)} \gtreqless \frac{1}{\overline{p}}.$$

Then a necessary and sufficient condition for $V'(p)$ to be negative is

$$\left[U_L'(w)-U_D'(w)\right] \leq \frac{1}{\overline{p}}\left[\overline{p}U_D'(w)+(1-\overline{p})U_L'(w)\right]. \tag{8}$$

Proposition 1 *A sufficient condition for the approximated value of life $V(\overline{p},\overline{w})$ to be a decreasing function of the initial probability of death, regardless of the assumption made about the magnitude of the marginal utilities in both states, is that $\overline{p} \leq \frac{1}{2}$.*

Proof. Rearranging (8) yields $\frac{U_D'(w)}{U_L'(w)} \geq 1 - \frac{1}{2\overline{p}}$ for $V_p'(\overline{p},\overline{w})$ to be negative . Since the l.h.s is always positive a sufficient condition is that $\frac{1}{2\overline{p}} \geq 1$ which immedialety leads to $\overline{p} \leq \frac{1}{2}$. ■

Consequently, even if the marginal WTP is increasing in the initial probability, this effect is not large enough to compensate for the downward effect of $\frac{1}{\overline{p}}$. The fact that we are dividing by the average probability (a small number) leads the overall effect to be negative even though individuals are willing to pay more marginally. There exists a threshold probability p^* where, depending on the amplitude of $U_L'(w) - U_D'(w)$, the approximated value of life will be increasing in the initial level of the probability. It is clear, from Proposition 1, that this p^* should be greater than one half. This result is thus puzzling from a welfare point of view.

In Elvik (1995) a similar counterintuitive result was found: the VOL is inversely related to the initial level of the fatal-accident probability across studies. Earlier, Viscusi (1993) noted that studies using the labour market as an experimental setting tend to find a lower VOL when they use fatal-accident probabilities from the Society of Actuaries which are more than 10 times higher than mean fatality rates in the U.S. As Viscusi noted, labour market imperfections and biases in the perception of risks and probabilities may explain this inverse relationship. Here, we suggest that the result may also be a methodological problem related to the use of the initial probability of accident rather than the variation in the probabilities associated with the project. Thus, many effects may come into play here and, since we are discussing a marginal concept, small variations lead (marginally) to possibly large differences in the value-of-life estimates.

However, from the results of contingent studies, de Blaeij et al. (2000) show that the initial level of the fatal-accident probability is positively related to the VOL. Contingent studies may more effectively detect the approximation bias since there are wider variations in probabilities of death when the individual states his WTP; this personal WTP is less sensitive both to marginal changes and to the initial level of the probability of death. If an individual is willing to pay \$100,000 to make a 10/100 reduction in the probability of death, the value of life will not be calculated using the mean probability but rather the effective change, and the value calculated would be \$1,000,000. The positive relationship found by these authors may therefore be attributable to the positive relationship between the WTP and the level of the probability of death. The application of the hedonic method is more subject to the problem analyzed in this article.

3 Review of the Hedonic Wage Method

According to Thaler and Rosen (1976), the labour market offers a unique experimental setting for observing the probability of fatal accident-wage trade-off. Workers are willing to accept additional risks of death in the workplace if they can obtain a monetary compensation affording them the same expected utility level. Much like workers, firms may manage workplace risks for which they are willing to pay workers a wage premium. This premium is bounded by the firm's capacity to meet the cost of providing additional workplace security while maintaining the same profit maximizing level. Therefore, an equilibrium point is obtained at the marginal price of the fatal-accident-probability level. Under classical labour market assumptions of efficiency, this equilibrium price is equal to the WTP and the willingness to accept (WTA) on the part of the firm and the worker, respectively.

This equilibrium price can be obtained by computing a classical wage equation augmented by results obtained from measuring the probability of a fatal workplace accident in a sample of workers facing different risks of experiencing a fatal workplace accident. The workers' mean WTP for a marginal reduction of this probability can be retrieved by using the coefficient of the fatal-accident-probability variable in the wage equation. From the estimated coefficient, we can derive the implicit VOL, using the approximation method discussed above.

Measurement bias—As can easily be seen, the fatal-accident-probability variable inserted in the wage equation plays a crucial role in estimating the WTP. This variable must, therefore, be carefully measured so as to obtain the fatal-accident probability actually taken into account when the workers and the firm made their decision. However, as workers rarely have a precise idea of these probabilities, they approximate their values by using a multidimensional concept called risk. This is a contextual concept based on prior information about danger in the workplace (Benjamin & Dougan [1997]).

What researchers want to do is obtain a measurement of the perceived fatal-accident probability which is perfectly congruent with what the worker actually perceives. Since, in many situations, no such measurement is available, perception of the fatal-accident probability will tend to be biased. In the United States where most of the studies have been conducted (23/38), authors often use the rates for fatal industrial or occupational accidents reported by different agencies such as the Bureau of Labor Statistics or the Society of Actuaries (Thaler & Rosen, 1976; Arnould & Nichols, 1983). These rates are generally defined as the number of workplace deaths per 10,000 workers and aggregated on an industry or occupational level. As this approach may not adequately reflect the risk of fatal accident faced by a particular worker, it may in turn undermine the accuracy of the rates reported.[8]

Some authors constructed proxied measures of the perceived probability of a fatal accident (Marin & Psachalopoulos, 1982; Abaresheini & Marin, 2000). Apart from bias due to direct measurement of the variable, individuals are known to overestimate low probabilities and underestimate high probabilities as found by Lichtenstein et al. (1978) and confirmed by many others (Benjamin and Dougan, 1997; Viscusi and Hakes, 1997). Therefore, constructed measures of perceived probability of a fatal accident may fail to take into account this common phenomena accurately. More sophisticated models involving simultaneous-equation estimation have been proposed and used to obtain a proxy of the perceived fatal accident probability that is not correlated with the random error term of the wage equation (Garen, 1988). Finally, some researchers conduct interviews to collect information about the workers included in the sample used to estimate the wage-equation: these workers are asked direct questions about their perceived fatal-accident probability (Gegax, Gerking, and Schulze, 1991; Lanoie et al., 1995). This procedure is rare in the literature, since it is less costly and easier to use official data. But note

[8] An industry based rate will not make a difference between the risk faced by a mine worker and an office clerk on the mine site. However, these two workers face fairly different probabilities of a fatal accident. Another example would be the machinery worker in a refinery and another one working for a textile company. No reasonable equivalence can be unambiguously made about the risk they both face.

that official fatal-accident rates may affect the outcome of the estimation, namely the mean WTP used to calculate the VOL. We may want to take a careful look at how the characteristics of the fatal-accident-probability variable used in studies condition the distribution of results, as this may in part explain the variance in VOL results.

Specification bias—Although a coefficient's sensitivity to the variables included in a specification may not be unique to the hedonic-wage method, it here takes on a particularly crucial significance given the need for robustness in estimating the implicit value of life. Failure to include regressors theoretically linked and statistically correlated to the WTP as well as to wage factors may distort the VOL estimate. In examining the model estimated by these authors, our goal is not to construct a perfect model but to isolate the effect of specific excluded regressors which we believe to be correlated with the WTP. For example, union membership is one of the regressors that may affect the WTP. Competing theories exist in the literature, with their own empirical evidence about the effect of unionism on the WTP.[9]

Arnould and Nichols (1983) first noted that the specifications proposed by Thaler and Rosen (1976) implicitly assumed full compensation and thus failed to take any account of what effect variations in work-injury compensation might have on determining the WTP. As an accident's expected cost decreases with the generosity of compensation schemes, workers should be willing to receive less for accepting the accident risk. Since these compensation schemes differ form one firm to the next (and from state to state) in countries such as the United States, Arnould and Nichols (1983) argue that workers compensation schemes should be taken into account in the augmented wage equation.

The probability of a non-fatal accident is correlated with the probability of a fatal one and this may affect the WTP for a reduction in the probability of a fatal accident. If these two contrasting probabilities are positively correlated, failure to include them both may lead us to overestimate the WTP by according too much weight to the probability

[9] See Elliot and Sandy (1996) for a treatment of those competing theories.

of a fatal accident. But if these two probabilities are nearly colinear (i.e. each can be expressed as a linear combination of the other), including them as a variable may lead to serious problems of inference, as the model will not be able to differentiate between the fatal and non-fatal probability effect on wages. This has prevented many researchers from including such a variable in their calculations. Problems of compatibility between different sets of measurement for fatal and non-fatal accidents have also raised doubts about the desirability of including such a variable (Viscusi, 1993).

Sample selection bias—The sample of workers used should be representative of the population to which the WTP will be applied. Constructing a representative sample is more difficult than one may think when it comes to measure the WTP for a reduction in the fatal-accident probability. For example, the fatality rates reported by the Society of Actuaries —used among others by Thaler and Rosen (1976) and Arnould and Nichols (1983)—relate to high-risk occupations and consequently yield average fatality rates 10 times higher than normal. This may seriously affect the VOL, as we have seen in theory. Moreover, low risk averse individuals who freely select a high-risk job may occasion a lower VOL than would be predicted by the conceptual framework featuring average individuals who face choices between low-risk and high-risk jobs. The question here is the plausibility of assuming the worker's freedom to choose an acceptable level of risk and indirectly express the willingness to accept (or pay) for a higher (lower) probability of a fatal accident.

These three potential sources of bias may possibly explain the high variance of the results found in the literature. Added to this, the approximation problem outlined above may also play a part in increasing the variance of results, since small differences in accident probabilities at the margin can produce large differences in the VOL estimates.

4 Statistical Framework

We may think of the process generating these estimates of the value of life (V_i) from a study i as being given by the following functional form:

$$V_i = \alpha_0 + \alpha_1 p_i + \alpha_2 w_i + x_i' \delta + \varepsilon_i, \tag{9}$$

where $\alpha_0, \alpha_1, \alpha_2$ are parameters and δ is a $K \times 1$ vector of parameters for the vector of other characterics of each study i, x_i. The error term ε_i may be left unspecified for now. As discussed in the previous section, we may include the average probability of death p_i as part of the arguments along with the average income w_i. Other methodological characteristics entering the control vector x_i may consist in dichotomous variables (fixed effects): injury/accident probability or inclusion of the compensation variable or endogenous treatment of the risk variable.

As unobserved characteristics of the studies that may affect the VOL and its variability, we may think of the variance in that process as heteroscedastic: each study may have a different variance since the precision with which the VOL was measured would depend on the sample size and the rigour of the researcher's method. If, instead, the VOL was estimated by replication of the same model on different samples of the population of workers, then the variance of estimates observed would be fully accounted for by sampling error. If so, we could then calculate the weighted means of the values found in the studies (using sample size as weights) and obtain a more efficient estimator of the value of life (Cooper and Hedges, 1994). But we know that, since these studies differ in many ways, the observed variability cannot be assumed to be solely the result of sampling error. So if we want to explain the variability of results (and perhaps reduce their slipperiness), we need to condition the distribution of results on the characteristics of the different studies: namely, the representativity of their sample and their relative success in handling the possible biases mentioned in Section 3.

Since we have a relatively small sample of estimates, we must be prudent in inferring the determinants of this distribution. We have therefore limited the number of explanatory factors in order not to lose too many degrees of freedom for testing our hypotheses. Furthermore, there is the risk of violating assumptions about normality and i.i.d errors. Our investigation will use three estimation techniques, each dedicated to different degrees of the problems associated with classical OLS assumptions. Since common diagnostic tests rely on asymptotic properties, we used an indirect method to assess the possibilities mentioned.

We first estimated the parameters with the feasible generalized least squares (FGLS) method using White's (1980) heteroscedastic standard errors. We then applied a procedure (Robust) enabling us to check for the effect of influential data points. We weighted the different observations based on their plausibility. The problem with this procedure is finding a rule in order to estimate these weights. We used Huber (1964) weights until convergence was attained and then further applied biweights (Beaton and Tuckey, 1974).[10] Huber weights have trouble dealing with extreme outliers while biweights have trouble attaining convergence, because they are more sensitive to outliers. The above approachs should enable us to assess the impact of outliers on the estimates. However, this gain in dealing with influential data points is obtained to the detriment of the efficiency of the estimators. To the extent to which influential data points do not change the parameter estimates, we shall resort to FGLS estimates.

Another way is to use semiparametric techniques like the Least Absolute Deviation (LAD) estimator. This estimator does not assume any distribution for the error term except that the median is equal to zero and thus is less sensitive to influential data

[10] See Stata version 6.0 manual for description of the procedure. Biweights apply a more important downweighting than Huber weights on the observations that are far from the mean, eventually discarding those observations.

points. The LAD estimator attains efficiency gains only if the true distribution of the error term is not normal. Otherwise, the OLS estimator is the best linear unbiased estimator. Furthermore, estimating the covariance matrix for the LAD estimator is more troublesome, particularly in small samples (Horowitz, 1992).

The most reasonable form of the dependent variable seems to be logarithmic since an histogram of its unconditional distribution is closest to a log-normal distribution. By taking the logarithm we obtain that the errors may be approximated by the normal distribution. We also use the same form of the dependent variable with the other two estimation techniques, although this is not important for the LAD estimator which does not make any distributional assumption.

4.1 The Data

The quantitative variables used are the sample selection variables of the different studies, namely the average probability of a fatal accident and the average after-tax income implied by the data. We include the average income of the sample to control for income effects which have been shown to positively influence the results (Bowland et al., 1998; Miller, 2000; de Blaeij et al., 2000).[11]

[11] However, these authors use country income levels, namely GDP per capita, in order to account for such an effect. Given that samples used in the studies may not be representative of the total population (Viscusi, 1993) we use the average income level in the sample of the studies in order to account for such effects.

Table 1 Descriptive Statistics

Variable	Definition	Mean	Std. Dev.
VOL estimates	Million, \$CAN, 2000	8.65	6.68
Average income	(000'), \$CAN, 2000	26.11	8.23
Average probability of death	Probability $\times$ 10,000	2.13	2.42
Nature of probability measure	:=1 if objective, :=0 if not	.87	.34
Union membership effect	:=1 if union, :=0 if not	.42	.50
Compensation for injury effect	:=1 if included :=0 if not	.24	.43
Non-fatal accident prob. effect	:=1 if included :=0 if not	.55	.50
Endogenous probability effect	:=1 if included :=0 if not	.18	.39
Publication in type A periodicals	:=1 if type A, :=0 if not	.42	.50
United States study	:=1 if U.S :=0 if not	.58	.50

Sample size (N=38)

We include the average probability of death in the sample for each estimate in order to gain insight into the relationship we are studying. Figure 1 shows the observed relationship between the value-of-life estimates in the hedonic-wage method and the average probability of death in the sample the authors used to make their estimates. A negative trend seems to emerge confirming our theoretical predictions.

In Table 1, we present the descriptive statistics of the studies for which we have complete data. The average of VOL estimates is \$8.65 millions with a large standard deviation (\$6.68 millions) or a range from 0.37 million to 23.45 millions. Possible wealth effects may arise since the range of average mean income is also large, from \$4,400 to \$43,494. We observe a similar dispersion for the average probability of death in the studies retained, with a dispersion from 0.3/10,000 to 10/10,000.

Figure 1 here

Dichotomous variables are introduced to catch the fixed-effects arising from any specification bias. For example, we may want to measure that including or excluding job-injury compensation may lead to a fixed-effect on the WTP. We can test for this assumption by using dichotomous variables in the specification for the value-of-life equation. The same comment may apply to other specification effects that we shall henceforth call methodological effects. Differences in methodology, especially those dealing with biases, are undeniably important. While 87% of authors used an observed and published probability of death, only 24% of them made any attempt to account for job-injury compensation in their estimates. Arnould and Nichols (1983) showed that this omission strongly affects WTP estimates and, consequently, the VOL. Reflecting the thorniness of including the job-injury probability, only 55% of the studies included any such measurement. Only 18% of the authors took into account the possible endogeneity of the probability of death. The fact that more than 58% of the studies come from the United States is partly explained by the ready availability of official fatality rates and labour market data in that country. We did also control for the union membership effect.

Finally, we included proxies for the quality of publications to test their impact on the magnitude of the value-of-life estimates. We used the publication index compiled by the Department of Research of a well known university, mainly based on the Social Sciences Citations Index. Basically, this index uses a citation count to proxy the quality of a periodical. The highest possible score is A. We defined a dichotomous variable which would assume the value 1 if the study was drawn from a quality A periodical or 0 if not.

It is possible to test for a publication bias by estimating the strength of this variable's impact. But a higher or lower statistical effect may also mean that these studies were chosen by those periodicals because they systematically seek results that differ from those in other periodicals. Since we have no means of assessing the validity of this hypothesis, we shall keep it in mind while sticking with the quality explanation. Bowland and Beghin (1998) discuss a way of dealing with the publication bias which consists in performing a logit to estimate a study's probability of publication based on such factors as the year it was produced. Such a test can be performed only if there are enough unpublished and published articles available. In our case, only two unpublished papers have been found over the whole period, which precludes the use of this test.

5 Results

On a general basis, influential data points do not greatly affect the results, especially the relationship between VOL and the probability of death. The explanatory power of the different specifications is high, with adjusted R^2 ranging from 0.62 to 0.69 for the FGLS estimates. Using Robust estimates, the R^2 increases but we have to be careful since this estimation method has discarded some observations when using the biweights. Since the coefficients do not change significantly from one estimation method to the next, and since Robust estimates and LAD estimates are less precise, we concentrate on FGLS estimates for the analysis. The LAD estimates make the normality assumption acceptable. In fact, if the parametric estimates do not differ significantly from Robust and LAD estimates, this indicates that influential observations have no significant effect on estimations and only lead to a loss of efficiency. However, when results for some variables change significantly from one method to the next, we shall take these effects into consideration in the interpretation.

TABLE 2 RESULTS OF REGRESSION ANALYSIS*; Dependent variable: Log(VOL)

	FGLS			Robust			LAD		
Variables	A	B	C	A	B	C	A	B	C
Constant	-80.37	-65.4	-110.47	9.92	14.7	-122.38	-33.06	-7.94	-19.31
	(1.33)	(1.21)	(1.46)	(.23)	(.34)	(1.78)	(.28)	(.10)	(.14)
Year of publication	.04	.03	.05	-.002	-.005	.06	.02	.01	.01
	(1.36)	(1.21)	(1.46)	(.11)	(.23)	(1.8)	(.31)	(.14)	(.16)
Average income (log)	1.72	1.72	1.59	1.08	1.09	1.39	1.39	1.34	1.33
	(4.26)	(4.46)	(4.79)	(3.86)	(3.87)	(3.62)	(1.59)	(2.04)	(1.26)
Average probability of	-.2	-.23	-.23	-.24	-.25	-.21	-.23	-.25	-.24
fatal accident	(4.26)	(4.99)	(4.59)	(5.20)	(5.17)	(3.30)	(2.41)	(3.99)	(1.54)
Nature of probability	.86	.83	.73	-.29	-.22	.69	.25	.33	.33
measure	(1.79)	(2.04)	(1.78)	(.93)	(.69)	(1.63)	(.27)	(.35)	(.38)
Union membership	.04	-.04	.12	.11	.08	.18	.20	.20	.21
effect	(.16)	(.15)	(.43)	(.39)	(.27)	(.47)	(.43)	(.47)	(.41)
Compensation for	-.50	-.58	-.81	-.13	-.19	-.78	-.42	-.58	-.57
injury effect	(1.56)	(1.89)	(2.78)	(.47)	(.67)	(1.84)	(.84)	(1.11)	(.84)
Non-fatal accident	.31	.22	.29	.26	.22	.41	.18	.11	.14
probability effect	(1.25)	(.88)	(1.05)	(1.23)	(1.01)	(1.40)	(.46)	(.32)	(.29)
Endogenous	.90	.86	.66	1.22	1.16	.51	1.08	1.02	.98
probability effect	(3.22)	(3.50)	(2.01)	(4.26)	(3.98)	(1.23)	(1.76)	(3.68)	(1.44)
Publication in type	..	.53	.52	..	.20	.53	..	.25	.25
A periodicals	..	(2.0)	(2.08)	..	(.84)	(1.74)	..	(.57)	(.42)
United States study	..	..	.26	..	..	.36	..	..	.04
	..	..	(1.08)	..	..	(1.59)	..	..	(.10)
R-squared**	.62	.66	.69	.68	.72	.82	.46	.49	.49
F statistic (N=38)	12.85	12.47	11.49	8.43	7.12	4.18	..	..	..

Notes: *t-values are in parenthesis using White (1980) standard errors for FGLS estimates.

** R-squared for Robust method calculated from correlation between fit and observations.

5.1 VOL-Probability of Death Relationship

Our interpretation is mainly restricted to parameters from the FGLS estimates. What emerges from the estimates in Table 2 is the negative relationship predicted between the VOL and the average probability of death for all specifications. We therefore find strong evidence that the value-of-life estimates using the hedonic-wage method are negatively linked to the average probability of death in a given sample. This result is consistent with the observations made by Viscusi (1993) and the analysis performed by Elvik (1995) but it contradicts Miller's results (2000) which find the opposite relationship. However Miller used the country-level probability of death which may not reflect the heterogeneity of the sample used in the studies. Furthermore, we were not able to base our analysis on contingent valuation studies, which prevents us from comparing them with the results of de Blaeij et al. (2000).

The coefficient estimate for the probability of death is almost constant at -0.20 for all specifications. The implied effect is large, since a 1/10,000 increase in the average probability of death in a sample decreases the estimate of the VOL by 20%, which, at the average VOL level, is \$1.73 M. This argues against using the approximation method to estimate the VOL, if the approximation works from the initial probability of death rather than from the variation in this probability, as it should.

5.2 VOL-Income Effect

As expected and found in earlier studies, the VOL increases along with the sample's average income. The implied income elasticity in the range of 1.08 to 1.72 is similar to that found by Miller (2000). Wealth effects are thus an important element in explaining variations in results. In terms of economic policy, this highlights the need to be very cautious in choosing the VOL, as it may reflect the characteristics of the population under study. Moreover, as Viscusi (2000) notes, this introduces some important equity questions: It would suggest that higher values should be used when the population under study enjoys higher average wealth, so their projects are more likely to be approved. This result, as Miller (2000) notes, also has important implications for international agencies planning projects in developing countries.

5.3 VOL-Methodological Factors

First of all, it is important to note that the year of the study does not seem to have any clearly significant impact on the VOL estimates, which tempers suspicions about a publication bias.

Another important result indicates that using an objective probability-of-death measurement will increase the VOL on average. This result could be considered as a confirmation of the Lichtenstein et al. (1978) empirical regularity suggesting that individuals overestimate lower probabilities and obtain an upwardly biased VOL; for, as discussed above, the probability measurement has a negative impact on the VOL. However, this interpretation is not clearly apparent in the model, as the variable in question could capture other unobserved characteristics of studies using an official probability-of-death measurement.

Including the union effect does not seem to have any influence on VOL estimates. This could be a reflection of Elliot and Sandy's (1996) observation that there are any number of explanations for the union effect's influence on the WTP. We obtain an interesting result with the FGLS estimates: Compensation for job injuries seems to have a clear downward effect on the VOL, as predicted by Arnould and Nichols (1983). Expected compensation lowers the cost of an accident and, consequently, the willingness to pay to prevent it. This result should, however, be viewed with caution, as it seems to be very sensitive to influential observations.

Including the probability of an injury in the estimation does not seem to lead to a decrease in the VOL as predicted by many authors such as Viscusi (1993). A potential explanation is that the estimate of this effect lacks precision, since including such a variable often leads to problems of colinearity when estimating the VOL.

Another notable result shows that a simultaneity or measurement bias (depending on the viewpoint adopted) will have a downward effect on VOL estimates. When an endogenous model is used to account for the simultaneity between the WTP and the probability of death, authors, on average, find a higher WTP and consequently a higher VOL. This revealing effect must either lead us to question the results or acknowledge the weight of the simultaneity bias. Further investigation is needed to fully determine the nature and significance of this effect.

Estimates published in type A periodicals seem to be 50% higher than those published in less cited periodicals. Although interesting, this result does not confirm any publication bias. It could be that the studies published in non-A periodicals have more serious methodological flaws and thus lead to estimates with a downward bias. But if publishers prefer results placing a higher value on life-saving benefits, this may lead to a selection bias which would prevent us from observing the true distribution of VOL estimates.

Methodological effects apparently do have a significant influence on the VOL estimate. But it is also apparent from our analysis that further investigation is needed, given that our results present no definite and direct picture of the factors influencing VOL estimates. This present exercise seeks merely to identify what future research methods must do to gain a better understanding of the factors generating the enormous variability in the values obtained in the literature.

6 Conclusion

This paper has investigated the validity of results published in the VOL literature using the hedonic-wage method. Perhaps the most important result found is the conclusive evidence that the VOL does not behave like the WTP with regard to the probability of death if one uses the common approximation adopted in the wage premium literature. We, in fact, find that the VOL is a decreasing function of the death-probability measurement. We also show (theoretically) that this result does not conflict with the potentially positive relationship between the WTP and the probability of death. But it does cast doubt on using the approximation method to derive the VOL from the WTP when it is based on the initial probability of death instead of its variation, as done in the hedonic-wage literature. If we still believe that a population facing a higher risk may be willing to pay more to save one life, we may want to reconsider current applications of the approximation method.

In another vein, we find that income effects do carry substantial weight, a result previously confirmed by all authors who performed a similar analysis (Miller, 2000; de Blaeij et al., 2000; Bowland and Beghin, 1998). We obtain income elasticity values that stand between 1.07 and 1.72.

Methodological factors do have their effects on the VOL estimates. However, it will take further research on these issues to gain a better understanding of their meaning for the practitioner who consults the literature to choose estimates for application on the ground.

It is perhaps even more urgent to underscore the need to be more concerned about what practitioners need to get from the literature. Impact studies have their role to play in analyzing the effectiveness of projects but they do not solve the dilemma of finding a range of plausibly relevant values of life. Many have suggested using cost-effectiveness analyses that measure in terms of cost per life saved. Yet, although this procedure could be used to rank projects, it will not tell us what minimum cost-per-life-saved value will make the project beneficial and so it does not remove the need for a value-of-life estimate. Contingent valuation can be used to reveal the WTP for non-marginal change in the probability of death, but it poses other serious challenges that have yet to be dealt with adequately. There is a greater need than ever to understand the determinants of VOL estimates and to pursue research for new methods of estimating this value.

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Figure 1

VOL-Probability of Fatal Accident Relationship Observed