Economic Valuation of Mortality Risk Reduction: Assessing the State of the Art for Policy Applications

PROCEEDINGS
BSession IIIB
The Search for Improved Mortality Risk Estimates for Use in Policy Analyses

A workshop sponsored by the
US Environmental Protection Agency=s
National Center for Environmental Economics
and National Center for Environmental Research

November 6, 2001
The Holiday Inn Silver Spring Hotel
8777 Georgia Avenue
Silver Spring, MD 20910

Edited by Abt Associates Inc.
4800 Montgomery Lane, Suite 600
Bethesda, MD 20814

Acknowledgements

Sections of this report indicated as Asummarizations@ were prepared by Abt Associates Inc. with funding from the National Center for Environmental Economics. Abt Associates wishes to thank Nicole Owens and Kelly Maguire of EPA's National Center for Environmental Economics.

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An Empirical Bayes Approach to Combining Estimates of the Value of a Statistical Life for Environmental Policy Analysis

--Working Paper*--

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*This is a working paper developed for the US Environmental Protection Agency National Center for Environmental Economics and National Center for Environmental Research's workshop, "Economic Valuation of Mortality Risk Reduction: Assessing the State of the Art for Policy Applications," held November 6-7, 2001 at the Holiday Inn Silver Spring Hotel in Silver Spring, MD.

An Empirical Bayes Approach to Combining Estimates of the Value of a Statistical Life for Environmental Policy Analysis

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* Acknowledgement: The authors thank David Higdon for comments on an earlier draft of this manuscript.

NOTE: DO NOT CITE WITHOUT THE PERMISSION FROM AUTHORS.

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Abstract

The article presents empirical Bayes pooled estimates of Value of a Statistical Life (VSL). Our data come from 45 selected studies published between 1974 and 2000, which contain 234 VSL estimates. We estimate that the composite distribution of empirical Bayes adjusted VSL has a mean of $6.3 million and a standard deviation of $3.7 million. We find that the overall mean VSL estimate is not greatly affected by the addition of new estimates from the past decade or by use of the empirical Bayes method. However, this method greatly reduces the variability of the VSL estimate. We also find that the pooled VSL estimates are sensitive to the choice of estimation method (contingent valuation estimates are lower than hedonic wage estimates), and study location (industrialized nations have different VSL).

Key words: Value of a Statistical Life (VSL), empirical Bayes estimate, environmental policy, health policy, contingent valuation method, hedonic wage method

JEL subject category number: J17, C11, I18, Q28

The value of a statistical life is one of the most controversial and important components of any analysis of the benefits of reducing environmental health risks. Health benefits of air pollution regulations are dominated by the value of premature mortality benefits. In recent analyses of air pollution regulations (U.S. EPA, 2000), benefits of reduced mortality risks accounted for well over 90 percent of total monetized benefits. The absolute size of mortality benefits is driven by two factors, the relatively strong concentration-response function, which leads to a large number of premature deaths predicted to be avoided per microgram of ambient air pollution reduced, and the value of a statistical life, estimated to be about $6.3 million[1]. In addition to the contribution of VSL to the magnitude of benefits, the uncertainty surrounding the mean VSL estimate accounts for much of the measured uncertainty around total benefits. Thus, it is important to obtain reliable estimates of both the mean and distribution of VSL.

EPA uses the value of a statistical life (VSL) to estimate the benefits of reducing premature mortality from exposure to pollution. The VSL is the measurement of the sum of society's willingness to pay (WTP) for one unit of fatal risk reduction. Rather than the value for any particular individual's life, the VSL represents what a whole group is willing to pay for reducing each member's risk by a small amount (Fisher et al. 1989). For example, if each of 100,000 persons is willing to pay $10 for the reduction in risk from 2 deaths per 100,000 people to 1 death per 100,000 people, the VSL is $1 million ($10 × 100,000). Since fatal risk is not directly traded in markets, non-market valuation methods are applied to determine WTP for fatal risk reduction. The two most common methods for obtaining estimates of VSL are the revealed preference approach including hedonic wage and hedonic price analyses, and the stated preference approach including contingent valuation, contingent ranking, and conjoint methods. EPA does not conduct original surveys but relies on existing VSL studies to determine the appropriate VSL to use in its cost-benefit analyses. The primary source for VSL estimates used by EPA in recent analyses has been a study by Viscusi (1992). Based on the VSL estimates recommended in this study, EPA fit a Weibull distribution to the estimates to derive a mean VSL of $6.3 million, with a standard deviation of $4.2 million.

We extend Viscusi's study by surveying recent literature to account for new VSL studies published between 1992 and 2001. This is potentially important because the more recent studies show a much wider variation in VSL than the studies recommended by Viscusi (1992). The estimates of VSL reported by Viscusi range from 0.8 to 17.7 million. More recent estimates of VSL range from as low as $0.1 million per life saved (Hammitt and Graham, 1999), to as high as $87.6 million (Arabsheibani and Marin, 2000). Careful assessment is needed to determine the plausible range of VSL, taking into account these new findings.

There are several potential methods that can be used to obtain estimates of the mean and distribution of VSL. In a study prepared under section 812 of the Clean Air Act Amendments of 1990 (henceforth called the EPA 812 report), it was assumed that each study should receive equal weight, although the reported mean VSL in each study differs in its precision. For example, Hammitt and Graham (1999) estimate a VSL of $12.8 million with standard error of $0.6 million, while Leigh (1987) reports almost the same VSL ($12.3 million) but with a much larger standard error ($6.1 million). As Marin and Psacharopoulos (1982) suggested, more weight should be given to VSL estimates that have smaller standard errors.

Our analysis takes a different approach by estimating the mean and distribution of VSL using the empirical Bayes estimation method in a two-stage pooling model. The first stage groups individual VSL estimates into homogeneous subsets. The second stage uses an empirical Bayes model to incorporate heterogeneity among samples. This approach allows the overall mean and distribution of VSL to reflect the underlying variability of the individual VSL estimates, as well as the observed variability between VSL estimates from different studies. Our overall findings suggest the mean VSL is relatively robust and the empirical Bayes method reduces the variability of the estimates. In addition, we conduct sensitivity analyses to examine how mean VSL is affected by estimation method, study location, and the addition of estimates with missing information on standard errors.

1. Methodology

1.1 Study selection

We obtained published and unpublished VSL studies by examining previously published meta-analysis or review articles, citations from VSL studies and by using web searches and personal contacts.

The data were prepared as follows. First, we selected qualified studies based on a set of selection criteria applied in Viscusi (1992). Second, we recorded all possible VSL estimates and associated standard errors in each study. Third, we made subsets of homogeneous VSL estimates and calculated the representative VSL for each subset by using the fixed effects approach. Each step is discussed in detail below.

Since the empirical Bayes estimation method (pooled estimate model) does not control for the overall quality of the underlying studies, careful examination of the studies is required for selection purposes. In order to facilitate comparisons with the EPA 812 report, we applied the same selection criteria that were applied in that report.

Viscusi (1992) examined 37 hedonic wage (HW), hedonic price (HP) and contingent valuation (CV) studies of the value of a statistical life, and listed four criteria for determining the value of life for policy applications. The first criterion is the choice of VSL estimation method. Viscusi (1992) found that all the HP studies evaluated failed to provide an unbiased estimate of the dollar side of the risk-dollar tradeoff, and tend to underestimate VSL. Therefore only HW studies and CV studies are included in this study.

The second criterion is the choice of the risk data source for HW studies. Viscusi argues that actuarial data reflect risks other than those on the job, which would not be compensated through the wage mechanism, and tend to bias VSL downward. Therefore some of the initial HW studies that used actuarial data are removed from this analysis. The third criterion is the model specification in HW studies. Most studies apply a simple regression of wage rates on risk levels. However, a few of the studies estimate the tradeoff for discounted expected life years lost rather than simply risk of death. This estimation procedure is quite complicated, and the VSL estimates tend to be less robust than in a simple regression estimation approach. Only studies using the simple regression approach are used in this analysis.

The fourth criterion is the sample size for CV studies. Viscusi argues that the two studies he considered whose sample sizes were 30 and 36 respectively were less reliable and should not be used. In this study, a threshold of 100 observations was used as a minimum sample size[2].

There are several other selection criteria that are implicit in the 1992 Viscusi analysis.[3] The first is based on sample characteristics. In the case of HW studies, he only considered studies that examined the wage-risk tradeoff among general or blue-collar workers. Some recent studies only consider samples from extremely dangerous jobs, such as police officer. Workers in these jobs may have different risk preferences and face risks much higher than those evaluated in typical environmental policy contexts. As such, we exclude those studies to prevent likely downward bias in VSL relative to the general population. In the case of CV studies, Viscusi only considered studies that used a general population sample. Therefore we also exclude CV studies that use a specific subpopulation or convenience sample, such as college students.

The second implicit criterion is based on the location of the study. Viscusi (1992) considered only studies conducted in high income countries such as U.S., U.K. and Japan.

Although there is an increasing number of CV or HW studies in developing countries such as Taiwan, Korea and India, we exclude them from our analysis due to differences between these countries and the U.S. Miller (2000) found that income level has a significant impact on VSL, and because we are seeking a VSL applicable to U.S. policy analysis, inclusion of VSL estimates from low income countries may bias VSL downward. In addition, there are potentially significant differences in labor markets, health care systems, life expectancy, and preferences for risk reductions between developed and developing countries. Thus, our analysis only includes studies in high-income OECD member countries.[4].

1.2 Data preparation

In VSL studies, authors usually report the results of a hedonic wage regression analysis, or WTP estimates derived from a CV survey. A few authors report all of the VSL that could be estimated based on their analysis, but most authors reported only selected VSL estimates and provided recommended VSL estimates based on their professional judgment. This judgment subjectively takes into account the quality of analysis, such as statistical significance of the result, or the target policy to be evaluated. Changes in statistical methods and best practices for study design during the period covered by our analysis may invalidate the subjective judgments used by authors to recommend a specific VSL. To minimize potential judgment biases, as well as make use of all available information, we re-estimate all possible VSLs based on the information provided in each study and included them in our analysis as long as they met the basic criteria laid out by Viscusi (1992).

Estimation of VSL from HW studies

Most of the selected HW studies use the following equation to estimate the wage-risk premium:

$$LnY_i = a_1\, p_i + a_2\, q_i + X_i\, ß + e_i \qquad (1)$$

where Y_i is equal to earnings of individual i, p_i and q_i are job related fatal and non-fatal risk faced by i (q_i often omitted), X_i is a vector of other relevant individual and job characteristics (plus a constant) and e_i is an error term. Based on equation (1), the VSL is estimated as follows.

$$VSL = (dlnY/\, dp_i) \times wage \times unit\ of\ fatal\ risk \qquad (2)$$ [5]

VSL is usually evaluated at the mean annual wage of the sample population. The unit of fatal risk is the denominator of the risk statistic, i.e. 1000 if the reported worker's fatal risk is 0.02 per 1000 workers. If there is an interaction term between fatal risk and human capital variables such as "Fatal Risk" × "Union Status", the VSL is also evaluated at the mean values of the union status variable.

Estimation of standard error of VSL from HW studies

The standard error of the VSL (SE(VSL)) from a HW study is:

$$SE\ (VSL) = SE\ ((dlnY/\, dp_i)) * mean\ annual\ wage * unit\ of\ fatal\ risk \qquad (3)$$

If there are interaction terms between the fatal risk and human capital variables, the covariances are required to estimate *SE* $((dlnY/dp_i))$. However, no studies report those covariances. Therefore, these variables are assumed to be independent of each other and to have zero covariance. This can lead to an overestimation or underestimation of SE(VSL) depending on the sign of the covariance term[6].

Estimation of VSL and standard error from CV studies

For most of the CV surveys, we could not estimate the VSL and its standard error unless the author provided mean or median WTP and standard error for a certain amount of risk reduction. The VSL and its standard error are simply calculated as WTP divided by the amount of risk reduction, and SE(WTP) divided by the amount of risk reduction, respectively.

Estimation of representative VSL for each study

Most studies reported multiple VSL estimates. For the empirical Bayes approach, which we use in our analysis, each estimate is assumed to be an independent sample, taken from a random distribution of the conceivable population of studies. This assumption is difficult to support given the fact that there are often multiple observations from a single study. To solve this problem, we constructed a set of homogeneous (and more likely independent) VSL estimates by employing the following approach.

We arrayed individual VSL estimates by study author (to account for the fact that some authors published multiple articles using the same underlying data). We then examined homogeneity among sub-samples of VSL estimates for each author by using Cochran's Q-statistics. The test statistic Q is the sum of squares of the effect about the mean where the i_{th} square is weighted by the reciprocal of the estimated variance. Under the null hypothesis of homogeneity, Q is approximately a χ^2 statistic with n -1 degrees of freedom (DerSimonian and

Laird, 1986). If the null hypothesis was not rejected, we applied the fixed effects model to estimate the representative mean VSL for that author. The mean VSL and its standard error for a fixed effects model were computed by following equations:

$$\textit{Fixed Effects Adjusted VSL} = \frac{\sum VSL_i \times \frac{1}{Var(VSL_i)}}{\sum \frac{1}{Var(VSL_i)}} \qquad (4)$$

$$\textit{Fixed Effects Adjusted SE of VSL} = \sqrt{\left(\sum \frac{1}{Var(VSL_i)}\right)^{-1}} \qquad (5)$$

If the hypothesis of homogeneity was rejected, we further divided the samples into subsets according to their different characteristics such as source of risk data and type of population, and tested for homogeneity again. We repeated this process until all subsets were determined to be homogeneous.

1.3 The empirical Bayes estimation model

In general, the empirical Bayes estimation technique is a method that adjusts the estimates of study-specific coefficients (ß's) and their standard errors by combining the information from a given study with information from all the other studies to improve each of the study-specific estimates. Under the assumption that the true ß's in the various studies are all drawn from the same distribution of ß's, an estimator of ß for a given study that uses information from all study estimates is generally better (has smaller mean squared error) than an estimator that uses information from only the given study (Post et al. 2001).

The empirical Bayes model assumes that

$$ß_i = m_i + e_i \qquad (6)$$

where $ß_i$ is the reported VSL estimate from study i, μ_i is the true VSL, e_i is the sampling error and N(0, s_i^2) for all i = 1,…, n. The model also assumes that

$$\mu_i = \mu + d_i \tag{7}$$

where μ is the mean population VSL estimate, d_i captures the between study variability, and N(0, t^2), t^2 represents both the degree to which effects vary across the study and the degree to which individual studies give biased assessments of the effects (Levy et al., 2000; DerSimonian and Laird, 1986).

The weighted average of the reported $ß_i$ is described as μ_w. The weight is a function of both the sampling error (s_i^2) and the estimate of the variance of the underlying distribution of $ß$'s (t^2). These are expressed as follows;

$$\mu_w = \frac{\sum w_i^* b_i}{\sum w_i^*} \tag{8}$$

$$s.e.\ (\mu_w) = (?\ w_i^*)^{-1/2} \tag{9}$$

where $w_i^* = \dfrac{1}{w_i^{-1} + t^2}$ and $w_i = \dfrac{1}{s_i^2}$

t^2 can be estimated as

$$t^2 = max \left(0, \left(\frac{(Q-(n-1))}{\sum w_i - \frac{\sum w_i^2}{\sum w_i}} \right) \right) \tag{10}$$

where Q = $?\ w_i\ (ß_i - ß^*)^2$ (Cochran's Q-statistic) and $ß^* = \dfrac{\sum w_i b_i}{\sum w_i}$

The adjusted estimate of the $ß_i$ is estimated as

$$\text{Adjusted } ß_i = \frac{\frac{b_i}{e_i} + \frac{m_w}{t^2}}{\frac{1}{e_i} + \frac{1}{t^2}} \qquad (11)$$

This adjustment pulls the estimates of $ß_i$ towards the pooled estimate. The more within-study variability, the less weight the $ß_i$ receives relative to the pooled estimate, and the more it gets adjusted towards the pooled estimate. The adjustment also reduces the variance surrounding the $ß_i$ by incorporating information from all ß's into the estimate of $ß_i$. (Post et al. 2001). In our analysis, $ß_i$ corresponds to the VSL of the *i*th study.

In order to construct a composite distribution of the adjusted VSL, we used kernel density estimation. The kernel estimation provides a smoother distribution than the histogram approach. The Kernel estimator is defined by $f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right)$. The kernel function, $\int_{-\infty}^{\infty} K(x)dx = 1$, is usually a symmetric probability density function, e.g. the normal density, and *h* is window width. The kernel function K determines the shape of the bumps, while the window width *h* determine their width. The kernel estimator is a sum of 'bumps' placed at observations and the estimate *f* is constructed by adding bumps up (Silverman 1986). We assumed a normal distribution for K and a window width *h* equal to 0.7, which was wide enough to give a reasonably smooth composite distribution while still preserving the features of the distribution (e.g. bumps). The choice of window width is arbitrary, but has no impact on the statistical comparison which is described below.

To compare the different distributions of VSL, we applied the bootstrap method, which is a nonparametric method for estimating the distribution of statistics. Bootstrapping is equivalent to random sampling with replacement. The infinite population that consists of the *n* observed sample values, each with probability 1/*n*, is used to model the unknown real population (Manly 1997). We conducted re-sampling 1000 times, and compared the distributions in terms of mean, median and interquartile range.

2. Results and sensitivity analyses

In total, we collected 48 HW studies and 29 CV studies. After applying the selection criteria outlined in section 2.1, there were 31 HW studies and 14 CV studies left for the analysis (see Appendix). In our final list, there are 22 new studies published between 1990 and 2000. We re-estimated all possible VSL for those studies, and obtained 234 VSL estimates[7]. There were 26 VSL estimates for which standard errors were not available, and thus they are excluded from our primary analysis, although we examine the impact of excluding those studies in a sensitivity analysis. After testing for homogeneity among sub-samples, we obtained 59 VSL subsets, and estimated a representative VSL and standard error for each subset. Finally, we applied the empirical Bayes method and obtained an adjusted VSL value for each subset. The unadjusted and empirical Bayes adjusted VSL estimates for the 59 subsets are presented in Table 1.

It is worthwhile to note how the empirical Bayes approach reduces the variability among VSL estimates. Our 234 VSL estimates show an extremely wide range from $0.1 million to $87.6 million. The VSL estimates from the 59 subsets range from $0.3 million to $78.8 million and the adjusted VSL estimates range from $0.7 million to $17.1 million.

2.1 The distribution of VSL

Figure 1 shows the kernel density estimates of the composite distribution of the empirical Bayes adjusted VSL (using the 59 representative VSL estimates) and for the 26 unadjusted VSL estimates included in the EPA 812 report. The summary results are shown in Table 2. The composite distribution of adjusted VSL has a mean of $6.3 million with a standard error of $3.7 million. Applying the same kernel density approach to the 26 VSL estimates in the EPA 812 report yields a composite distribution with a mean of $6.2 million and a standard error of $4.3 million, which are almost the same moments of the Weibull fitted distribution reported in the Section 812 report. The mean value of the new empirical Bayes derived distribution is almost identical to that of EPA 812 distribution, but has less variance even though our VSL sample has a range five times as wide as the EPA 812 sample.

2.2 Sensitivity analyses

2.2.1 Sensitivity to choice of estimation method

Many researchers argue that the VSL is sensitive to underlying study characteristics (Viscusi 1992, Carson, et al. 2000, Mrozek and Taylor 1999). One of the most interesting differences is in the choice of valuation method between HW and CV. To determine the difference between the empirical Bayes adjusted distributions of VSL using HW and CV estimates, we used bootstrap tests of significance to test the hypothesis that HW and CV estimates of VSL are from the same underlying distribution.

We divided the set of VSL studies into HW and CV and applied the homogeneity subsetting process and empirical Bayes adjustment method to each group. The kernel density estimates of the distributions for HW and CV sample are shown in Figure 2. The HW distribution has a mean value of $8.8 million with a standard error of $5.0 million, while the CV distribution has much smaller mean value of $2.8 million with a standard error of $1.3 million. Bootstrap tests of significance show the VSL based on HW is significantly larger than that of CV ($p<0.001$), comparing means, medians and interquartile ranges between the distributions.

2.2.2 Sensitivity to study location

Because of differences in labor markets, health care systems, and societal attitudes towards risk, VSL estimates from HW studies may potentially be sensitive to the country in which the study was conducted. Empirical Bayes estimation was applied to HW samples from the U.S., U.K. and Canada separately. The kernel density estimated distributions of VSL for the U.K. and U.S. are shown in Figure 3, and those for the U.S. and Canada are shown in Figure 4.

The distribution for the U.S. sample has a mean value of $8.3 million with a standard error of $5.0 million, while the distribution for the U.K. sample has a mean value of $15.6 million with a standard error of $7.4 million. Bootstrap tests of significance did not reject the hypothesis that the U.S. estimates are equal to the U.K. estimates, comparing means, medians and interquartile ranges between the distributions.

The distribution for the Canadian estimates has a mean value of $4.0 million with a standard error of $0.6 million. Bootstrap tests of significance show that the Canadian VSL estimates are significantly smaller than those from the U.S. ($p<0.001$) by comparing means, medians and interquartile ranges between distributions.

2.2.3 Sensitivity to excluded VSL estimates

We also examine the sensitivity of our estimates to excluded estimates. To do this, we added to the sample the VSL estimates that were excluded from the primary analysis due to the lack of a standard error. We assumed for this test that all reported VSL estimates should have passed at least a 95 percent significance test, and estimate the corresponding standard error for each VSL. This added seven adjusted VSL estimates to the set of 59 representative estimates, including two estimates from HW studies and five from CV studies. The kernel density estimated distributions derived from the new dataset are shown in Figure 5.

The distribution of the enhanced sample has a mean value of $5.7 million with a standard error of $3.5 million. Compared with the result of main analysis, the mean value is reduced by $0.6 million. This is because most of estimates that were excluded are derived from CV, which tends to produce relatively lower VSL. Bootstrap tests of significance show the VSL from HW studies is still significantly different from that from CV studies ($p<0.0001$), comparing means, medians and interquartile ranges.

3. Conclusions

Starting from a baseline of the literature used in Viscusi (1992), our analysis has demonstrated that the overall mean VSL estimate from the literature is not greatly impacted by the addition of new estimates from 1992 to 2001 or by the application of the empirical Bayes adjustment approach. However, the variability around that estimate is reduced when the empirical Bayes approach is applied. In our primary analysis, the standard error around the empirical Bayes estimate of the mean VSL is reduced by around $0.6 million, or 14 percent, even though our VSL sample has a much wider range than the EPA 812 sample. This suggests that there is significant within and between study variability present in the VSL estimates.

In addition, use of the empirical Bayes approach facilitates comparisons of subsamples of VSL estimates, allowing us to investigate important differences between hedonic wage and contingent valuation studies and the impact of study location. These sensitivity analyses demonstrated that HW studies produce VSL estimates that are significantly higher than those derived from CV studies. However, further efforts are required to generalize this conclusion.

Theoretically, the two methodologies should not provide the same results because the HW approach is estimating a local trade-off, while the CV approach approximates a movement along a constant expected utility locus (Viscusi and Evans 1990, Lanoie, Pedro and Latour 1995). However, the impact and direction of this difference have not been thoroughly investigated.

Aggregate level comparisons as we have done in this paper are useful in comparing the overall distribution of VSL estimates from each method, however the resulting comparison might be significantly affected by the differences in study design of each study, as the large variance in the HW distribution suggests. This problem could be addressed by applying meta-regression analysis, which can determine the impact of specific study factors by taking into consideration study characteristics such as sample population or study location (Levy et al., 2000; Mrozek and Taylor, 2001).

Study location does seem to matter, but additional investigation is necessary to identify location specific factors that cause differences. Simply lumping countries together as developed or developing may not be the best way to account for potential differences in VSL, as evidenced by our finding of differences between the U.S. and Canada, but not between the U.S. and the U.K. Differences in health care systems may be a potential factor, as the U.S. and U.K. systems are closer than the U.S. and Canadian systems, but there may be numerous other socio-cultural factors that can cause VSL estimates to diverge.

As the excluded studies sensitivity analysis indicates, our results are sensitive to the addition of small magnitude VSL estimates with low variances. For example, Krupnick (2000) estimated the VSL as $1.1 million with standard error of $1.1 million. If we remove this estimate from our main analysis, the overall mean VSL is increased to $6.6 million, implying that one study reduces the overall mean by $0.3 million. Therefore we should examine the reliability of CV studies very carefully by assessing the questionnaire and scope effects (Hammitt and Graham, 1999). In addition, it may be important to investigate why the VSL estimates from CV studies are so similar despite the differences in type of risk, study location and survey method.

In addition to the application of the empirical Bayes method, our analysis also demonstrates the importance of adopting a two-stage procedure for combining evidence from the literature when multiple estimates are available from a single source of data. The first stage sorting process using the Cochran's Q test for homogeneity seems a reasonable approach to control for over-representation of any one dataset. From the original set of 45 studies we obtained 234 VSL estimates and then classified these into 59 homogeneous subsets. This suggests that there was a high probability of assigning too much weight to some estimates if a single stage process were used, treating each of the 234 estimates as independent. Also, the two-stage approach does not discard information from each study. Instead it uses all the available information in an appropriate manner.

As in the epidemiology field, the economics profession should consider developing protocols for combining estimates from different studies for policy purposes. Consistent reporting of both point estimates of VSL and standard errors, or variance-covariance matrices would enhance the ability of future researchers to make use of all information in constructing estimates of VSL for policy analysis. Additional research is needed to understand how VSL varies systematically with underlying study attributes, such as estimation method or location of studies. The empirical Bayes approach outlined here provides a useful starting point in developing the dependent variables for such studies.

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Table 1. Unadjusted and Empirical Bayes Adjusted VSL Estimates

Author (year)	Type of study	# of estimates	Unadjusted VSL* (million $ in 2000)	Adjusted VSL
Dickens (1984) (1)	HW	1	21.4	16.1
Dickens (1984) (2)	HW	1	11.9	8.6
Dickens (1984) (3)	HW	1	7.5	7.1
Dickens (1984) (4)	HW	2	5.1	5.7
Dillingham (1985) (1)	HW	2	0.6	0.9
Dillingham (1985) (2)	HW	2	5.9	6.1
Dillingham (1985) (3)	HW	1	9.1	7.2
Dillingham (1985) (4)	HW	1	0.3	4.7
Dillingham (1985) (5)	HW	2	2.4	3.6
Dillingham (1985) (6)	HW	2	4.8	5.2
Dillingham (1985): New York	HW	8	1.1	1.2
Dorsey (1983), Dorsey and Walzer (1994)	HW	3	13.1	8.4
Garen (1988)	HW	1	7.1	6.6
Gegax et al. (1991)	HW	14	2.5	2.8
Gill (1998) (1)	HW	1	4.7	5.3
Gill (1998) (2)	HW	3	8.4	7.7
Gill (1998) (3)	HW	3	0.8	3.3
Herzog and Schlottman (1990)	HW	1	12.1	10.6
Leigh (1987), Leigh and Folson (1984)	HW	14	9.4	8.9
Leigh (1995) (1)	HW	1	8.1	7.3
Leigh (1995) (2)	HW	1	16.7	11.4

Leigh (1995) (3)	HW	1	12.8	7.0
Leigh (1995) (4)	HW	1	11.1	8.5
Moore & Viscusi (1988)	HW	8	6.3	6.3
Olson (1981)	HW	8	11.2	9.3
R.S. Smith (1974)	HW	2	12.8	9.8
R.S. Smith (1976)	HW	3	8.3	7.6
Scotton and Taylor (2000)	HW	1	19.7	17.8
Viscusi (1978, 1979, 1980)	HW	28	6.6	6.6
Visucusi(1981)	HW	4	11.0	9.7
Arabsheibani & Marin (2000) (1)	HW	2	29.6	10.0
Arabsheibani & Marin (2000) (2)	HW	1	18.2	8.2
Arabsheibani & Marin (2000) (3)	HW	2	78.8	7.1
Geogeou (1992)	HW	1	16.8	7.3
Marin & Psacharopulos (1982)	HW	7	5.7	5.7
Siebert & Wei (1994)	HW	12	7.7	7.4
Martinello & Meng (1992)	HW	13	3.4	3.5
Causineau et al. (1992)	HW	3	4.8	4.8
Meng & Smith (1990), Meng (1989)	HW	10	3.7	4.3
Miller (1997) (1)	HW	2	17.5	15.5
Miller (1997) (2)	HW	1	10.5	9.2
Corso et al. (2001)	CV	8	3.4	3.4
Gerking et al. (1988)	CV	1	4.3	4.8
Hamitt and Graham (1999) (1)	CV	1	1.9	1.9
Hamitt and Graham (1999) (2)	CV	1	1.1	1.1

Hamitt and Graham (1999) (3)	CV	1	0.7	0.7
Hamitt and Graham (1999) (4)	CV	2	7.2	6.9
Hamitt and Graham (1999) (5)	CV	2	2.5	2.5
Ludwig and Cook (1999)	CV	2	6.1	6.2
Viscusi et al. (1991)	CV	1	12.4	9.0
Cathy et al. (1999) (1)	CV	4	1.8	1.8
Cathy et al. (1999) (2)	CV	4	3.0	3.0
Jones-Lee (1989)	CV	1	7.0	6.7
Johannesson et al. (1996) (1)	CV	2	6.0	6.0
Johannesson et al. (1996) (2)	CV	1	3.4	3.5
Johannesson et al. (1996) (3)	CV	1	1.9	2.0
Miller and Gunia (1991)	CV	1	1.6	1.6
Krupnick (2000) (1)	CV	1	1.1	1.1
Krupnick (2000) (2)	CV	1	3.3	3.4

* Value after applying fixed effects model to homogeneous subsets.

Table 2. Results of Empirical Bayes Estimates and Bootstrap Test for Distribution Comparison

	Mean (million $)	SD (million $)	Bootstrap Test		
			Mean	Median	Interquatile
Distribution comparison by study method					
Total	6.3	3.7	P-value (Ho: HW = CV)		
CV	2.8	1.3	<0.001	<0.001	<0.001
HW	8.8	5.0			
Distribution comparison by study location					
USA	8.3	5.0	P-value (Ho: US =UK/Canada)		
UK	15.6	7.4	0.807	0.805	0.680
Canada	4.0	0.6	<0.001	<0.001	<0.001
Distribution comparison by study method after adding excluded estimates					
Total	5.7	3.5	P-value (Ho: HW = CV)		
CV	2.6	1.3	<0.001	<0.001	<0.001
HW	8.6	4.9			

Figure 1. Comparison of Kernel Distribution of Empirical Bayes Adjusted VSL with Distribution of VSL Based on EPA Section 812 Report Estimates

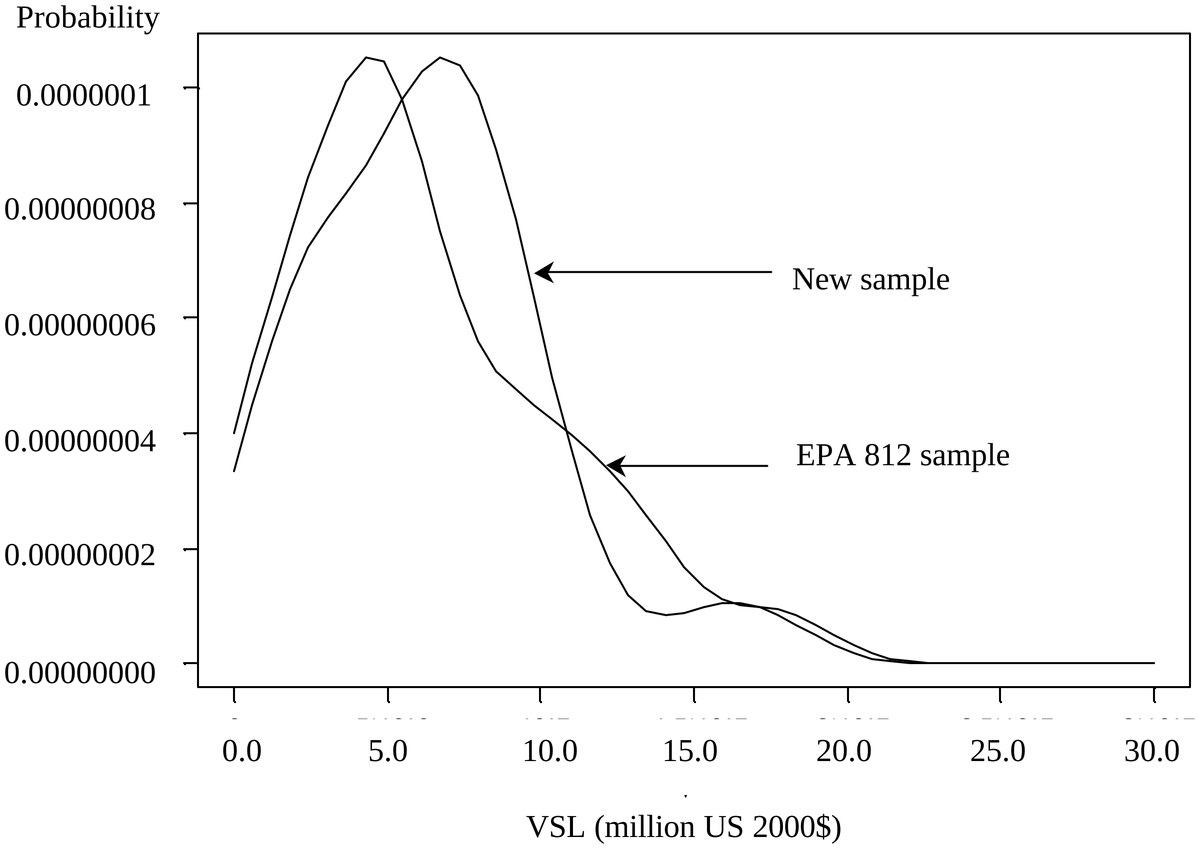


Figure 2. Comparison of Kernel Distribution of Empirical Bayes Adjusted VSL Based on HW and CV Estimates

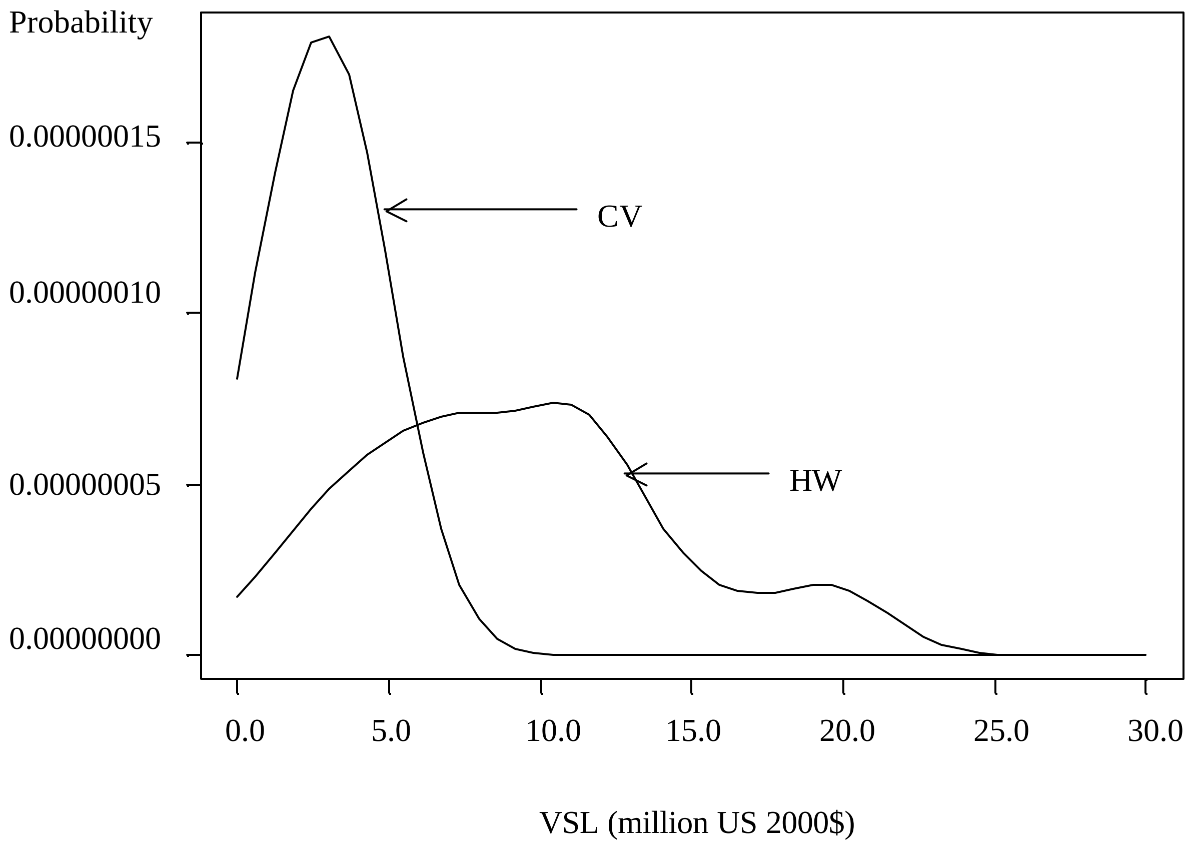


Figure 3. Comparison of Kernel Distribution of VSL Based on HW in U.S. and U.K.

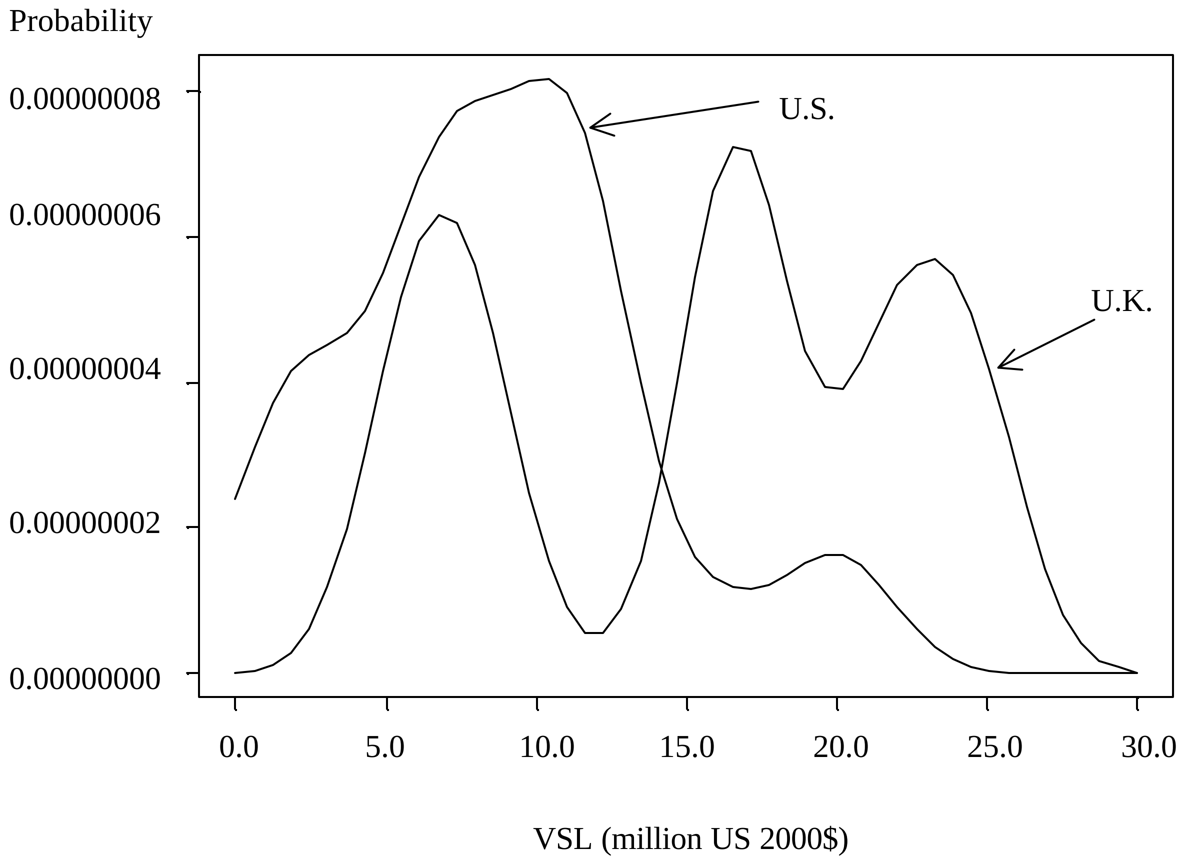


Figure 4. Comparison of Kernel Distribution of VSL Based on HW in U.S. and Canada

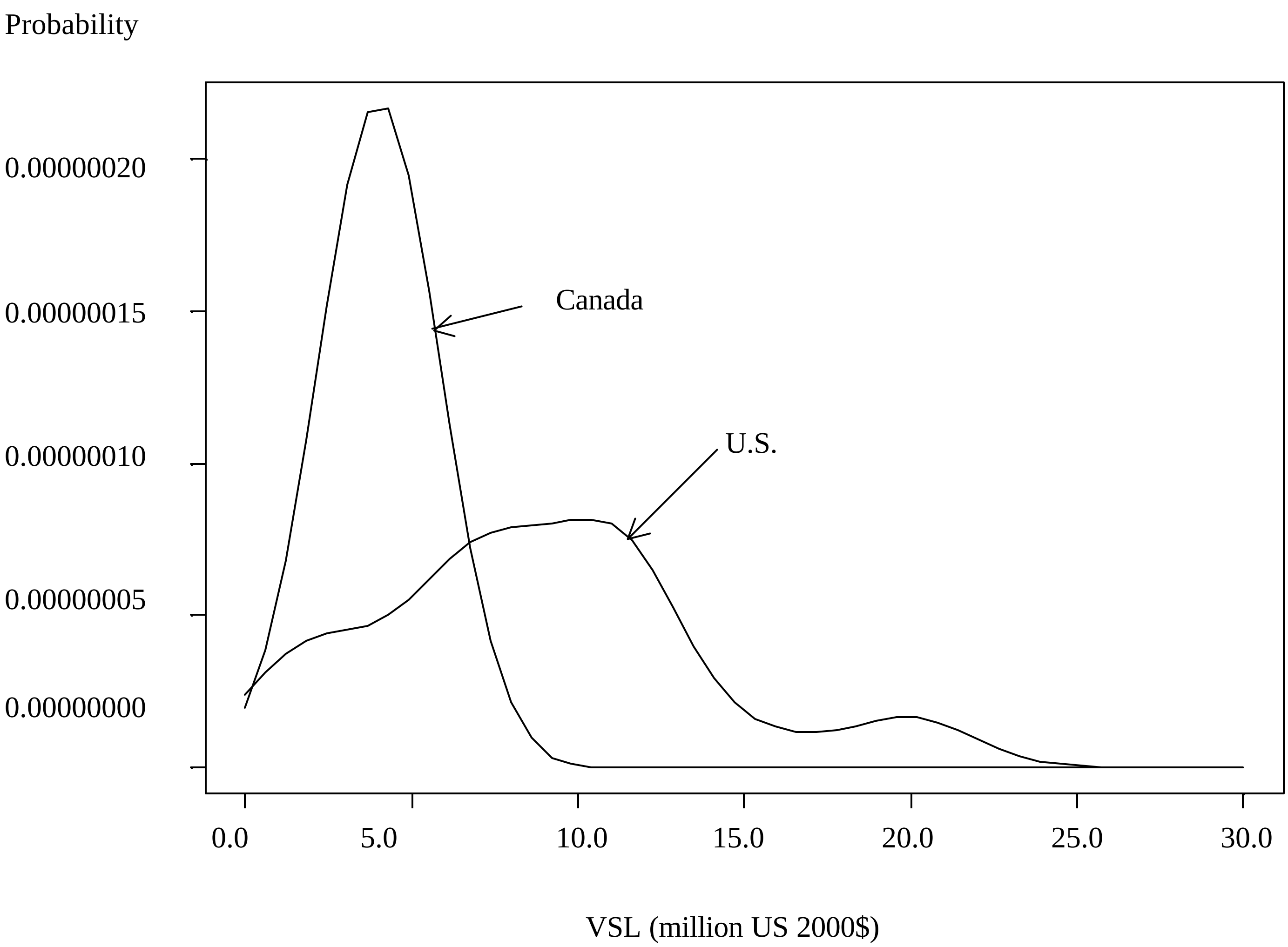
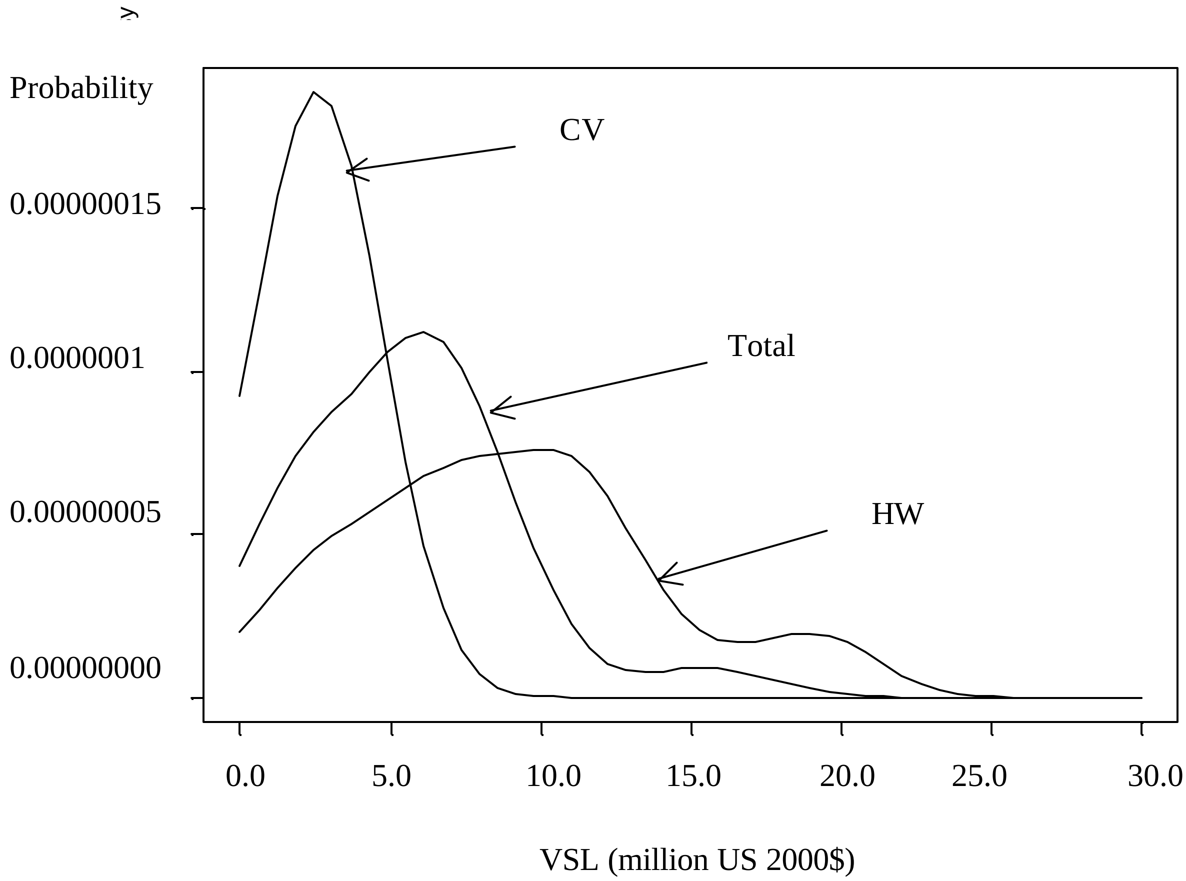


Figure 5. Comparison of Kernel Distribution of Empirical Bayes Adjusted VSL Based on HW and CV Estimates with Additional Estimates



Notes:

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[1] All estimates reported in this paper have been converted to constant 2000 dollars using the Bureau of Labor Statistics Consumer Price Index (CPI). The CPI inflation calculator uses the average Consumer Price Index for a given calendar year. These data represent changes in prices of all goods and services purchased for consumption by urban households. For estimates reported in foreign currency, we first converted to U.S. dollars using data on Purchasing Power Parity from the Organization for Economic Cooperation and Development, and then converted to 2000 U.S. dollars using CPI.

[2] This is admittedly an arbitrary cutoff. However, we determined that a sample size of 100 did not result in too many studies being excluded and smaller samples did not seem to be reasonable.

3 We exclude one additional study, by Eom (1994), due to concerns about the payment context for the willingness to pay question. In that study, individuals were asked to choose between produce with different levels of price and pesticide risk. The range of potential WTP was limited by the base price of produce. In order to realize an implied VSL within the range considered by Viscusi, individuals would need to have a WTP of around $400 per year. Because WTP in the study was tied to increases in produce prices, which ranged $0.39 to $1.49, it would be very unlikely that individuals would be willing to pay over a 100 times their normal price for produce to obtain the specified risk reduction. Tying WTP to observed prices thus limits the usefulness of this study for benefits transfer.

[4] From http://worldbank.org/data/databytopic/class.htm. High-income OECD member have annual income greater than $9,266 per capita.

[5] The coefficient $d\ lnY/\ d\ p_i$ does not depend on the units in which Y is measured. The requirement for a comparison is that result being converted in the same unit, e.g. per thousand

per year, over the studies.

[6] The estimated standard error of $\beta_1 + \beta_2$ is $\sqrt{1^2 Var(b_1) + 1^2 Var(b_2) + 2(1)(1)Cov(b_1, b_2)}$.

(Ramsey and Schafer (1996)). Therefore, if the coefficient of the interaction term is negative, our analysis overestimated the VSL and if the coefficient of the interaction term is positive, our analysis underestimated VSL.

[7] To assure quality of re-estimation of VSL we matched our results with estimates done by the original authors when available. Although the VSL estimates from Kneisner and Leeth (1991), Smith and Gilbert (1984) and V.K. Smith (1976) are included in EPA 812 report, the original manuscripts do not provide VSL estimates, and we could not replicate the estimates reported in EPA 812. Therefore we exclude those studies from our analysis.

Appendix 1: Excluded Contingent Valuation Studies

Study	risk type	country	VSL (million $ in 2000) *	Sample #	sample characteristics	Reason for exclusion
Aimola, Agostina. (1998). "Individual WTPs for Reductions in Cancer Death Risks", In R.C. Bishop and D. Romamo (eds.) Environmental Resource Valuation: Applications of the Contingent Valuation Method in Italy. Studies in Risk and Uncertainty.	multi	Italy	0.5 - 6.3	89	Residents of Sicily	Small sample/ not general population
Beattie, Jane. et al. (1998). "On the Contingent Valuation of Safety and the Safety of Contingent Valuation: part 1", Journal of Risk and Uncertainty 17, 5-26.	Road	UK	4.4	52	Newcastle, Bangor and York (broadly represent in terms of age, gender and household income)	Small population
Cookson, Richard. (2000). "Incorporating Psycho-Social Considerations into Health Valuation: an Experimental Study", Journal of Health Economics 19, 361-401.	multi	UK	55.8 - 186.4	52	Parents from local primary school /mostly women	Small population, not general population/ using "lives saved number"
Eastaugh, Steven R. (1991). "Valuation of the Benefits of Risk-Free Blood: Willingness to Pay for Hemoglobin Solutions", International Journal of Technology Assessment in Health Care 7, 51-57.	Blood	USA	9.7	70	Graduate in health service administration/ blood bank manager	Small sample/ not general population
Eom, Young Sook. (1994). "Pesticide Residue Risk and Food Safety Valuation: a Random Utility Approach", American Journal of Agricultural Economics 76, 760-771.	Food	USA	0.0 - 0.5	570	Shopper at NC (fairly similar to general population)	Inadeqate goods

Johannesson, Magnus and Per-Ovol Johansson. (1997). "Quality of Life and the WTP for an Increased Life Expectancy at an Advanced Age", Journal of Public Economics 65, 219-228.	WTP for increased life expectancy	Sweden	0.0 - 0.1	around 1900	Nation-wide survey/ 18-69 age	VSL for future risk (discounted)
Johannesson, Magnus, Bengt Jonsson and Lars Borgquist. (1991). "Willingness to Pay for Antihypertensive Therapy - Results of a Swedish Pilot Study", Journal of Health Economics 10, 471-474.	Antihypertensive	Sweden	0.1	481	Hypertension patients	Not general population
Jones-Lee, Michael W. and Graham Loomes. (1994). Towards a Willingness to Pay Based Value of Underground Safety", Journal of Transport Economics and Policy, 83-98.	Underground transportation	UK	3.8	54	Not randomly chosen	Adjustment from road VSL/ small population/ not general population
Jones-Lee, Michael W. and Graham Loomes. (1995). "Scale and Context Effects in the Valuation of Transport Safety", Journal of Risk and Uncertainty 11, 183-203.	Underground transportation	UK	1.9	225	Underground user as well as car user or passenger	Adjustment from road VSL
Krupnick, Alan E. et al. (2000). New Directions in Mortality Risk Valuation and Stated Preference Methods: Preliminary Results (not published)	WTP for risk reduction over 10 years	USA/ Japan	0.3- 0.4	10	College park, MD/ Tokyo	Small sample/ future risk
Lanoie, Paul, Carmen Pedero, and Robert Latour. (1995). "The Value of a Statistical Life: a Comparison of Two Approaches", Journal of Risk and Uncertainty 10, 235-257.	Occupational	Canada	30.7	200	Emproyee at large company in Montreal (include risk aversion people)	Not general population
McDaniels, Timothy L. (1992). "Reference Point, Loss Aversion and Contingent Values for Auto Safety", Journal of Risk and Uncertainty 5, 187-200.	Automobile	USA	9.6	around 50	Parents and worker at daycare center, economic specialist, middle class residents and graduate student in Pittsburgh	Small population

Schwab Christe, Nathalie G. (1995). The Valuation of Human Costs by the Contingent Method: the Swiss Experience, In N.G. Schwab Christe and N.C. Soguel (eds.) Contingent Valuation, Transport Safety and the Value of Life: Studies in Risk and Uncertainty. Boston, Kluwer.	Injury	Swiss	3.3	50	Sampling mehot not clear	Small sample/ not general population
Shogren, Jason F. et al. (1994). "Resolving Differences in Willingness to Pay and Willingness to Accept", American Economic Revview 84, 255-270.	Food	USA	0.1-13.5	15	Graduate/ undergraduate at Iowa U.	Not general population/ small sample
Smith, Kerry V. and Willian H. Desvousges. (1987). "An Empirical Analysis of the Economic Value of Risk Changes". Journal of Political Economy 95, 89-114.	Hazardous Waste	USA	n.a. **	30-50	Residents of Boston	Small sample

* Reported estimates in the article.

* WTPs for risk reduction are provided, but not fully information to esitmate VSL are not provided in the article.

Appendix 2: Selected Contingent Valuation Studies

Study	Risk type	Country	sample #	Sample source	Amount of risk reduction	Scope sensitivity	VSL (million $ in 2000)*	SE available?
Buzby, Jean C., Richard C. Ready and Jerry R. Skees. (1995). "Contingent Valuation in Food Policy Analysis: a Case Study of a Pesticide Residue Risk Reduction", Journal of Agricultural and Applied Economics 27, 613-625.	Pesticide	USA	512	Food Shopper (similar to general population)	5/100000	n.a.	4.9	No
Carthy, Trevor et al. (1999). "On the Contingent Valuation of Safety and the Safety of Contingent Valuation: Part 2-The CV/SG "Chained" Approach", Journal of Risk and Uncertainty 17, 187-213.	Trafic	UK	150	Nation-wide	n.a.	n.a.	1.2 - 10.1	Yes
Corso, Phaedra S., James K. Hammitt, and John D. Graham. (2000). "Valuing Mortality-Risk Reduction: Using Visual Aids to Improve the Validity of Contingent Valuation". Submitted to Journal of Risk and Uncertainty.	Automobile	USA	1100	Nation-wide	5/100000 - 1/10000	with visual aid: Yes without visual aid: No	2.7 - 6.2	Yes
Desaigues, Brigitte and Ari Rabl. (1995). "Reference Valuation for Human Life: an Econometric Analysis of a Contingent Valuation in France, In N.G.Schwab and N.C. Soguel (eds.) Contingent Valuation, Transport Safety and the Value of Life: Studies in Risk and Uncertainty, Boston: Kluwer.	Traffic	France	900	Nation-wide	5/100000	n.a.	1.3	No
Hammitt, James K. and John D. Graham. (1999). "Willingness to Pay for Health Protection: Inadequate Sensitivity to Probability?", Journal of Risk and Uncertainty 8, 33-62.	Multi	USA	300-900	Nationwide	6/1000000 - 1/10000	Conventional format: No Indifference-risk approach: Yes	0.7 - 10.1	Yes

Johannesson, M. Per-Olov Johasson and K. Lofgren. (1997). "On the Value of Changes in Life Expectancy: Blips versus Parametric Changes", Journal of Risk and Uncertainty 15, 221-239.	Not specified	Sweden	2000	Nation wide	2/10000	n.a.	3.8 - 5.9	No
Johannesson, Magnus, Per-Olov Johansson, and Richard M. O'Conor. (1996). "The Value of Private Safety Versus the Value of Public Safety", Journal of Risk and Uncertainty 13, 263-275.	Automobile/ Traffic	Sweden	1000	Nation-wide/above 16/ car owner	8/100000	n.a.	2.7 - 9.5	Yes
Jones-Lee, Michael W. (1989). "The Empirical Estimation of Individual Valuation of Safety: Results of a National Sample Survey", The Economics of Safety and Physical Risk, Oxford.	Multi	UK	1560	Nation-wide	n.a.	n.a.	2.1	Yes
Kidholm, K. (1995). "Assessing the Value of Traffic Safety Using the Contingent Valuation Technique: the Danish Survey", In N.G.Schwab Christe and N.C. Soguel. (eds.) Contingent Valuation, Transport Safety and the Value of Life: Studies in Risk and Uncertainty, Boston: Kluwer.	Traffic	Denmark	950	Nation-wide	3/100000	n.a.	2.5 - 3.2	No
Krupnick, Alan et al. (2000). Age, Health, and the Willingness to Pay for Mortality Risk Reductions: a Contingent Valuation Survey of Ontario Residents. Washington D.C.: Resources For the Future Discussion Paper 00-37, Resources For the Future.	Not specified	Canada	930	Age 40-75 in Hamilton & Ontalio	1/1000 - 5/1000	Visual aid: Yes	0.8 - 2.6	Yes
Loomis, John B. and Pierre H. duVair (1993). "Evaluating the Effect of Alternative Risk Communication Devices on Willingness to Pay: Results from a Dichotomous Choice Contingent Valuation Experience", Land Economics 69, 87-298.	Hazardous waste	USA	400	Residents of California	1/1000 - 3/1000	Risk ladder: Yes Pie chart: Yes	0.2 - 0.6	No
Ludwig, Jens and Philip J. Cook. (1999). The Benefits of Reducing Gun Violence: Evidence from Contingent Valuation Survey Data. Working Paper 7166. Cambridge: National Bureau of Economic Research.	Gun violence	USA	1200	Nationally representative	n.a.	n.a.	0.2 - 6.6	No

Miller, Ted and Jagadish Guria. (1991). The Value of Statistical Life in New Zealand. Wellington: Land Transport Division, New Zealand Ministry of Transport.	Traffic	New Zealand	630	Nation-wide	n.a.	n.a.	2.6	Yes
Viscusi, Kip W., Wesley A. Magat, and Joel Huber. (1991). "Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis", Journal of Environmental Economics and Management 21, 32-51.	Automobile	USA	390	Residens of Greensboro, NC (similar to general population)	n.a.	n.a.	12.4	Yes

* Reported estimates in the article.

Appendix 3: Selected Hedonic Wage Studies

Study	country	Sample characteristics	VSL estimates (million $ in 2000)*	SE availability
Arabsheibani, R. G., and A. Marin. (2000). "Stability of Estimates of the Compensation for Damage", Journal of Risk and Uncertainty 20, 247-269	UK	Whole/ Manual/ Others	13.0 - 62.7	Yes
Butler, R.J. (1983). "Wage and Injury Rate Response to Shifting Levels of Workers' Compensation". In John D. Worral. (eds.), Safety and the Work Force: Incentives and Disincentives in Worker's Compensation. Ithaca: Cornell University, ILR Press.	USA	Whole	0.9 - 1.3	No
Cousineau, Jean-Michel, Robert Lacroix and Anne-Marie Girard. (1992). "Occupational Hazard and Wage Compensating Differentials", Review of Economics and Statistics 74: 166-169.	Canada (Quebec)	Manual	5.1 - 6.1	Yes
Dickens, Williams T. (1984). "Differences Between Risk Premiums in Union and Nonunion Wages and the Case for Occupational Safety Regulation", The American Economic Review 74, 320-323.	USA	Whole/ Manual	4.6 - 21.4	Yes
Dilingham, Alan E. (1985). Dilingham, E. Alan. (1985). "The Influence of Risk Variable Definition on Value of Life Estimates", Economic Inquiry 24, 277-294.	USA (New York)	Manual (Manufacturing & Construction)	0.8 - 3.0	Yes
	USA	Whole	0.1 - 9.1	Yes
Dorsey, Stuart. (1983). "Employment Hazards and Fringe Benefits: Further Tests for Compensating Differentials". In John D. Worral. (eds.), Safety and the Work Force: Incentives and Disincentives in Worker's Compensation. Ithaca: Cornell University, ILR Press.	USA	Manual	14.2	Yes/ estimate
Dorsey, Stuart, and Norman Walzer. (1983). "Workers' Compensation, Job Hazards and Wages", Industrial and Labor Relations Review 36, 642-654.	USA	Manual	9.1 - 15.4	Yes/ estimate
Garen, John. (1988). "Compensating Wage Differentials and the Endogeneity of Job Riskiness", The Review of Economics and Statistics 70, 9-16.	USA	Whole	7.1	Yes
Gegax, Dougls, Shelby Gerking, and William Schulze. (1991). "Perceived Risk and the Marginal Value of Safety", Review of Economics and Statistics, 589-596.	USA	Whole/ Manual/ Others	0.5 - 32.1	Yes
Geirgiou, Stavros. (1992). Valuing Statistical Life and Limb: A Compensating Wage Differentials Evaluation for Industrial Accidents in the UK. Working Paper GEC 92-13. London: Center for Social and Economic Research on the Global Environment (CSERGE).	UK	Manual	6.3	Yes

Gill, Andrew M. (1998). "Cigarette Smoking, Illicit Drug Use and the Value of Life", Social Science Journal 35, 361-376.	USA	Whole	0.5-11.7	Yes
Herzog, Henry W., Jr., and Alan M. Schlottmann. (1990). "Valuing Risk in the Workplace: Market Price, Willingness to Pay, and the Optimal Provision of Safety", Review of Economics and Statistics 72, 463-470.	USA	Whole	12.1	Yes
Leigh, Paul J. (1987). "Gender, Firm Size, Industry and Estimates of the Value-of-Life", Journal of Health Economics 6, 255-273.	USA	Whole	7.6 - 14.4	Yes
Leigh, Paul J. (1995). "Compensating Wages, Value of a Statistical Life, and Inter-Industry Differentials", Journal of Environmental Economics and Management 28, 83-97.	USA	Manual	8.1- 16.7	Yes
Leigh, Paul. J. and Roger N. Folsom. (1984). "Estimates of the Value of Accident Avoidance at the Job Depend on Concavity of the Equalizing Differences Curve", The Quarterly Review of Economics and Business 24, 55-56.	USA	Whole	10.0 - 13.2	Yes/ estimate
Marin, Alan, and George Psacharopoulos. (1982). "The Reward for Risk in the Labor Market: Evidence from the United Kingdom and Reconciliation with Other Studies", Journal of Political Economy 90, 827-853.	UK	Manual / Whole/ Others	4.2 - 17.3	Yes/ estimate
Martinello, Felice and Ronald Meng. (1992). "Workplace Risks and the Value of Hazard Avoidance", Canadian Journal of Economics 25, 333-345.	Canada (non-Quebec)	Manual	2.3 - 7.9	Yes/ estimate
Meng, Ronald. (1989). "Compensating Differences in the Canadian Labour Market", Canadian Journal of Economics 12, 413-424.	Canada (Quebec)	Whole	3.9 - 4.6	Yes/ estimate
Meng, Ronald and Douglas Smith. (1990). "The Valuation of Risk of Death in Public Sector Decision-Making", Canadian Public Policy 16,137-144.	Canada (Quebec)	Manual	1.2 - 10.3	Yes/ estimate
Miller, Paul, Charles Mulvey, and Keith Norris. (1997). "Compensating Differentials for Risk of Death in Australia", Economic Record 73, 363-372.	Australia	Whole	11.3 - 19.1	Yes
Moore, Michael J. and Kip W. Viscusi. (1988). "Doubling the Estimated Value of Life: Results Using New Occupational Fatality Data", Journal of Policy Analysis and Management 7, 476-490.	USA	Whole	3.0- 10.3	Yes/ estimate
Olson, Craig A. (1981). "An Analysis of Wage Differentials Received by Workers on Dangerous Jobs", Journal of Human Resources 16, 167-185.	USA	Whole	5.5 - 38.2	Yes/ estimate

Sandy, Robert and Robert F. Elliott. (1996). "Unions and Risks: Their Impact on the Level of Compensation for Fatal Risk", Economica 63, 291-310.	UK	Manual	5.2 - 30.9	No
Scotton,Carol R. and Laura O. Taylor. (2000). "New Evidence from the Labor Markets on the Value of a Statistical Life", Working Paper. Atlanta: Department of Economics, Andrew Young School of Policy Studies, Georgia State University.	USA	Whole	19.7	Yes
Siebert, S.W. and X Wei. (1994). "Compensating Wage Differentials at Workplace Accidents: Evidence for Union and Nonunion Workers in the UK", Journal of Risk and Uncertainty 9, 61-76.	UK	Manual	2.1 - 5.2	Yes
Smith, Robert S. (1974). "The Feasibility of an 'Injury Tax' Approach to Occupational Safety", Law and Contemporary Problems 38, 730-744.	USA	Whole	8.0 - 14.7	Yes
Smith, Robert S. (1976). The Occupational Safety and Health Act: Its Goals and Achievements. Washington: American Enterprise Institute.	USA	Whole	7.8 - 13.1	Yes
Viscusi, Kip W. (1978). "Labor Market Valuations of Life and Limb: Empirical Evidence and Policy Implications", Public Policy 26, 359-386.	USA	Manual	2.8 - 8.3	Yes
Viscusi, Kip W. (1979). "Compensating Earnings Differentials for Job Hazards". In Viscusi, W. Kip (eds.), Employment Hazards: an Investigation of Market Performance. Cambridge: Harvard University Press.	USA	Manual	2.6 - 7.8	Yes
Viscusi, Kip W. (1980). "Union, Labor Market Structure, and the Welfare Implications of the Quality of Work", Journal of Labor Research 1, 175-192.	USA	Manual	5.5 - 14.1	Yes
Viscusi, Kip W. (1981). "Occupational Safety and Health Regulation: Its Impact and Policy Alternatives", Research in Public Policy Analysis and Management 2, 281-299.	USA	Whole	10.0 -21.0	Yes/ estimate

Appendix 4: Excluded Hedonic Wage Studies

Study	Country	Reason for exclusion
Arnold, Richard J. and Len M. Nichols. (1983). "Wage Risk Premium and Worker's Compensation: a Refinement of Estimates of Compensating Wage Differential", Journal of Political Economy 91, 332-340.	USA	Use actuarial risk
Brown (1980) Equalizing differences in the labor market, Quarterly Journal of Economics 94: 113-134	USA	Use actuarial risk
Dillingham, Alan E. (1979). The Injury Risk Structure of Occupations and Wages. Unpublished Ph.D. Dissertation. NY: Cornell University.	USA	Use actuarial risk
Hammitt, James K., Jin-Tan Liu, and Lin-Long Liu. (2000). Survival is a Luxury Good: The Increasing Value of a Statistical Life. Working Paper Prepared for the NBER Summer Institute Workshop on Public Policy and the Environment. Cambridge, Massachusetts.	Taiwan	Study in non high-income OECD member
Kim, Seung-Wook and Price V. Fishback (1999). "The Impact of Institutional Change on Compensating Wage Differentials for Accident Risk: South Korea 1984-1990", Journal of Risk and Uncertainty 18, 231- 248.	Korea	Study in non high-income OECD member
Kniesner, Tomas J. and John D. Leeth. (1991). "Compensating Wage Differentials for Fatal Injury Risk in Australia, Japan, and the United States", Journal of Risk and Uncertainty 4, 75-90.	USA	No VSL estimate
	JAPAN	No VSL estimate
	Australia	No VSL estimate
Lanoie, Paul, Carmen Pedero, and Robert Latour. (1995). "The Value of a Statistical Life: a Comparison of Two Approaches", Journal of Risk and Uncertainty 10, 235-257.	Canada	Use extremely dangerous job (firemen), small sample
Liu, Jin-Tan, James K. Hammitt, Jin-Long Liu (1997). "Estimated Hedonic Wage Function and Value of Life in a Developing Country", Economics Letters 57, 353-358.	Taiwan	Study in non high-income OECD member
Liu, Jin-Tan and James K. Hammitt (1999). "Perceived Risk and Value of Workplace Safety in a Developing Countries", Journal of Risk Research 2, 263-275.	Taiwan	Study in non high-income OECD member

Low, Stuart A. and McPheters L.R. (1983). "Age Differentials and Risk of Death: an Empirical Analysis", Economic Inquiry 21, 271-280.	USA	Use extremely dangerous job sample (policemen)
Moore, Michael J. and W.K.Viscusi (1989). The Quality Adjusted Value of Life, Economic Inquiry 16, 369-388.	USA	Use actuarial risk
Moore, Michael J. and W.K. Viscusi. (1990). "Model for Estimating Discount Rate for Long Term Health Risks Using Labor Market Data", Journal of Risk and Uncertainty 3, 381-401.	USA	Use actuarial risk
Shanmugam, K.R. (1997). "Value of Life and Injury: Estimating Using Flexible Function Form", Indian Journal of Applied Economics 6, 125-136.	India	Study in non high-income OECD member
Siebert, W.S. and Xiangdong Wei. (1998). "Wage Compensation for Job Risks: the Case of Hong Kong", Asian Economic Journal 12, 171-181.	Hong Kong	Study in non high-income OECD member
Smith, Kerry V.and Carol C.S.Gilbert. (1984). "The Implicit Risks to Life: a Comparative Analysis, Economics Letters 16, 393-399	USA	No VSL estimate
Taylor, R. and Rosen S. (1976). The Value of Saving a Life: Evidence from the Labor Market, In. N.Terleckyz (eds.), Household Production and Consumption. New York, NBER.	USA	Use actuarial risk

Willingness to Pay for Reductions in Fatal Risk: A Meta-Analysis of the Value of Statistical Life Literature

--Working Paper*--

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*This is a working paper developed for the US Environmental Protection Agency National Center for Environmental Economics and National Center for Environmental Research's workshop, "Economic Valuation of Mortality Risk Reduction: Assessing the State of the Art for Policy Applications," held November 6-7, 2001 at the Holiday Inn Silver Spring Hotel in Silver Spring, MD.

WILLINGNESS TO PAY FOR REDUCTIONS IN FATAL RISK: A META-ANALYSIS OF THE VALUE OF STATISTICAL LIFE LITERATURE[1]

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November, 2001

[1] We thank Jim Democker, Bryan Hubbell, and Ellen Post for helpful discussions, and Matthew Nelson for able research assistance. We are also grateful to the EPA Science Advisory Board for comments on an earlier summary of the VSL literature. All errors are the responsibility of the authors.

WILLINGNESS TO PAY FOR REDUCTIONS IN FATAL RISK: A META-ANALYSIS OF THE VALUE OF STATISTICAL LIFE LITERATURE

INTRODUCTION

Accurate and appropriate estimates of the value of a statistical life (VSL) are crucial inputs in cost-benefit analyses of government regulations that reduce fatality risks. VSL estimates have been used to estimate the benefits of regulations affecting air quality (e.g., EPA 2000), transportation (e.g., Miller and Guria 1991), and worker health and safety (e.g., Viscusi 1993). The empirical literature related to VSL is voluminous, including at least 89 primary studies with VSL estimates spanning three orders of magnitude, from $0.1 million (Johannesson and Johansson 1997) to $53.1 million (Sandy and Elliot 1996).[2] Clearly, policy makers could make good use of guidance when wading through this literature in search of a VSL estimate appropriate for a particular application.

Recently, several narrative literature reviews (e.g., Fisher et al. 1989, Miller 1990, and Viscusi 1993) and meta-analyses (e.g., Desvousges et al. 1995, Miller 2000, Mrozek and Taylor 2001, and Kochi et al. 2001) have begun to provide such guidance. However, the estimates put forward in these literature reviews also span a wide range, from a low of $2.1 million (Mrozek and Taylor) to a high of $13.6 million (upper end of the range from Fisher et al.). Furthermore, many of these reviews focus only on a particular branch of the VSL literature or advocate results from only those studies that use favored methodologies or datasets. This general lack of consensus among economists continues to make the selection of a single VSL for policy analysis particularly challenging.

In this paper, we present the results of a preliminary meta-analysis of the VSL literature. Our study differs from existing meta-analyses in three ways. First, rather than focusing on a particular branch of the literature, we examine VSL estimates from a wide variety of studies, including wage-risk studies, contingent valuation studies, and consumer market studies. This

[2] All figures are in January 2001 U.S. dollars.

inclusiveness in the selection of the studies is strongly recommended in the guidelines for meta-analyses recently laid out by Stanley (2001). Second, we derive a single estimate from each study that reflects the judgement of the study authors, rather than culling multiple estimates from each study. In this way, we seek to avoid the result of giving greater consideration to studies that simply may have reported results from a greater number of model specifications. Third, we make the consequences of our assumptions regarding "best practice" study methodologies transparent to the reader. In previous studies, the effects of these assumptions may have been obscured or downplayed, at least in their presentation of recommendations of values appropriate for policy purposes. Our aim is to provide a broad and balanced analysis of the VSL literature, highlighting factors that have a systematic effect on VSL, which we argue is the critical first step in applying the rich VSL literature to public policy questions. We nonetheless remain in the early stages of our work; as a result, we are not advocating the use of any particular estimate from among our results at this time.

EXISTING REVIEWS OF THE VSL LITERATURE

> In the 26 years since the publication of Thaler and Rosen's (1975) seminal study of the relationship between fatal risks and wages, nearly 100 different empirical studies have investigated individuals' willingness to pay for reductions in fatal risks. The range of methodologies employed in these studies is quite broad. The most common type of study, the wage-risk study, involves an investigation of the relationship between workers' wages and the risk of fatal accidents on the job. With contingent valuation studies, researchers directly ask individuals about their willingness to pay for a specific reduction in fatal risk. The remaining studies are a diverse collection of consumer market analyses, in which researchers study markets where consumers have the opportunity to pay for reductions in fatal risks, such as the market for automobiles or smoke detectors. The VSL estimates in the literature span a wide range, from a low of $0.1 million to a high of $53.1 million.

Existing reviews of the VSL literature generally fall into two categories. The first category, the narrative literature review, involves a thorough discussion and synthesis of the trends, arguments, and uncertainties within the literature. With the exception of the presentation of summary statistics (e.g., mean and range of VSL), these narrative literature reviews are primarily qualitative in nature. The second category, the meta-analysis, includes both a narrative discussion of the literature and a quantitative statistical analysis of VSL, typically involving a regression where VSL is the dependent variable and independent variables describe the data set analyzed and relevant aspects of the study design. Exhibit 1 summarizes key characteristics of the existing VSL literature reviews.

Fisher et al. (1989) is one of the earlier published reviews of the VSL literature. In this narrative literature review, the authors discuss the results of 21 VSL studies, presenting data on the mean risk level, the range in VSL estimates, and the "judgmental best estimate" for each study. The 21 studies comprise wage-risk studies, consumer market studies, and contingent valuation studies. The authors conclude that the estimates from consumer market studies have important limitations, and that the data sets used in several wage-risk studies are, for a variety of reasons, inadequate. Examining the results of the remaining 13 "most defensible" studies, they recommend a VSL range of $2.6 to $13.6 million for policy analysis.

Miller (1990) casts a wider net in his narrative review, identifying 67 wage-risk, consumer market, and contingent valuation VSL studies, and classifying 32 of these studies as reasonably sound. Rather than discarding the remaining estimates, he makes a series of rather bold adjustments to VSL estimates from 15 of the wage-risk studies that he considers unsound, and he includes the adjusted estimates in his analysis. VSL estimates are adjusted for differences in risk perceptions, age, marginal tax rates, the type of risk data used, and for differences in the specification of the wage-risk equation. While these adjustments are clearly documented by Miller, many are based on inconclusive evidence from the literature. The mean VSL from all 47 studies (32 sound studies plus 15 adjusted unsound studies) is $3.3 million.

Miller's study was followed by Viscusi's (1993) influential and comprehensive narrative review of the VSL literature. Viscusi thoroughly discusses the methodological challenges that arise in conducting wage-risk, contingent valuation, and consumer market studies. Perhaps most important for future researchers, he presents summary statistics for 37 different VSL studies, including a single VSL estimate for each study, mean income, and mean risk. (As we discuss below, two later studies use the data presented in Viscusi's narrative literature review to conduct meta-analyses.) Viscusi concludes that the majority of reasonable estimates are clustered in the $4.0 to $9.4 million range. He places the "greatest reliance" on three of his own studies (Viscusi 1978, Viscusi 1979, and Moore and Viscusi 1988), which "include the most comprehensive set of non-pecuniary characteristic variables" and which define the endpoints of his recommended range. Following Fisher et al. (1989), Viscusi finds the consumer market studies less reliable than the wage-risk studies.[3]

While narrative literature reviews have been valuable for summarizing the VSL literature, identifying trends, and describing the effects of various methodological choices, there has been a distinct shift in recent years towards the more quantitative meta-analysis. Since the publication of Viscusi's narrative review, there have been at least six meta-analyses of the VSL literature, while no new narrative reviews have emerged. The belief among many researchers is that a well-designed meta-analysis provides a more formal and objective process for reviewing an empirical literature than the traditional narrative literature review (e.g., Stanley 2001).

Desvousges et al. (1995) conducted one of the earlier meta-analyses of the VSL literature. This study focuses exclusively on 29 wage-risk studies, using a dataset assembled entirely from summary statistics reported in the narrative literature reviews of Fisher et al. (1989) and Viscusi (1993). The authors do not use VSL as the dependent variable in their analysis. Instead, they use the compensating differential from each study, which represents the additional compensation provided to workers who face higher risks. Their results indicate an overall VSL estimate of $4.1 million.[4]

[3] The EPA Guidelines (2000) relies heavily on Viscusi's work in recommending a set of 26 VSL estimates for use in analyzing the benefits of EPA policies that reduce mortality risks. The Guidelines recommends using the mean VSL from these 26 studies, which is $6.4 million.

[4] Liu et al. (1997) also conduct a meta-analysis of wage-risk studies using data obtained exclusively from Viscusi (1993). However, their regression is designed simply as a rough check on the estimates they obtain from a primary analysis of Taiwanese wage data, and they do not develop an overall VSL estimate from their results.

Mrozek and Taylor's (2001) recent meta-analysis of wage-risk studies is somewhat more comprehensive in that the authors collected data from the primary studies rather than from narrative literature reviews. This provides an opportunity to gather information about numerous study design and sample characteristic variables. It also allows them obtain data on all VSL estimates from a given study in their analysis, rather than relying on the single estimate presented in narrative literature reviews. They obtain data on 203 VSL estimates from 33 different wage-risk studies.[5] After making various best practice assumptions regarding appropriate methodologies and datasets (e.g., they assume that a best practice study uses BLS rather than NIOSH data), they obtain an overall VSL of $2.1 million.

One of the key arguments in the Mrozek and Taylor paper is that wage-risk studies are mis-specified if the authors fail to control for inter-industry variation in wages through the use of industry dummy variables. As Leigh (1995) points out, differences in wages between broad industry classes (e.g., retail versus manufacturing) may not be entirely attributable to differences in risk; the differences may instead reflect working conditions or other factors. Thus, Mrozek and Taylor include methodological variables in their analysis to investigate the impact of this potential mis-specification. In obtaining their best practice VSL estimates, they incorporate a variable that puts greater weight on those studies that included five or more industry dummy variables in the underlying wage-risk regression. This incorporation of their proposed best practice control has the effect of reducing the predicted VSL by roughly a factor of two.

In contrast to Desvousges et al. (1995) and Mrozek and Taylor (2001), Takeuchi (2000) focuses exclusively on the contingent valuation VSL literature, analyzing data from 69 willingness-to-pay estimates drawn from 25 studies. Like Desvousges et al. (1995), he does not use the reported VSL as a dependent variable, but instead regresses actual willingness to pay on the size of the risk change and other study characteristics in order to investigate sensitivity to scope (for which he finds weak evidence). Takeuchi does not use his estimation results to obtain an overall VSL estimate.

[5] Each study received a weight of 1/N during estimation, where N equals the number of VSL estimates drawn from that study. This approach allows each study to have equal weight, regardless of the number of VSL estimates presented.

Perhaps the principal disadvantage of these meta-analyses is that they focus only on a particular branch of the literature—either wage-risk studies or contingent valuation studies. Two recent studies, Miller (2000) and Kochi et al. (2001), attempt to be more comprehensive. Miller examines the results from 68 studies, including wage-risk, contingent valuation, and consumer market studies. In calculating an overall VSL estimate, Miller assumes that wage-risk studies are more appropriate due to concerns about the effect of altruism on the results from contingent valuation studies. He presents an overall VSL estimate of $4.3 million for the United States.[6]

Kochi et al.'s (2001) analysis represents a departure from the recent literature in that empirical Bayesian techniques are applied in order to incorporate the precision of each VSL estimate during estimation (see, e.g., Raudenbush and Bryk, 1985).[7] The authors argue that by using VSL as a dependent variable in a traditional regression framework, standard meta-analyses give the same weight to VSL estimates with varying levels of precision and are therefore inefficient. The dataset consists entirely of studies conducted in developed countries, including 52 separate VSL estimates from 13 wage-risk studies and 7 contingent valuation studies. Kochi et al. obtain an overall mean VSL of $6.4. Because the Kochi et al. methodology does not involve the use of study characteristics to explain variation in VSL, the authors do not need to make any best practice assumptions in calculating an overall mean VSL. However, the authors do apply several selection criteria designed to eliminate studies deemed to be low quality.

As this discussion indicates, the quantitative meta-analysis is not necessarily more objective than the narrative literature review. When an "overall estimate" of VSL is desired from a meta-analysis, the researcher must assign values to methodological dummy variables in order to use the estimated regression coefficients to obtain a VSL estimate. The choice of these values is necessarily somewhat arbitrary, and different researchers will make different choices.

[6] Miller adjusts many of the labor market VSL estimates downwards prior to including them in his regression. This adjustment is intended to account for the fact that researchers typically use data on *pre-tax* wages, while we are interested in individuals' willingness to pay for risk reduction with *after-tax* dollars.

[7] Mrozek and Taylor (2001) also investigated the possibility of incorporating information about precision in their analysis, but they abandoned this effort after finding "insufficient reporting of standard errors or exact t-statistics, and complex interaction terms between risk and other covariates (see footnote 12)."

In the narrative literature review, the author tends to present a series of VSL estimates and then argue that a subset of those estimates use inappropriate methodologies or datasets and should be discounted. Thus, both approaches to summarizing the literature require that the researcher make subjective decisions. This is not surprising, nor is it necessarily undesirable; these subjective decisions are what add value to what otherwise could be a stale and uninformative presentation of data. However, it is important that the consequences of these subjective methodological decisions be transparent to the reader.

METHODOLOGY

We conduct a quantitative meta-analysis of the VSL literature. We choose this approach over a narrative literature review because it allows us to investigate the influence of various sample characteristics (e.g., age or income) on VSL. By including these characteristics, we provide policy analysts with a functional relationship that will allow them to tailor VSL to specific populations. In addition, a meta-analysis allows us to use statistical techniques to investigate systematic effects of different methodologies or datasets on VSL.

In contrast to Mrozek and Taylor (2001), Kochi et al. (2001), and Desvousges et al. (1995), we include estimates in our analysis from *all* legitimate VSL studies that we identified. That is, we allow the statistical analysis to reveal any systematic effects due to inappropriate methodologies or datasets rather than completely eliminating such studies. Thus, we include wage-risk, contingent valuation, and consumer market studies in our analysis. As we discuss in the next section, we exclude only pilot studies, literature reviews, studies that do not estimate VSL based on individual willingness-to-pay (e.g., public choice studies), and several consumer market studies that provide lower bound VSL estimates by design.

Quite often, several different VSL estimates are reported in a single study. For example, wage-risk studies often examine the wage-risk relationship using different functional forms, and contingent valuation studies often report VSL estimates for several different risk reduction survey questions. Following Stanley (2001) and Miller (2000), we select a single VSL estimate from each study, and we use only these selected estimates in our analysis. This differs from the approach taken in Mrozek and Taylor (2001) and Kochi et al. (2001), who include all VSL estimates presented in a given study, arguing that each estimate provides potentially useful information.

We rejected this approach because in most of the studies, the authors recommend only a subset of the VSL estimates that they present. For example, Gayer et al. (2000) estimate VSL by combining a risk perceptions model with a standard hedonic property value model. They present seven VSL estimates. Three of the estimates are approximately \$55 million and represent a situation where consumers are uninformed about true risk levels. Four of the estimates are approximately \$4 million and represent a situation where consumers are informed about risk levels. The authors recommend the \$4 million dollar VSL, and this is the estimate that we use in our analysis. As a second example, Jones-Lee (1989) present VSL estimates from contingent valuation questions using both mean willingness to pay and trimmed mean willingness to pay. They recommend the VSL estimates based on trimmed means, because the survey code for "would pay 10,000 pounds or more" differs by only one digit from the survey code for "don't know." As a result, they had reason to suspect that many of the outliers in their dataset were actually interviewer coding errors. We follow the authors' guidance and use the VSL estimates based on trimmed means.

We recognize that this approach may allow the subjective judgement of the author to influence our results. However, the author's judgement already permeates each study; it is reflected in the choice of data and methodology and in decisions regarding which results to present to the reader. Thus, we consider following the author's judgement in selecting a single estimate from each study to be a natural extension of using the study in our analysis at all.

After selecting a single VSL estimate and coding the relevant characteristics of each study, we estimate the parameters of a VSL equation,

(1) $$VSL = f(X, Z; J, e),$$

where X represents a vector of methodological variables, Z represents a vector of sample characteristics, ϑ represents the vector of parameters to be estimated, and ε is a random error term. In estimating such an equation, we are assuming that at least a portion of the substantial observed variation within the VSL literature is systematic and explainable.

Next, we choose specific values for *X* and *Z*, and we use our estimate of ϑ to obtain predicted values for VSL. Clearly, these predicted values will depend not only on the estimated parameters, ϑ, but also on the choice of methodology, *X*, and population characteristics, *Z*. In selecting values for *X*, the researcher's judgement can potentially affect the results of a meta-analysis and undermine its purported objectivity. For example, the researcher could choose to present a predicted VSL that is appropriate only for wage-risk studies or only for contingent valuation studies. We try to avoid this pitfall by presenting the results from several potential choices for *X*.

DATA AND EMPIRICAL SPECIFICATION

We reviewed the economics and social sciences literature to identify studies that report an estimate of the value of a statistical life. An online search was conducted (using Dialog) to identify potentially relevant articles, book chapters, working papers, and government reports. We also interviewed numerous academic and government researchers working in this area to identify more recent work.

Over the last three decades, at least 93 empirical studies have investigated willingness-to-pay for reductions in fatal risks and presented an estimate for VSL. An initial review of these 93 studies indicated that some were inappropriate for our analysis. We omitted studies from further consideration if they fell into one or more of the following categories:

- *Pilot studies*: These studies report the results of a pilot survey or preliminary analysis (e.g., Krupnick et al. 1999).
- *Studies estimating WTP for fewer deaths within the general population*: These studies ask individuals for their willingness to pay to reduce a particular number of deaths in the general population, rather than their willingness to pay to reduce the probability of their own death (e.g., Cookson 2000).

- *Public choice studies*: These studies estimate VSL by evaluating the decisions of government agencies rather than the decisions of individuals (e.g., Ghosh, Lees, and Seal 1975).

- *Literature reviews*: These studies review existing studies (e.g., Miller 2000), conduct a meta-analysis (e.g., Mrozek and Taylor 2001), apply a transformation to an earlier VSL estimate (e.g., Jones-Lee and Loomes 1995), or replicate the results of an earlier published study (e.g., Viscusi 1979) rather than analyzing an original data set.

- *Studies estimating WTP for a reduction in someone else's risk*: These studies estimate Individual A's willingness to pay for a reduction in risk to Individual B. (e.g., Carlin and Sandy 1991).

- *Studies reporting lower bound VSL estimates*: These studies report a lower bound estimate of VSL rather than an unbiased point estimate (e.g., Dardis 1980, Blomquist 1979).

The 33 studies omitted from the analysis are listed in Exhibit 2 along with the justification for the omission in each case.

After omitting these 29 studies, 60 relevant VSL studies remained for our analysis (Exhibit 3). We reviewed each of these studies in detail and recorded the VSL estimate as well as other information about the dataset and the empirical methodology applied. Whenever possible, we followed the author's judgement in choosing a single VSL estimate from each study. When the author recommends a range rather than a single VSL estimate, we recorded the midpoint of the range. When several VSL estimates are reported but the author does not recommend any particular estimate, we recorded the arithmetic mean of the estimates. Several wage-risk studies investigate the effect on VSL of controlling for non-fatal risk (e.g., Viscusi 1978, Dreyfus and Viscusi 1995, Cousineau et al. 1992). In these cases, we recorded the VSL estimate calculated from the regression that controlled for non-fatal risks.

When the estimates within a single study are derived from different risk datasets, we include the VSL estimates associated with each dataset independently in our analysis. For example, Gegax, Gerking, and Shultze (1991) report the estimates from two separate hedonic wage equations in their paper. One wage equation uses data on self-reported risk perceptions, while the other uses risk data from the Bureau of Labor Statistics. Thus, we include this study as two independent VSL estimates in our analysis.

We converted all estimates to January 2001 U.S. dollars using the Bureau of Labor Statistics Consumer Price Index for all urban consumers (CPI-U). For estimates reported in foreign currency, we first converted to U.S. dollars using data on Purchasing Power Parity from the Organization for Economic Cooperation and Development, then converted to January 2001 U.S. dollars using the CPI-U. In cases where the VSL estimate is reported without a currency year, we used the year of the survey. In cases where no survey year is reported, we used the year of publication.

The 60 studies identified encompass a wide variety of analytical techniques and data sets. The majority of the studies are from the United States (35 studies), Canada (7 studies), Great Britain (6 studies), Taiwan (3 studies), or Sweden (3 studies), with the remainder originating in Australia, New Zealand, Hong Kong, South Korea, Denmark, and India (1 study each). The 60 studies are dominated by wage-risk (41 studies) and contingent valuation (15 studies) analyses, with three consumer market studies and one hedonic property value study. With the exception of three working papers, all of the 60 studies have been published in academic journals, books, or government reports.

The entire distribution of VSL estimates from the 60 studies is presented in Exhibit 4. While over half of the VSL estimates are less than $6 million, the distribution is skewed with a long tail to the right. The VSL estimates range from $0.1 million to $53.2 million, with a mean of $8.3 million and a median of $5.3 million. In comparison, the EPA Guidelines recommended VSL is $6.4 million. Thus, the mean VSL from these 60 studies is 30 percent higher than the prevailing VSL recommendation in the EPA Guidelines. This difference is due in part to three wage-risk studies that report VSL estimates over $25 million. These three studies are not reflected in a five percent trimmed mean, which eliminates five percent of the studies at the upper and lower tails of the distribution. The trimmed mean of the 60 studies is $7.1 million.

The distribution of VSL estimates by study type is presented in Exhibit 5. It appears that the contingent valuation studies generally report VSL estimates that are lower than the estimates reported in wage-risk studies. This is confirmed through a comparison of means: the mean VSL estimate from wage-risk studies is 68 percent higher than the mean estimate from contingent valuation studies.

In order to examine potential time trends in the data, we plotted the VSL estimates versus study vintage in Exhibit 6. In constructing this exhibit, the year of the source data was used rather than the year of publication, as the year of publication often lags the collection of data by several years.

A cursory visual analysis of this exhibit indicates that there may be an upward trend in the VSL estimates over time, beginning in 1985. Over time, as empirical techniques and the quality of available data sets improve, one would expect VSL estimates to converge. Exhibit 6 indicates that the opposite may be occurring: the estimates appear to be more scattered in recent years. This is confirmed through a comparison of variances: the variance of pre-1985 studies is $25.7 million, while the variance of post-1985 studies is $140.3 million. The underlying cause of this lack of convergence of VSL estimates is unclear.

The definitions and means of the independent variables used in our analysis are presented in Exhibit 7. We expect that VSL will be positively related to mean income (INCOME), as several empirical studies have found the income elasticity of VSL to be positive (see, for example, Jones-Lee et al. 1989, Miller and Guria 1991, and Mitchell and Carson 1986). Mean income data was not reported in approximately one third of the studies. For these studies, we tried to obtain income data from another study that used a similar dataset. When no other study used a similar dataset, we used country-level data on mean income for the appropriate year.

We also suspect that VSL estimates may be related to the level of development and type of economy that exists in the country where the study was conducted. For example, in countries with efficient markets and adequate information about workplace risks, workers are more likely to be compensated for jobs with higher risk of fatal accidents. In order to capture this effect, we include a dummy variable that is equal to one if the data for the study was collected in an OECD member country. OECD member countries are generally highly developed and have a stated commitment to a market economy.

We include two dummy variables to represent the general type of study conducted. Thus, CV is equal to one for contingent valuation studies and LABOR is equal to one for wage-risk studies. The omitted category is consumer market studies. We suspect that the contingent valuation coefficient will be smaller than the LABOR coefficient, as the mean age of respondents in contingent valuation surveys tends to be somewhat older than the mean age of individuals represented in wage-risk studies (who, of course, must be of working age). Jones-Lee (1989) and his subsequent re-analysis (Jones-Lee et al. 1993) provide empirical evidence that VSL declines with age after about age 55, and declines rapidly after about age 65.

Three variables included in our analysis are only germane for wage-risk studies, so we interact these variables with the LABOR dummy variable. First, we expect that the baseline level of risk may influence VSL in wage-risk studies, although we do not have any *a priori* expectations about the sign of this variable (LABOR*RISK). On one hand, theoretical work has shown that as risk levels increase, individuals will be willing to pay more for a given amount of risk reduction (the "dead anyway" effect; see Pratt and Zeckhauser 1996). On the other hand, there may be a self selection of less risk averse workers into dangerous jobs, so that wage-risk studies using data exclusively from high-risk industries would obtain lower VSLs. Second, we expect that studies controlling for non-fatal risks will obtain lower VSL estimates (LABOR*NONFATAL). Non-fatal risks tend to be positively correlated with fatal risks, so that omitting non-fatal risks in a wage-risk regression would lead to a fatal risk coefficient (and hence VSL) that is biased upwards. Third, there has been widespread criticism in the wage-risk literature of studies that use actuarial data, as these data are thought to poorly reflect on-the-job risk of death. We include an interaction term (LABOR*ACTUARIAL) in order to investigate the effect of using such data.

Several authors have expressed concern about VSL estimates from contingent valuation studies where willingness to pay is insensitive to the magnitude of the risk change (see e.g., Hammitt and Graham, 1999). Thus, we include a dummy variable in our analysis that indicates whether or not the study passes a scope test (SCOPETEST), and we interact this variable with a contingent valuation dummy (CV). In constructing this variable, we assume that a study passes a scope test if willingness to pay is approximately proportional to the size of the risk change.

We use a semi-log functional form in estimation, with the natural logarithm of VSL as the dependent variable. We choose this form primarily because the distribution of VSL estimates is skewed to the right (see Exhibit 4). By taking the natural logarithm of VSL, we obtain a distribution that is closer to a normal distribution and therefore more appropriate for a statistical analysis where the error term is assumed to be normal. In addition, the semi-log form restricts VSL to be non-negative, which is theoretically desirable. We also experimented with the double-log and linear forms, but we found that the semi-log form provided the best fit for our data.[8]

[8] For Model 1, we obtain an r-squared of 0.38 using the semi-log form versus 0.37 and 0.18 for the double-log and linear forms, respectively.

RESULTS

The parameter estimates for two different specifications of the model are presented in Exhibit 8. In Model 1, the coefficients on INCOME and OECD are positive and significant at the five percent level, while the coefficient on LABOR*ACTUARIAL is negative and significant at the five percent level. The remaining coefficients are not significantly different from zero. The magnitude of the INCOME coefficient implies that a $1,000 increase in income leads to a 3.2 percent increase in VSL. Evaluating this change at the mean income across all studies ($27,000), we obtain an income elasticity of 0.86. The positive coefficient on OECD indicates that studies conducted in OECD countries obtain higher VSL estimates, and the negative coefficient on LABOR*ACTUARIAL indicates that labor market studies using actuarial data obtain VSL estimates that are lower than the estimates from other labor market studies.

Model 2 is identical to Model 1, except that the OECD variable has been omitted. We omit this variable because INCOME and OECD are highly correlated (correlation coefficient of 0.53), which may lead to a downward bias in the INCOME coefficient in Model 1, with the OECD coefficient capturing a portion of the impact of INCOME on VSL. The parameter estimates from Model 2 indicate that this may indeed be the case: the parameter on INCOME increases by nearly 50 percent when OECD is omitted from the model, leading to an income elasticity estimate of 1.3 (again evaluated at an income level of $27,000). Otherwise, the results are generally consistent with the results from Model 1.

Although we are reasonably confident in concluding that income, country-of-origin, and type of labor market data all have a significant effect on VSL, we are somewhat disappointed by our inability to explain more of the variation in VSL estimates. Our r-squared is relatively low (0.38), and only three of our estimated coefficients are significantly different from zero. We experimented with a number of other variables, including squared terms, a NIOSH data dummy for labor market studies, a series of time trend variables, mean age, variables describing the type of risk scenario used in contingent valuation surveys, and a dummy variable for U.S. studies. None of these variables led to a significant improvement in our ability to explain VSL.

Despite these reservations, we continue with the next step, which is to use our parameter estimates (and the variance-covariance matrix) to obtain predicted values for VSL. These values are intended to be illustrative, as our dataset is preliminary and we continue to experiment with approaches to estimation. In predicting VSL, we focus on the parameter estimates from Model 1. The first step in predicting VSL is to choose values for the explanatory variables included in estimation. Several of these variables represent methodological choices, so that choosing a single value can often be difficult. For example, setting the LABOR variable equal to one and the CV variable equal to zero leads to a predicted VSL for wage-risk studies, but there is clearly no consensus that wage-risk studies are more appropriate than contingent valuation and consumer market studies. As we discuss in our literature review, this is the point where the author's judgement can have an enormous influence on the results of a meta-analysis.

We present VSL estimates under several different methodological assumptions in an effort to make the consequences of these assumptions transparent. The coefficients associated with only three of our explanatory variables, INCOME, OECD, and LABOR*ACTUARIAL were significantly different from zero. Rather than investigating the sensitivity of VSL to our assumption about LABOR*ACTUARIAL, we set ACTUARIAL equal to zero for all VSL predictions, as there is general agreement among researchers that actuarial data are inappropriate for wage-risk studies. In addition, we set OECD equal to one for all VSL predictions, as we expect the results of our analysis to be applied only within the United States. In order to investigate the sensitivity of our predicted VSL to mean income, we use values for INCOME of $25,000, $30,000, and $35,000. Because the LABOR dummy variable was nearly significant at the ten percent level, we also investigate the sensitivity of predicted VSL to our assumption regarding study type. Given the insignificant coefficients, our methodological assumptions regarding the remaining variables are unlikely to effect our results. These assumptions are as follows: NONFATAL = 0, RISK = 0.5, and SCOPE = 1. We use a value of 0.5 for RISK because the approximate mean annual risk of death for all U.S. workers is 0.5 in 10,000.

To obtain VSL predictions, we first multiply these values for the independent variables by their respective coefficients, sum over all variables, then take the anti-log of the sum. In the semi-log specification we are using, this relatively straightforward calculation results in estimates of the *median* of the distribution of VSL. In order to recover the mean of the distribution, we must multiply our estimate of the median by $\exp(s^2/2)$, where s^2 is the estimated variance of log(VSL).[9]

[9] If the error term is normally distributed then z = logVSL is also distributed normally, with a probability density function (pdf) given by $f(z) = \frac{1}{2sp}\exp\left[-\frac{z-m}{2s^2}\right]$, with mean = μ and variance = σ^2. Using a

The mean predicted VSLs under various assumptions regarding income and study type are presented in Exhibit 9. The VSLs for consumer market studies are the lowest, ranging from $3.4 million (with mean income of $25,000) to $4.7 million (with mean income of $35,000). Contingent valuation studies provide intermediate VSLs, ranging from $5.6 million to $7.8 million, while wage-risk studies provide the highest VSLs, ranging from $7.0 million to $9.7 million. Clearly, these VSL estimates vary substantially with our assumed mean income level. Considering only the estimates corresponding to mean income equal to $30,000 our estimates are $4.0 million for consumer market studies, $6.6 million for contingent valuation studies, and $8.2 million for wage-risk studies. These estimates approximately mirror Viscusi's recommended range of $4.0 million to $9.4 million but are substantially higher than the estimates obtained in recent meta-analyses by Desvousges et al. (1995), Miller (2000), and Mrozek and Taylor (2001). For comparison, the estimate recommended in EPA's *Guidelines for Economic Analyses* is $6.4 million (U.S. EPA 2000).

CONCLUSION

The wide range of VSL estimates presented in the economics literature can be particularly vexing to policy analysts. With estimates in primary studies ranging from $0.1 million to $53.1 million and the estimates in literature reviews ranging from $2.1 million to

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transformation of variables, it can then be shown that the pdf for x = VSL is given by $f(x) = \frac{1}{x * 2s p} \exp\left[-\frac{\log x - m}{2s^2} \right]$. This is the pdf of a lognormal distribution with median equal to exp(μ) and mean equal to $\exp(m) * \exp(s^2/2)$.

$13.6 million, it is difficult to choose an appropriate VSL for use in benefit cost analyses of government regulations. Much of the substantial variation in VSL estimates from primary studies is of course due to differences in methodologies as well as differences in the characteristics of the study population. We find that methodological choices may also contribute to the wide disparity in VSL estimates recommended by reviewers of the VSL literature. Both narrative literature reviews and meta-analyses impose "best practice" assumptions in obtaining an overall VSL estimate or range of estimates, and the effect of these assumptions can be substantial.

We argue that while best practice methodological assumptions are necessary, it is important that the impact of these assumptions be transparent to the reader. We present overall VSL estimates for three types of studies (wage-risk studies, contingent valuation studies, and consumer market studies), and we investigate the sensitivity of these estimates to our assumptions regarding income. Our remaining best practice methodological assumptions have a relatively small effect on our VSL results. We obtain overall VSL estimates ranging from a low of $3.4 million (for consumer market studies and income of $25,000) to a high of $9.7 million (for labor market studies and income of $35,000). As our results are preliminary, we present neither a single recommended "best estimate" nor a recommended range.

These results, when finalized, will complete the critical first step in improving the use of existing mortality valuation literature in regulatory analyses - defining a base VSL value suitable for benefits transfer. More important than the best practices estimates we derive, the meta-analytic equation provides a basis for facilitating a benefits transfer, by providing coefficients for transferring estimates across individual and risk characteristics such as population income and, as we finalize this work, population age. Additional work is needed to develop a working "best practice" assumption that weights results from wage-risk, contingent valuation, and consumer market studies. For example, it is possible that one class of studies may be more suitable for a particular regulatory analytic application owing to the nature of the risk-dollar tradeoff inherent in the method. Additional work also is needed to characterize the uncertainty around these estimates to support quantitative uncertainty analyses that inform decision makers about the robustness of benefit-cost comparisons.

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Exhibit 1: Summary of VSL Literature Reviews

Study	Type of Review	Types of Studies Included[a]	Recommended VSL (millions of January 2001 dollars)	Comments
Fisher et. al (1989)	Narrative	WR, CV, CM	$2.6 to $13.6	Excludes consumer market studies in developing a recommended range for VSL.
Miller (1990)	Narrative	WR, CV, CM	$3.3	Adjusts VSL estimates for age, risk perceptions, taxes, and other factors.
Viscusi (1993)	Narrative	WR, CV, CM	$4.0 to $9.4	Excludes consumer market and contingent valuation studies in developing a recommended range for VSL.
Desvousges et al. (1995)	Meta-Analysis	WR	$4.1	Uses compensating differential (rather than VSL) as dependent variable.
Takeuchi (2000)	Meta-Analysis	CV	No overall estimate provided	Uses willingness to pay (rather than VSL) as dependent variable. Uses multiple estimates from each study.
Miller (2000)	Meta-Analysis	WR, CV, CM	$4.3	Assumes best practice study is wage-risk study in obtaining recommended VSL estimate. Adjusts wage-risk VSLs downwards to obtain after-tax estimates.
Kochi et al. (2001)	Empirical Bayesian Meta-Analysis	WR, CV	$6.4	Estimation approach incorporates precision of VSL estimate. Uses multiple estimates from each study. Excludes studies conducted in developing countries.
Mrozek & Taylor (2001)	Meta-Analysis	WR	$2.1	Uses multiple estimates from each study. Assumes best practice study includes industry dummies and uses BLS data (rather than NIOSH data).

Notes:
[a] WR = Wage-risk, CV = Contingent valuation, and CM = Consumer market.

Exhibit 2: VSL Studies Omitted from the Analysis

Study	Justification for Omitting Study: Pilot study	Estimates WTP for fewer deaths within the general population	Public choice study	Meta analysis, literature review, or transformation of earlier VSL estimate	Estimates WTP for a reduction in someone else's risk	Estimates lower bound for VSL	Notes
Acton (1973)	X						
Aimola (1998)		X					Cancer CV study
Beattie et al. (1998)	X						
Blomquist (1979)						X	Seat belt study
Blomquist (1981)				X			Literature survey
Bowland and Beghin (1998)				X			Meta-analysis
Carlin and Sandy (1991)					X		Infant car seat study
Cookson (2000)		X					CV study
Dardis (1980)						X	Smoke detector study
Desvousges, Johnson, and Banzhaf (1995)				X			Meta-analysis
Desvousges, Johnson, and Banzhaf (1998)				X			Meta-analysis
Fisher et al. (1989)				X			Literature review
Garbacz (1989)						X	Smoke detector study
Garbacz (1991)						X	Smoke detector study
Ghosh, Lees, and Seal (1975)			X				Study of optimal highway speed
Halvorsen (1999)		X					
Jenkins, Owens, and Wiggens (1999)						X	Bicycle helmet study
Jones-Lee (1976)	X						
Jones-Lee, Hammerton, and Philips (1985)				X			Replicates Jones-Lee (1985)
Jones-Lee and Loomes (1995)				X			Authors calculated VSL by tranforming previous estimate.
Jones-Lee and Loomes (1994)	X						
Kochi et al. (2001)				X			Meta-analysis
Krupnick, et al. (1999)	X						
Ludwig and Cook (1999)		X					Gun violence CV study
McDaniels, Kamlet, and Fischer (1992)		X					
Magat, Viscusi, and Huber (1996)				X			Based on previous study.
Miller (1990)				X			Literatture review
Miller (2000)				X			Literature review
Mrozek and Taylor (2000)				X			Meta-analysis
Savage (1990)				X			Meta-analysis
Shanmugam (2000)				X			Replicates Shanmugam (1997)
Takeuchi (2000)				X			Meta-analysis
Viscusi (1979)				X			Replicates Viscusi (1978)
Viscusi (1993)				X			Literature review

Exhibit 3: VALUE OF LIFE STUDIES

Study ID	Author and Year	Publication	VSL (million January 2001 $)	Method	Country	Mean Annual Risk of Death (X in 10,000)[a]	Risk Data	Individual Data	n
1	**Arabsheibani and Marin (2000)**	Journal of Risk and Uncertainty	28.7	Labor market	Great Britain	Not reported	Occupational Mortality Decennial Survey (3-digit level), 1979 to 1983	General Household Survey, 1980s	3,608
2	**Arnould and Nichols (1983)**	Journal of Political Economy	1.2	Labor market	U.S.	10	Society of Actuaries	U.S. Census	
3	**Atkinson and Halvorsen (1990)**	Review of Economics and Statistics	5.4	Consumer market	U.S.	2.1 (median)	Fatal Accident Reporting System Database of the National Highway Traffic Safety Administration	NA	112
4	**Berger and Gabriel (1991)**	Applied Economics	8.5	Labor market	U.S.	2.5 to 2.9	Bureau of Labor Statistics (BLS,three-digit level), 1979	U.S. Census, 1980	14,979 to 22,837

5	**Butler (1983)[c]**	Book Chapter	1.2	Labor market	U.S.	0.47	South Carolina Industrial Commission, 1940 to 1970	South Carolina Department of Labor, 1940 to 1970	468
6	**Buzby, Ready, and Skees (1995)**	Journal of Agricultural and Applied Economics	5.0	Contingent valuation	U.S.	0.5	Environmental Protection Agency estimates of cancer risks from pesticide consumption	Telephone/mail survey, 1992	512
7	**Carthy et al. (1999)**	Journal of Risk and Uncertainty	1.7	Contingent valuation	Great Britain	1.0	NA	In-person survey, 1997	167
8	**Corso, Hammitt, and Graham (2000)**	Journal of Risk and Uncertainty	3.9	Contingent valuation	U.S.	2.25	NA	Telephone survey, 1998 to 1999	264
9	**Cousineau, Lacroix, and Girard (1992)[c]**	Review of Economics and Statistics	5.1	Labor market	Canada	0.76	Quebec Compensation Board (seven-digit level), 1981 to 1985	Labour Canada, 1979	32,713
10	**Dillingham (1985)[c]**	Economic Inquiry	3.9	Labor market	U.S.	1.4 and 0.83	BLS (three-digit level), 1970.	Quality of Employment Survey (QES), 1977	514
11	**Dillingham, Miller, and Levy (1996)**	Applied Economics	4.8	Labor market	U.S.	Not reported	U.S. Census and Workers' Compensation Data, 1977	QES, 1977	513

12	**Dreyfus and Viscusi (1995)**	Journal of Law and Economics	3.8	Consumer market	U.S.	1.96	U.S. Department of Transportation Fatal Accident Reporting System, 1989	Residential Transportation Energy Consumption Survey (U.S. Department of Energy), 1988	1,775
13	**Garen (1988)[c]**	Review of Economics and Statistics	17.7	Labor market	U.S.	Not reported	BLS (three-digit level), 1980 and 1981	Panel Study of Income Dynamics (PSID), 1981-1982	2,863
14	**Gayer, Hamilton, and Viscusi (2000)**	Review of Economics and Statistics	4.6	Hedonic property value	U.S.	0.02	Calculated from U.S. Environmental Protection Agency Remedial Investigation data	Sample of houses sold in greater Grand Rapids, 1988-1993.	16,928
15	**Gegax, Gerking, and Schulze (1991): Perceived risk data[c]**	Review of Economics and Statistics	2.9	Labor market	U.S.	6.5 (perceived risk)	Individual perceived risk of death on the job, 1984 survey	Mail survey, 1984	737
16	**Gegax, Gerking, and Schulze (1991): BLS risk data[c]**	Review of Economics and Statistics	16.9	Labor market	U.S.	Not reported	BLS (two-digit level), 1984	Mail survey, 1984	737
17	**Gerking, de Haan, and Schulze (1988)[c]**	Journal of Risk and Uncertainty	4.5	Contingent valuation	U.S.	6.5 (perceived risk)	Individual perceived risk of death on the job,	Mail survey, 1984	861

							1984 survey		
18	**Gill (1998)**	Social Science Journal	4.9	Labor market	U.S.	0.54	Workers' Compensation data from 11 states (three-digit level), 1977 to 1980	National Longitudinal Survey of Youth, 1984	2,139
19	**Hammitt and Graham (1999)**	Journal of Risk and Uncertainty	6.0	Contingent valuation	U.S.	2.0	NA	Telephone survey	973
20	**Hammitt, Liu, and Liu (2000)**	Working Paper	3.5	Contingent valuation	Taiwan	1.1 to 2.8	Taiwan Labor Insurance Bureau (two-digit level), 1982 to 1997	Taiwan Labor Force Survey, 1982 to 1997	6,912 to 10,092
21	**Herzog and Schlottmann (1990)[c]**	Review of Economics and Statistics	16.8	Labor market	U.S.	Not reported	BLS (three-digit level), 1971	U.S. Census, 1970	2,954
22	**Ippolito and Ippolito (1984)**	Journal of Public Economics	1.0	Consumer market	U.S.	Not reported	Scientific literature on the health effects of smoking	U.S. Department of Agriculture, 1980 (aggregate data)	NA
23	**Johannesson and Johansson (1997)**	Journal of Public Economics	0.1	Contingent valuation	Sweden	Not reported	NA	Telephone survey, 1995	2,824

24	**Johannesson, Johansson, and Lofgren (1997)**	Journal of Risk and Uncertainty	3.6	Contingent valuation	Sweden	Not reported	NA	Telephone survey, 1996	1,659
25	**Johannesson, Johansson, and O'Conor (1996)**	Journal of Risk and Uncertainty	10.7	Contingent valuation	Sweden	Not reported	NA	Telephone survey, 1995	389
26	**Jones-Lee (1989)[c]**	Book Chapter and Economic Inquiry	5.4	Contingent valuation	Great Britain	0.8 to 1.0	NA	In-person survey, 1982	950 to 999
27	**Kidholm (1995)**	Book Chapter	3.0	Contingent valuation	Denmark	1.1	NA	In-person survey, 1993	945
28	**Kim and Fishback (1999)**	Journal of Risk and Uncertainty	0.8	Labor market	South Korea	4.9	Korean Ministry of Labor's Analysis for Industrial Accident, 1984 to 1990	Korean Ministry of Labor's Report on Monthly Labor Survey, 1984 to 1990	321
29	**Krupnick et al. (2000)**	RFF Discussion Paper	2.2	Contingent valuation	Canada	123	NA	Self-administered computer survey, 1999	930
30	**Lanoie, Pedro, and Latour (1995): Contingent valuation**	Journal of Risk and Uncertainty	30.3	Contingent valuation	Canada	1.26 (actual risk)	NA	In-person survey, 1990	162
31	**Lanoie, Pedro, and Latour (1995): Labor market**	Journal of Risk and Uncertainty	22.7	Labor market	Canada	1.26 (actual risk; entire	Individual perceived risk of death on the job	In-person survey, 1990	63

						sample)			
32	**Leigh (1987)**[c]	Journal of Health Economics	14.2	Labor market	U.S.	Not reported	BLS (three-digit level), 1979 to 1984	QES, 1977; CPS, 1977	541 (QES) to 2,159(CPS)
33	**Leigh (1995): BLS Data**	Journal of Environmental Economics and Management	12.8	Labor market	U.S.	1.3	BLS (three-digit level), 1976, 1979 to 1981	PSID, 1981, CPS, 1977, and QES, 1977	1,528
34	**Leigh (1995): NIOSH Data**	Journal of Environmental Economics and Management	9.6	Labor market	U.S.	1.1	NIOSH (one-digit level, disaggregated by state), 1980 to 1985	PSID, 1981 and CPS, 1977	1,505
35	**Leigh and Folsom (1984)**[c]	Quarterly Review of Economics and Business	12.0	Labor market	U.S.	1.34	BLS (three-digit level), 1974 and 1977	PSID, 1974 and QES, 1977	361 (QES) to 1,592 (PSID)
36	**Liu and Hammitt (1999)**	Journal of Risk Research	0.7	Labor market	Taiwan	5.1	Individual perceived risk of death on the job	In-person survey, 1995	546
37	**Liu, Hammitt, and Liu (1997)**	Economic Letters	0.5	Labor market	Taiwan	2.9	Taiwan Labor Insurance Agency (three-digit level), 1982 to 1986	Taiwan Labor Force Survey, 1982 to 1986	17,250 to 18,987

38	**Low and McPheters (1983)**	Economic Inquiry	2.5	Labor market	U.S.	3.3	Federal Bureau of Investigation, 1972 to 1975	International City Management Association, 1976; City and County Data Book, 1977	72
39	**Marin and Psacharopoulos (1982)**[c]	Journal of Political Economy	5.6	Labor market	Great Britain	0.2	Office of Population Censuses and Survey's Occupational Mortality Decennial Supplement, 1970 to 1972	General Household Survey, 1975	5,509
40	**Martinello and Meng (1992)**	Canadian Journal of Economics	7.2	Labor market	Canada	2.5	Labour Canada, 1985 to 1986	Labour Market Activity Survey, 1986	4,352
41	**Meng (1989)**	Canadian Journal of Economics	4.1	Labor market	Canada	1.9	Labour Canada and Quebec Workman's Compensation Board (four-digit level), 1981	National Survey of Class Structure and Labour Process in Canada, 1981	718
42	**Meng and Smith (1990)**	Canadian Public Policy	6.9	Labor market	Canada	1.2	Labour Canada and Quebec Health and Safety Board, 1981 to 1983	Canadian National Election Study, 1984 to 1985	777

43	**Miller and Guria (1991)[c]**	Report to Ministry of Transport	1.7	Contingent valuation	New Zealand	6.0	NA	In-person survey, 1989 to 1990	308
44	**Miller, Mulvey, and Norris (1997)**	Economic Record	14.5	Labor market	Australia	0.7	Worksafe Australia, National Occupational Health and Safety Commission (two-digit level), 1992 to 1993	Australian Census of Population and Housing, 1991	18,850
45	**Moore and Viscusi (1988): NIOSH data[c]**	Journal of Policy Analysis and Management	8.3	Labor market	U.S.	0.79	NIOSH (one-digit level, disaggregated by state), 1980 to 1985	PSID, 1982	1,349
46	**Moore and Viscusi (1988): BLS data[c]**	Journal of Policy Analysis and Management	3.4	Labor market	U.S.	0.52	BLS (two-digit level), 1972 to 1982	PSID, 1982	1,349
47	**Moore and Viscusi (1988)**	Economic Inquiry	9.6	Labor market	U.S.	0.59	BLS (two-digit level), 1973 to 1976	QES, 1977	317
48	**Moore and Viscusi (1990)**	Journal of Risk and Uncertainty	7.8	Labor market	U.S.	Not reported	Not reported	Not reported	Not reported
49	**Olson (1981)[c]**	Journal of Human Resources	12.6	Labor market	U.S.	0.95	BLS (three-digit level), 1973	CPS, 1973	5,993

50	**Sandy and Elliott (1996)**	Economica	53.2	Labor market	Great Britain	0.45	Office of Population Censuses and Survey's Occupational Mortality Decennial Supplement, 1979 to 1980 and 1982 to 1983	Social Change and Economic Life Initiative Survey, 1986	440
51	**Scotton and Taylor (2000)**	Working Paper	20.1	Labor market	U.S.	0.49	BLS Census of Fatal Occupation Injuries (four-digit industry level, three-digit occupation level), 1992 to 1997	CPS, 1998	4,891
52	**Siebert and Wei (1994)**	Journal of Risk and Uncertainty	13.0	Labor market	Great Britain	0.38	Health and Safety Executive of the United Kingdom, 1986 to 1988	General Household Survey, 1983	2,062
53	**Siebert and Wei (1998)**	Asian Economic Journal	1.9	Labor market	Hong Kong	1.3	Employees Compensation Division, Labour Department of Hong Kong (two-digit industry level, three-digit occupation level)	Population Census, 1991	8,414

54	**Shanmugam (1997)**	Environmental and Resource Economics; Indian Journal of Applied Economics	1.0	Labor market	India	1.0	Administrative Report of the Chief Inspector of Factories, Madras, India (two-digit level), 1987 to 1990	In-person survey, 1990	522
55	**Smith (1974)[c]**	Law and Contemporary Problems	9.1	Labor market	U.S.	Not reported	BLS (three-digit level), 1966 and 1967	CPS, 1967	3,183
56	**Smith (1976)[c]**	Book Chapter	13.6	Labor market	U.S.	Not reported	BLS (three-digit level), 1966 and 1967	CPS, 1967 and 1973	3,183
57	**Thaler and Rosen (1975)**	Book Chapter	1.0	Labor market	U.S.	11	Occupation Study of the Society of Actuaries, 1967	Survey of Economic Opportunity, 1967	907
58	**Viscusi (1978)[c]**	Public Policy	5.5	Labor market	U.S.	1.18	BLS (three-digit level), 1969	Survey of Working Conditions, 1969 to 1970	496
59	**Viscusi (1981)[c]**	Research in Public Policy Analysis and Management	8.7	Labor market	U.S.	1.0	BLS (two digit level), 1973 to 1976	Panel of Income Dynamics, 1976	3,977
60	**Viscusi, Magat, and Huber (1991)[c]**	Journal of Environmental Economics and Management	3.5	Contingent valuation	U.S.	Not reported	NA	Self-administered computer survey	195

Notes:

[a] For contingent valuation studies, the baseline annual risk of death is reported.
[b] Unless otherwise noted, mean income is pre-tax individual income for labor market studies and pre-tax household income for contingent valuation studies.
[c] This study was among the 26 included in the 1992 IEc memorandum to EPA.

Study ID	Author and Year	Original VSL Reported in Study (Millions)	Selection of Single VSL from Study	Mean Income[b]	Other
1	**Arabsheibani and Marin (2000)**	9.7 (1985 British pounds)	Only one VSL reported	10,238 (1985 British pounds)	
2	**Arnould and Nichols (1983)**	0.9 (1990 $; from Viscusi 1992)	Only one VSL reported	Not reported	
3	**Atkinson and Halvorsen (1990)**	3.4 (1986 $)	Only one VSL reported	Not reported	Hedonic analysis of automobile prices

4	**Berger and Gabriel (1991)**	3.4 and 4.6 (1980 $)	Average the two estimates	19,755 to 20,249 (1980 $)	
5	**Butler (1983)[c]**	0.25, 0.26, and 0.18 (1967 $)	Average the three estimates	3,217 (after tax; 1967 $)	
6	**Buzby, Ready, and Skees (1995)**	4.1 (1993 $)	Only one VSL reported	Not reported	WTP for reduction in pesticide risk from grapefruit consumption
7	**Carthy et al. (1999)**	0.3, 0.4, 0.5, 0.6, 0.9, 1.0, 1.3, and 1.6 (1997 British pounds)	Select 1.0, the estimate recommended by the authors.	Not reported	
8	**Corso, Hammitt, and Graham (2000)**	2.4, 3.0, 3.2, 3.3, 3.7, 4.2, 4.7, and 5.7 (February 1999 $)	Average 3.2 and 4.2, the estimates recommended by the authors	46,000 (1999 $)	
9	**Cousineau, Lacroix, and Girard (1992)[c]**	3.2 (1986 $)	Only one VSL reported	16,580 (1986 $)	
10	**Dillingham (1985)[c]**	1.4, 1.7, 1.8, 2.6, 3.0, and 3.8 (1979 $)	Average 1.4, 1.7, and 1.8, the estimates recommended by the author	9,818 (1977 $)	
11	**Dillingham, Miller, and Levy (1996)**	1.3 to 2.0 (1977 $)	Average 1.3 and 2.0, the endpoints of the range recommended by the authors	8,540 (after tax; 1977 $)	
12	**Dreyfus and**	2.6, 3.1, and 3.7 (1988	Select 2.6, the	Not reported	

	Viscusi (1995)	$)	estimate that controls for non-fatal risk		
13	**Garen (1988)[c]**	4.0 and 9.2 (1981 $)	Select 9.2, the estimate recommended by the author	Not reported	
14	**Gayer, Hamilton, and Viscusi (2000)**	3.9, 3.9, 4.1, 4.6, 49.9, 51.1, and 51.3 (1996 $)	Average 3.9, 3.9, 4.1, and 4.6, the estimates recommended by the author	37,914 (median household income in census tract; 1996 $)	
15	**Gegax, Gerking, and Schulze (1991): Perceived risk data[c]**	0.8, 1.2, 1.6, and 2.1 (1983 $)	Average 1.2 and 2.1, the endpoints of the range recommended by the authors	21,361 (1983 $)	
16	**Gegax, Gerking, and Schulze (1991): BLS risk data[c]**	8.8, 9.8, and 11.8 (1983 $)	Average the three estimates	21,361 (1983 $)	
17	**Gerking, de Haan, and Schulze (1988)[c]**	2.66 and 6.82 (1984 $)	Select 2.66, the estimate which is based on willingness-to-pay	21,361 (1983 $)	
18	**Gill (1998)**	0.3, 0.9, 2.4, 2.9, 3.5, 5.3, and 7.1 (1984 $)	Select 2.9, the full sample estimate	Not reported	Mean age is 23
19	**Hammitt and Graham (1999)**	0.8, 1.3, 1.3, 2.1, 2.4, 2.8, 6.4, and 11.3 (1999 $)	Average 2.4, 2.8, 6.4, and 11.3, the estimates	Not reported	The VSL estimates reported for Survey 2 were

			recommended by the authors		incorrect in the published version of the paper. We use revised estimates based on personal communication with James Hammitt, 3/13/01.
20	**Hammitt, Liu, and Liu (2000)**	Numerous estimates, ranging from 0.1 to 8.3 (1991 $)	Average 0.5 and 5.0, the range reported by the authors in the abstract	3,818 to 12,556 (1991 $)	
21	**Herzog and Schlottmann (1990)[c]**	1.8, 1.9, 2.2, 2.3, 2.5, 3.1, 3.5, and 5.0 (1969 $)	Average 2.5, 3.1, 3.5, and 5.0, the estimates recommended by the author	8,850 (1969 $)	
22	**Ippolito and Ippolito (1984)**	0.2 to 1.0 (1980 $)	Average 0.3 and 0.6, the end points of the range recommended by the authors	Not reported	Study is designed to estimate the value of a life year; only smokers considered in analysis
23	**Johannesson and Johansson (1997)**	0.07 to 0.13 (1995 $)	Average 0.07 and 0.13, the endpoints of the range recommended by the authors	Not reported	Analysis is based on willingness-to-pay for life extension, conditional on

					survival to age 75
24	**Johannesson, Johansson, and Lofgren (1997)**	23.3, 29.8, 30.3, 34.3, 34.6, and 36.1 (1996 SEK)	Average the six estimates	Not reported	
25	**Johannesson, Johansson, and O'Conor (1996)**	4.50 to 8.90 and 2.6 to 7.4 (1986 $)	Average 4.5 and 8.9, the range associated with a reduction in private risk	Not reported	
26	**Jones-Lee (1989)[c]**	0.5, 0.7, 0.8, 1.2, 1.2, 1.4, 1.4, 1.6, 2.2, 2.2, 2.2, and 3.4 (1982 British pounds)	Average 1.2, 1.4, 1.6, and 2.2, the estimates recommended by the author	Not reported	
27	**Kidholm (1995)**	1.4 to 1.8 (1993 British pounds)	Average 1.4 and 1.8, the endpoints of the range recommended by the authors	Not reported	
28	**Kim and Fishback (1999)**	0.5 (1985 $)	Only one VSL reported	5,000 (1986 $)	
29	**Krupnick et al. (2000)**	0.7, 0.9, 1.2, 1.2, 1.5, 1.5, 2.3, 2.7, 3.7, 3.8, 4.5, and 4.6 (1999 Canadian dollars)	Average 1.2 and 3.8, the estimates recommended by the authors	58,000 (1999 Canadian dollars)	Risk reduction occurs over a ten year period; study focuses on WTP for risk reduction of individuals over 40 years old

30	**Lanoie, Pedro, and Latour (1995): Contingent valuation**	1.5, 1.5, 1.6, 2.0, 2.6, 2.8, 23.0, 24.1, 24.9, 26.2, 27.3, 31.5, and 39.2 (1986 Canadian $)	Average 23.0, 24.1, and 26.2, the estimates based on job safety and the entire sample	Not reported	VSL estimates for car safety are not used. The car safety survey question asks about one-time WTP for a risk reduction that occurs over several years
31	**Lanoie, Pedro, and Latour (1995): Labor market**	17.3 to 19.2 (1986 Canadian $)	Average 17.3 and 19.2, the endpoints of the range recommended by the authors	43,924 (1986 Canadian $)	VSL is for unionized manual workers using perceived risk (regressions using actual risk had coefficients that were not significantly different from zero)
32	**Leigh (1987)**[c]	2.7, 2.7, 4.3, 4.6, 4.7, and 5.1 (1977 $)	Average 4.7 (QES) and 5.1 (CPS), the two estimates that are based on both male and female workers	13,125 and 8,694 (1977 $)	
33	**Leigh (1995): BLS Data**	5.6, 11.5, and 8.9 (1988 $)	Average the three estimates	16,242 (1988 $)	Author concludes that these VSL estimates are unreliable

					because they do not control for inter-industry wage differentials
34	**Leigh (1995): NIOSH Data**	5.4 and 7.6 (1988 $)	Average the two estimates	16,224 (1988 $)	Author concludes that these VSL estimates are unreliable because they do not control for inter-industry wage differentials
35	**Leigh and Folsom (1984)[c]**	4.3, 4.3, 4.7, 4.7, 3.7, 3.5, 4.0, and 3.9 (1977 $)	Average the eight estimates	12,788 (1977 $)	
36	**Liu and Hammitt (1999)**	0.6 and 1.3 (1995 $)	Select 0.6, the estimate that controls for non-fatal risk	17,961 (1995 $)	
37	**Liu, Hammitt, and Liu (1997)**	0.4 and 0.5 (1990 $)	Select 0.4, the estimate recommended by the authors	4,785 (1990 $)	
38	**Low and McPheters (1983)**	0.6 (1972 $)	Only one VSL reported	10,961 (1976 $)	Sample consists solely of urban police officers; unit of observation is a city rather than an individual; risk variable is number

					of deaths per city rather than death rate
39	**Marin and Psacharopoulos (1982)[c]**	0.6, 0.7, 2.2 to 2.3, and 0.6 to 0.7 (1975 British pounds)	Average 0.6 and 0.7, the estimates based on the entire sample which use the author-recommended measure of risk	2,974 (1975 British pounds)	
40	**Martinello and Meng (1992)**	4.7 to 6.0 (1986 Canadian dollars)	Select 5.3, the mean estimate reported by the authors	23,358 (1986 Canadian dollars)	
41	**Meng (1989)**	2.5, 2.6, 2.7, 2.8, and 2.9 (1981 Canadian $)	Average the five estimates	27,747 (1981 Canadian dollars)	
42	**Meng and Smith (1990)**	0.8, 4.6, 6.1, 7.0, and 7.3 (1983 Canadian $)	Average the five estimates	21,124 (1983 Canadian dollars)	
43	**Miller and Guria (1991)[c]**	1.4, 1.8, 1.9, 1.9, 1.9, 2.0, and 2.3 (1989 New Zealand dollars)	Select 2.0, the estimate which is based on individual WTP for a decrease in individual risk	Not reported	
44	**Miller, Mulvey, and Norris (1997)**	11.5 to 19.4 (1991 Australian $)	Average the two estimates	27,600 (1991 Australian $)	
45	**Moore and Viscusi (1988): NIOSH data[c]**	5.2, 5.9, 6.0, 6.6 (1986 $)	Select 5.2, the estimate recommended by the authors	14,581 (1981 $)	

46	**Moore and Viscusi (1988): BLS data**[c]	1.9, 2.0, 2.1, 2.1 (1986 $)	Select 2.1, the estimate recommended by the authors	14,581 (1981 $)	
47	**Moore and Viscusi (1988)**	6.0, 6.2, 6.2, and 6.8 (1986 $)	Select 6.0, the estimate recommended by the authors	11,419 (after tax; 1976 $)	Study designed to estimate value of life year and consumers' implicit discount rate
48	**Moore and Viscusi (1990)**	4.8 (1985 $)	Only one VSL reported	Not reported	Study designed to estimate consumers' implicit discount rate
49	**Olson (1981)**[c]	1.5, 1.8, 3.2, 3.4, and 8.0 (1973 $)	Select 3.2, the estimate recommended by the author	8,900 (1973 $)	
50	**Sandy and Elliott (1996)**	2.5, 14.0, 14.9, 29.9, 33.7, and 33.9 (1985 British pounds)	Average 14.9, 29.9, and 33.9, the estimates recommended by the authors	Not reported	We only consider estimates based on job-related fatality risk variable
51	**Scotton and Taylor (2000)**	8.6, 15.9, 17.3, 18.7, and 20.3 (1998 $)	Select 18.7, the estimate recommended by the authors	35,257 (1998 $)	
52	**Siebert and Wei (1994)**	3.6 to 4.4 (1983 British pounds)	Average the two estimates	4,888 (1983 pounds)	

53	**Siebert and Wei (1998)**	1.4 (1990 $)	Only one VSL reported	8,943 (1990 $)	
54	**Shanmugam (1997)**	0.8 to 1.0 (1990 $)	Select 0.8, the estimate recommended by the author	10,606 (after tax; 1990 Rupies)	
55	**Smith (1974)**[c]	1.8 to 3.3 (1967 $)	Average the two estimates	Not reported	VSL estimate reported in footnote
56	**Smith (1976)**[c]	1.5 (1973 $) and 2.6 (1967 $)	Select 2.6, the estimate which controls for non-fatal risk	Not reported	
57	**Thaler and Rosen (1975)**	0.1, 0.2, 0.2, and 0.3 (1969 $)	Average the four estimates	6,600 (1967 $)	Survey of Economic Opportunity targets low income individuals; authors experimented with BLS risk data and chose not to use it in the analysis
58	**Viscusi (1978)**[c]	0.6, 0.9, 1.1, 1.2, 1.4, 1.4, 1.5, 1.5, 1.6, 1.6, 1.7, and 1.8 (1969 $)	Select 4.1 (1990 $) the estimate recommended by the author (Viscusi 1992)	6,810 (1970 $)	
59	**Viscusi (1981)**[c]	3.2, 4.2, 4.8, and 7.6 (1978 $)	Select 6.5 (1990 $), the estimate	10,060 (1978 $)	

			recommended by the author (Viscusi 1992)		
60	**Viscusi, Magat, and Huber (1991)[c]**	1.4, 1.3, 2.3 and 8.2 (1987 $)	Select 2.3, the estimate recommended by the authors	37,154 (1987 $)	

Notes:
[a] For contingent valuation studies, the baseline annual risk of death is reported.
[b] Unless otherwise noted, mean income is pre-tax individual income for labor market studies and pre-tax household income for contingent valuation studies.
[c] This study was among the 26 included in the 1992 IEc memorandum to EPA.

Exhibit 4: Distribution of VSL Estimates (n = 60)

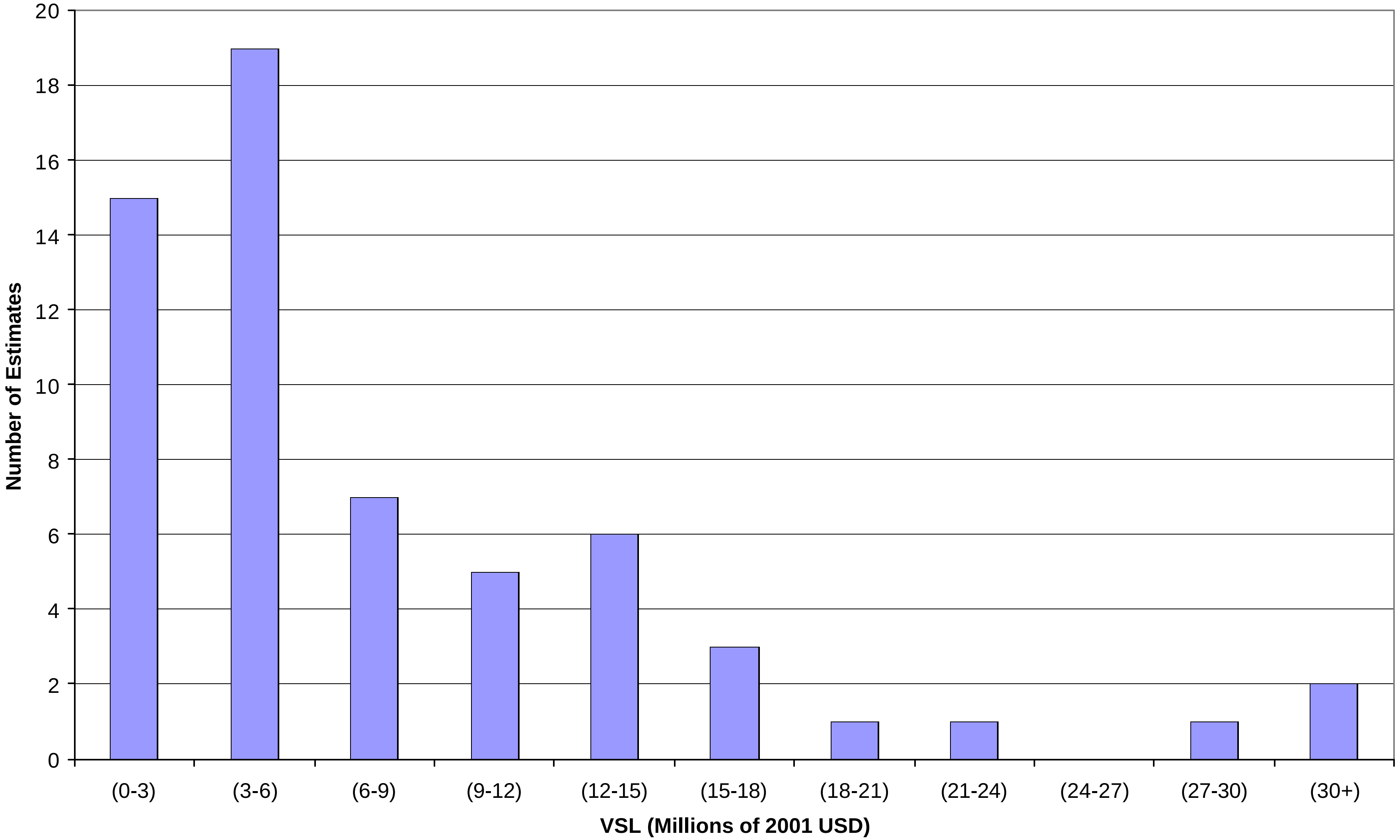


Exhibit 5: Distribution of VSL by Study Type (n = 60)

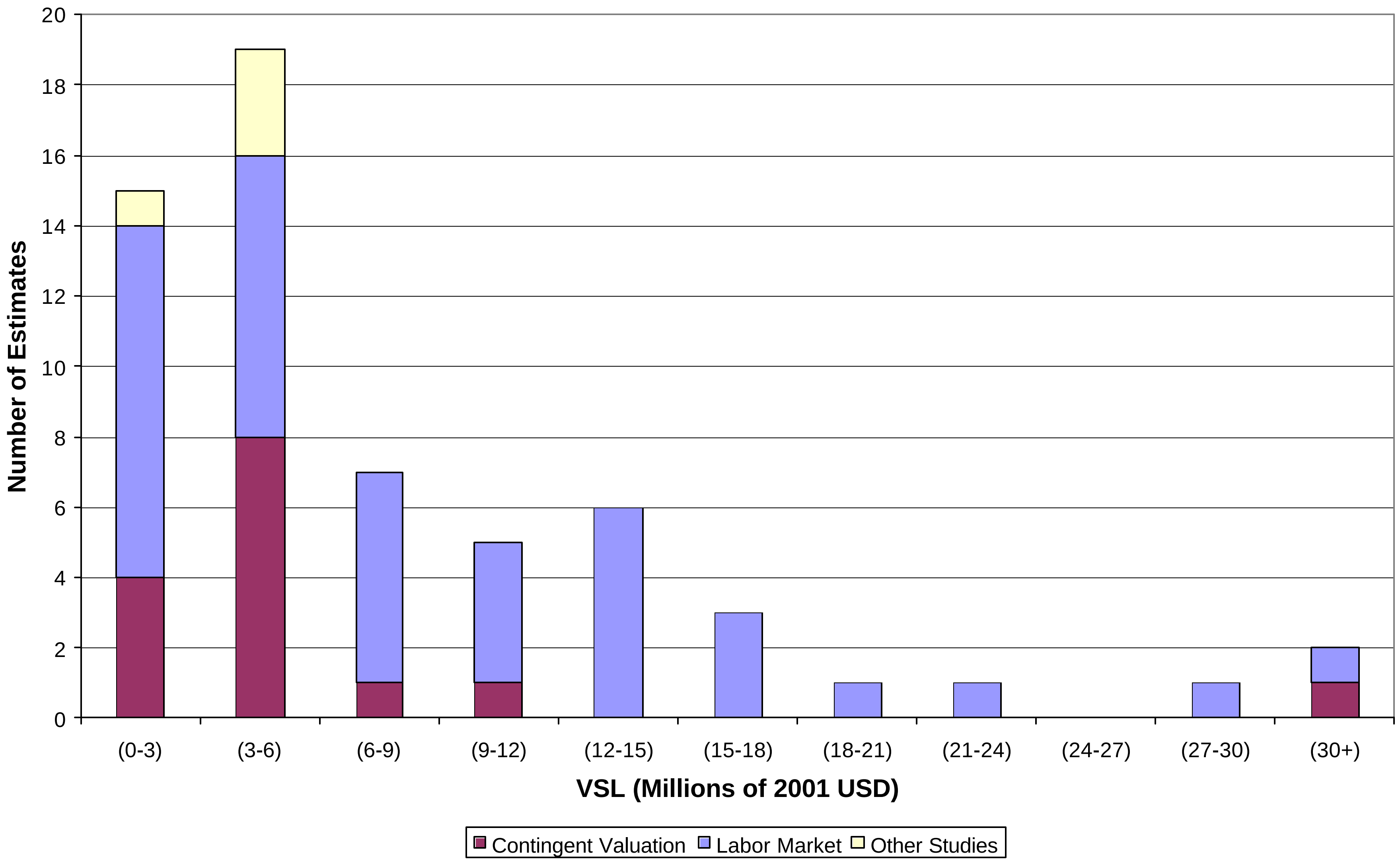


Exhibit 6: VSL Estimates by Year of Data

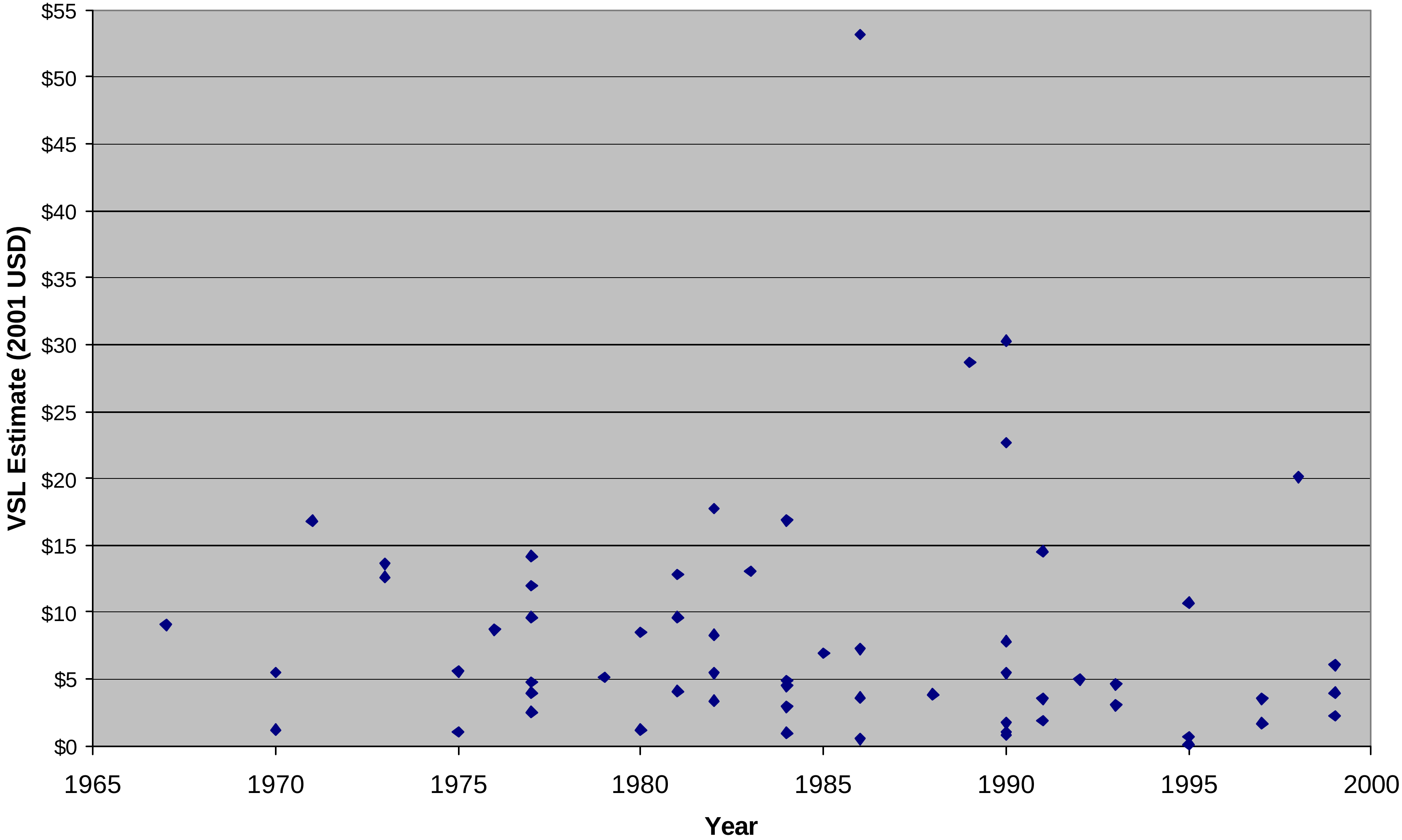


Exhibit 7

VARIABLE DEFINITIONS

Variable	**Definition**	**Mean**
VSL	Value of statistical life (millions of 2001 U.S. dollars)	8.26
INCOME	Individual income (thousands of 2001 U.S. dollars)	27.0
OECD	= 1 if study conducted in OECD country = 0 otherwise	0.92
LABOR	= 1 if wage-risk study	0.68
CV	= 1 if contingent valuation study	0.25
LABOR*NONFATAL	= 1 if wage-risk study and authors fail to control for nonfatal risk = 0 otherwise	0.37
LABOR*RISK	= mean baseline risk (in 10,000) if wage-risk study = 0 otherwise	1.86
LABOR*ACTUARIAL	= 1 if wage-risk study and authors use	0.03

	actuarial risk data = 0 otherwise	
CV*SCOPETEST	= 1 if contingent valuation study and WTP is approximately proportional to change in risk (passes scope test) = 0 otherwise	0.05

Exhibit 8

PARAMETER ESTIMATES[a, b]

Variable	Model 1	Model 2
CONSTANT	-0.81 (-1.21)	-0.15 (-0.24)
INCOME	0.032** (2.10)	0.049*** (3.70)
OECD	1.10** (2.05)	--
LABOR	0.81 (1.49)	0.69 (1.23)
CV	0.04 (0.08)	-0.06 (-0.10)
LABOR*NONFATAL	0.027 (0.09)	0.001 (0.00)
LABOR*RISK	-0.007 (-0.19)	-0.005 (-0.12)
LABOR*ACTUARIAL	-1.93** (-2.39)	-1.88** (-2.25)
CV*SCOPETEST	0.43	0.53

	(0.69)	(0.83)
R-SQUARED	0.38	0.33
N	60	60

Notes:

[a] Dependent variable for all models is natural logarithm of VSL

[b] * indicates significance at the ten percent level, ** indicates significance at the five percent level, and *** indicates significance at the one percent level

Exhibit 9

MEAN PREDICTED VSL

(Millions of January 2001 U.S. Dollars)

Study Type	Mean Income		
	$25,000	$30,000	$35,000
Wage-Risk	7.0	8.2	9.7
Contingent Valuation	5.6	6.6	7.8
Consumer Market	3.4	4.0	4.7

Discussion of Session III

David Widawsky, US EPA Office of Pesticide Programs

IMPROVING VSL ESTIMATES FOR USE IN POLICY ANALYSIS

Meta-analysis can provide valuable insight to economic inquiries, to the extent that the method allows one to incorporate a wider set of conditions than those represented any given individual study. Other discussants have provided perspectives on the opportunities, as well as numerous pitfalls, associated with meta-analyses of VSL estimates, in general. With respect to the two meta-analyses by Legget et al. (referred to the IEC study) and Kochi et al. (referred to ast the Duke study), the comments contained herein focus on three sets of questions relevant to a "consumer"of such analyses, specifically an economist *cum* regulator who might use these types of analyses in evaluating regulatory options.

In order to evaluate the degree to which these analyses might be useful to the regulatory economist, it is necessary to ask six basic questions about each of the studies:

a. what policy issue does the study address?
b. what does the study attempt to accomplish?
c. by what technique does the study approach its stated goal?
d. how successful is the study in meeting this goal?
e. what new insights are gained?
f. what additional work needs to be done, if any, to develop concrete and usable results?

The regulatory economist is also interested in describing the strengths and weaknesses of each approach. These strengths and weaknesses may be theoretical or applied. Because of my institutional interest as an economist in EPA's Office of Pesticide Programs, I will concentrate my final comments on issues that these meta-analyses raise for EPA's pesticide regulatory program.

Review of IEC and Duke Studies

With respect to the six questions posed above, the IEC and Duke studies appear to start out from similar places, take divergent paths, and then end up in similar places (summarized in Table 1). Both studies identify a relevant policy issue as the need for regulators of human health risk to have a robust set of VSL estimates to employ in evaluating policy analyses. The IEC study concentrates on understanding the variability of VSL estimates, and whether these are systematically related to conditions that apply to particular regulatory situations. The Duke study concentrates on reducing the variability among VSL estimates, so that regulators can have more confidence in a central VSL value to employ in regulatory analyses.

From here, the studies diverge significantly. The IEC study uses a set of VSL estimates from studies that varied in the a number of ways including method of approach (contingent valuation vs. hedonic wage), inclusion of non-fatal risks, and country of origin (e.g. less developed vs. OECD countries). Using a pretty simple log-linear, the IEC study found few of the parameters to significantly explain the variability in VSL estimates. As a result, it is not clear that the IEC study does a better job than previous work, in explaining the components of VSL that may vary across populations, risk types, or method of calculation.

In contrast to the IEC study, the Duke study attempted to incorporate VSL estimates not contained in the Viscusi (1992) study that forms the basis of EPA's current estimates of VSL. The object was to get a larger sample of estimates and use a two-step method to adjust (reduce) variance estimates, thus narrowing the uncertainty associated with VSL estimates. The method starts by grouping VSL estimates by author. The mean and standard error of these author-based groups are used, along with the standard error of estimates, to reduce the uncertainty of a given estimator by "pulling" it toward a variance adjusted central estimate of VSL. Finally, differences in VSL estimates are suggested by creating and comparing density functions of VSL estimates for different groups of estimates (i.e., those estimating with contingent valuation versus hedonic wage methods). The Duke study provides a method to reduce uncertainty by pooling information, even though the mean values differ little from previous estimates. There is some support for the hypothesis that hedonic wage studies differ systematically from contingent valuation studies, but once again, this is not a particularly new revelation.

Unfortunately, for a potential customer for these type of studies, there was very little one could take away and apply in a practical regulatory sense. The IEC study was mainly exploratory, and reached few conclusions about the nature of variability of VSL estimates. One of the IEC studies main implications for further research was that more work was need to better characterize uncertainty. Ostensibly, this was the purpose of the Duke study. But, one of the main implications of the Duke study was that it could help to identify candidate variables for a meta-regression analysis that was ostensibly the purpose of the IEC study.

One interesting factoid is that the studies used a very similar set of studies to do entirely different analyses. Of the estimates included in the Duke study, 80% were also used in the IEC study. Of the estimates used in the IEC study, 67% were also used in the Duke study. Given the symmetric implications from the two studies, each being claimed as a precursor to the other, it suggests that either more explication of the existing estimates is needed, or new estimates are needed that vary in ways mirroring actual societal conditions. Table 2 summarizes some of the strengths and limitations of these two studies.

Table 1.	Legget, Neumann, and Penumalli (IEC Study)	Kochi, Hubbell, and Kramer (Duke Study)
1. What is the issue?	Policy analysts need to tailor VSL analyses for varying conditions, and need to understand the components that influence VSL estimates.	EPA must choose VSL value from a wide range, for policy analyses. This requires ongoing work to update(verify) VSL estimates and reduce uncertainty associated with these estimates.
2. What does the study try to accomplish?	Analyze existing studies to see if there are reliable estimates of the components of VSL, to provide regulatory analysts the tools to tailor VSL estimates, as needed.	Incorporate new VSL data into estimates that EPA already uses (from Viscusi, 1992). Estimate mean and variance of VSL with a different type of meta-analysis (2-step Bayes model)
3. By what means does the study approach goals?	Meta-analysis regression on log(VSL): a. income b. OECD c. method - CV or HW d. HW*baseline risk e. HW*non-fatal risk f. HW*actuarial g. CV*scope test	Two step approach to Bayes Method a. Group VSL estimates by author b. Use mean and SE of groups to reduce uncertainty for any estimate of VSL, based on VSL_i and SE_i from all studies. μ_w is a variance adjusted "centroid", toward which individual estimates are pulled, by construction. c. Construct density functions using bootstrapped kernal estimator.
4. How successful is the study in meeting the goals?	*Theoretical:* ad hoc regression mixing population and methodological characteristics. *Empirical:* strongest estimates are for coefficients on income, OECD, and HW*actuarial. *Question:* Does it do better than Viscusi or Moore and Viscusi?	*Theoretical:* provides a method to reduce uncertainty of estimates, by pooling information. *Empirical*: supports previous central values, and reduces uncertainty. Supports hypotheses that HW and CV come from different distributions, and countries may as well.
5. What new insights do we gain?	Mostly an initial exploration	Information from among (and within) studies can be used to reduce uncertainty of VSL estimates. Helps to identify candidate variables for meta-regression analysis (in this case HW vs. CV and location of study).
6. What else do we need to do?	a. get better/complete data b. identify "best practice" for particular applications. c. characterize uncertainty to improve robustness of estimates.	a. conduct meta-regression to determine impact of specific study factors.

Table 2.	Legget, Neumann, and Penumalli (IEC Study)	Kochi, Hubbell, and Kramer (Duke Study)
Strengths	1. Combined data from different countries, which can be important when international migrant labor plays a role. 2. Policy analysts DO need to tailor estimates to different sets of conditions that are not fixed.	1. Develops method for testing distributional differences among methodological variables. 2. Helps reduce uncertainty for single VSL estimates. 3. Identifies candidates for meta-regression analysis.
Limitations	1. Combined data from different countries, which can obfuscate policy analysis if U.S. is sole locus. 2. Data do not seem to generate expected results, using the models presented.	1. Does not tell us much about marginal effects (i.e. only identifies candidates for meta-regression analysis).

<u>Issues for Pesticide Regulatory Program</u>

There are several issues that need to be addressed before analysts in EPA's Office of Pesticide Program would be able to employ meta-analyses of VSL estimates. To begin with, it is important to recognize that mortality risk is not all the same, and VSL estimate do not conform to a one-size-fits-all standard. Pesticide mortality risk can arise from different types of exposure scenarios, which suggests different estimation methods may be more appropriate in different circumstances. More specifically, pesticide can pose fatal risks from dietary exposure (e.g., residues on food) and from occupational exposure (e.g., to farm-workers). In cases of dietary risk, consumer market studies may be an appropriate vehicle, even though the method was not favored in either the IEC or Duke study.

In cases of occupational risk, a hedonic wage study may be appropriate. Besides the fact that none of the wage studies currently used to estimate VSL are based on farm-worker wages (and associated risk), such studies would depend on the fragile assumption that workers can control risk. For instance, occupational risks may be very different for mixer/loader/applicator of pesticides than they are for field laborers. Figure 1 illustrates the point on a safety/wage indifference curve where one might be able to observe the wage-premium associated with a given degree of risk. Economists generally assume that the wage premium declines as safety increases. However, looking at all farmworkers, one might observe the situation in Figure 2, where wages decrease as risk increases. This could represent a situation where different types of exposure risk are associated with different type of farm work and the different groups of workers. Figure 3 might represent the sets of indifference curves for different workers, where behavior within each group is consistent with economic theory, but failing to separate these heterogeneous groups would lead to biased or counterintuitive results.

The type of industry could also affect the VSL estimate for occupational risk from pesticides. In the same way that different groups of agricultural workers may face different sets of risk, non-agricultural pesticide applicator wage studies may generate different VSLs for a given level of risk reduction that a study involving only agricultural workers.

In contemplating employing a VSL to estimate the value of dietary risk reduction from pesticides, a regulatory analysis would need to be able to address a number of concerns with existing estimates of VSLs. Wage decisions and risk control may not play into decisions on reducing dietary risk. Two of the important sub-populations of concern for pesticide dietary risk are infants and children, neither of which make wage decisions. Careful consideration needs to paid to these issues, including accounting for latency between exposure and mortality, in order to adapt these estimates and methods to pesticide regulatory decisions.

Methods for valuing human health risk reduction are critically important to analyses of regulatory decisions in EPA. VSL estimates offer one approach to meet this need, and EPA has recognized the validity of the considerable effort that has gone into generating and analyzing estimates of VSL. From a practical regulatory standpoint, there would be great benefit from knowing whether different types of exposure, or different exposed populations, are associated systematically with different VSLs. Even though their results were not conclusive, the IEC approach of trying to explain variability among VSL estimates may represent a step in the right direction. While the Duke study did not explain this variability, their work was an attempt to identify some of the important variables that could explain these systematic differences in VSL. There clearly remains, however, substantial work to be done before these types of results would be able to address some of the issues faced by regulatory "customers" in program offices within EPA.

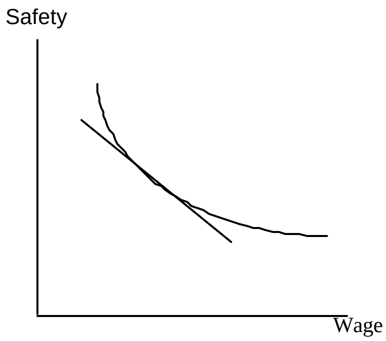


Figure 1

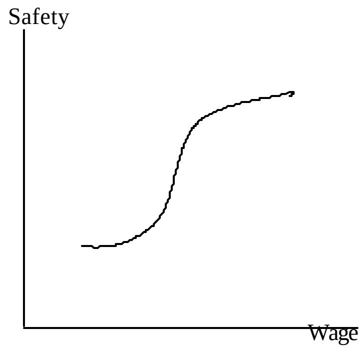


Figure 2

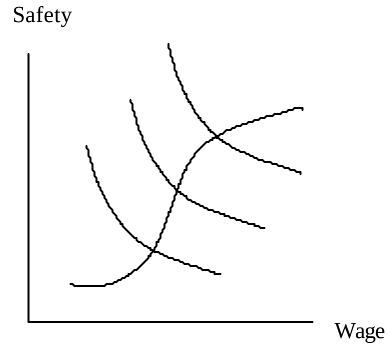


Figure 3

Discussion of Session III

F. Reed Johnson, Research Triangle Institute

Two Meta-Analyses of the Value of Statistical Life

Meta-analysis, by its nature, requires analysts to make a variety of judgments about how to handle questions of definition, admissibility of evidence, and methodology. Meta-analysis evolved as a more formal way of synthesizing evidence from multiple studies than simple literature reviews. The latter approach requires reviewers to exercise considerable judgment in weighing the evidence offered by various studies, taking into account the quality of the research and applying various implicit and explicit weights to reach a summary conclusion. Leggett, Neumann, and Penumalli (IEC study) and Kochi, Hubbell, and Kramer (Duke Study) take quite different meta-analytic approaches to synthesizing the existing literature on the value of a statistical life (VSL). Nevertheless, they share a certain timidity about evaluating such study characteristics as econometric rigor, sample size, and survey design, preferring instead to take results at face value. Both studies might benefit from the exercise of careful professional judgment in addition to statistical analysis.

Table 1 compares various features of the two studies. Although both studies include all available studies without screening for quality, the IEC study includes consumer market studies, while the Duke study does not. The Duke study includes all estimates, including multiple values from the same study, but weights the importance by the inverse of the variance, using an empirical Bayes approach without controls for source of data or other study characteristics. In contrast, the IEC study uses a single "best" estimate from each study and employs regression analysis to control for study characteristics. The empirical Bayes approach yields a posterior distribution, while the IEC authors report only point estimates.

Despite their disparate approaches, the results of the two studies do not change the conventional wisdom. EPA currently uses a VSL of $6.3 million with standard deviation of $4.2 million derived from Viscusi's (1992) recommended set of VSL estimates. Using a different methodology and a different set of estimates, the Duke study surprisingly obtains virtually identical estimates of $6.2 million with standard deviation of $4.3 million. The midpoint of the three IEC ranges is a similar $6.45 million. Although these estimates might be interpreted as evidence of convergent validity, both the Duke and IEC studies have significant conceptual and empirical problems that undermine confidence in this conclusion.

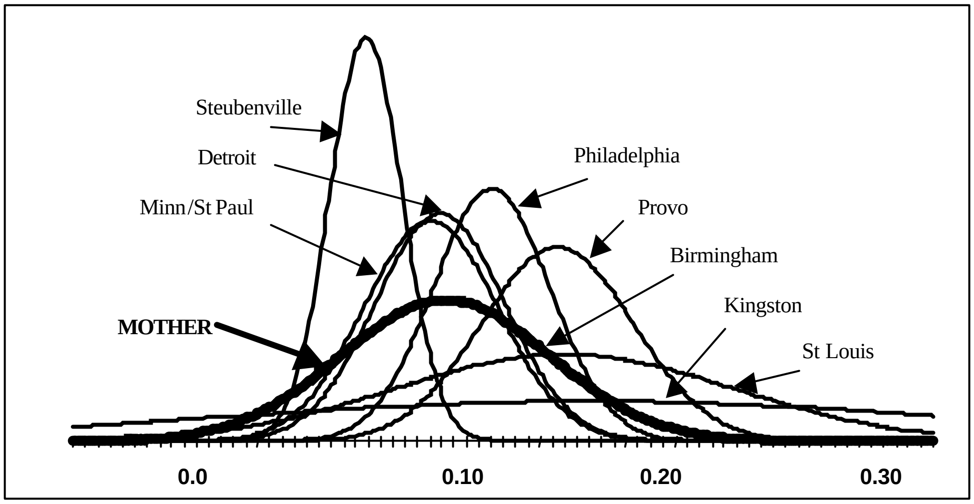
Table 1. Comparison of Study Features

Study Feature	Duke Study	**IEC Study**
Labor market studies	Yes	Yes
Contingent valuation studies	Yes	Yes
Consumer market studies	No	Yes
Multiple values from single study	Yes	No
Importance or quality weights	Variance	"Best" estimate from each study
Statistical approach	Empirical Bayes	Regression
Covariates	No	Yes
Measures	Posterior Distribution	Predicted Means
Results	Mean: $6.2 mill. St Err: $4.3 mill.	Labor: $7.0 - 9.7 mill. CV: $5.6 - 7.8 mill. Consumer: $3.4 - 4.7 mill.

The Duke Study

The empirical Bayes approach assumes that all the relevant information necessary for synthesizing a consensus estimate of the value of a statistical life is contained in the reported means, standard errors, and sample sizes. Desvousges, Johnson, and Banzhaf (1999) report a similar synthesis of particulate concentration-response coefficient estimates using a classical statistical approach. Figure 1 plots the individual study distributions and the estimated mother distribution. In this case, all the studies were undertaken by the same group of researchers, using similar data and the same methods for each city, and modeled an identical underlying toxicological process. In this case, the assumption that each study is drawn from the same underlying distribution seems plausible.

Figure 1. Particulate Concentration-Response Coefficient Mother Distribution



The Duke authors must make the same assumption, but in their case, the assumption is far less plausible. The studies are disparate with respect to measurement methods, the context in which mortality values are assessed, econometric estimation, and numerous other factors. Thus they appear to be working with a highly heterogeneous set of distributions rather than a single underlying distribution.

The Duke study employs a two-stage approach. First the authors derive a single, representative VSL for studies that report multiple estimates. Their strategy is intended to prevent giving such studies disproportional weight in the second stage. Using a fixed-effect formulation:

$$\text{Re presentative Study Mean} = \frac{\sum VSL_i \frac{1}{Var(VSL_i)}}{\sum \frac{1}{Var(VSL_i)}}$$

$$\text{Re presentative Study Variance} = \left(\sum \frac{1}{Var(VSL_i)}\right)^{-1}$$

Unfortunately, this procedure does not produce the desired adjustment. Suppose a study reports two estimates, both with mean 10 and variance 5.

$$\text{Representative Study Mean} = \frac{\frac{10}{5} + \frac{10}{5}}{\frac{1}{5} + \frac{1}{5}} = 10$$

$$\text{Representative Study Variance} = \left(\frac{1}{5} + \frac{1}{5}\right)^{-1} = 2.5$$

Thus the calculation yields an unbiased representative mean, but the variance of the representative estimate is half that of the separate estimates, giving the representative mean the same effective weight as the individual estimates. Thus the calculation does not reduce the weight of the contribution of this study to the second-stage estimate.

The IEC Study

The IEC study synthesizes published estimates by regressing the log of the "best" VSL estimate from each study on various study-specific covariates, including the type of risk data the study used:

$$\ln(\text{VSL}) = \beta_o + \beta_1 \text{Income} + \beta_2 \text{OECD} + \beta_3 \text{Labor} + \beta_4 \text{CV} + \beta_5 \text{Labor} \cdot \text{Nonfatal} + \beta_6 \text{Labor} \cdot \text{Actuarial} + \beta_7 \text{CV} \cdot \text{Scopetest}$$

Unfortunately, the authors obtain low statistical significance and poor fit and caution against using their preliminary estimates for policy purposes.
The authors indicate that they expected convergence in estimates over time. However, a plot of estimates over time shows an increase in the variance of study VSL results. A ready explanation is the well-known phenomenon of publication bias. Results tend to be more publishable if they vary from previous studies rather than replicating existing estimates.

The authors' disappointing results call for alternative strategies to explain the variation in VSL estimates. A couple of possibilities come to mind. First, some of the variance they are trying to explain may be spurious. Results may be strongly influenced by poor research design, questionable econometrics, small sample sizes, and other technical problems. In such cases, source of data and other observable study characteristics will not explain the resulting variance.

The authors should consider applying some well-reasoned and clearly stated criteria to determine whether a given study passes minimum scientific muster.

Second, unobservable sources of heterogeneity can be modeled explicitly by methods such as latent class analysis or random parameters methods. Accepting unobserved heterogeneity that may or may not be correlated with observable study characteristics as an inherent feature of the problem may ultimately lead to additional econometric insights. Finally, the authors' ambition to produce a meta-analytic equation for "facilitating a benefits transfer by providing coefficients for transferring estimates across individual and risk characteristics" may simply be impossible. This ambition presupposes existing studies successfully contain that information and that it is possible to disentangle that information from other confounding features of the available studies.

Policy-Relevant Outcomes, Cognition, and Methods

Although both these studies are well grounded in the conventional VSL wisdom, the estimates they are trying to synthesize answer the wrong question. Exposure to air pollution does not strike 35 year-old male construction workers dead. Rather, exposures shorten the lives of elderly individuals and perhaps others with compromised health because of chronic or acute respiratory disease. Because risk is strongly contingent on age and health status, the policy-relevant question is rather: what is the value of a life extension of a few months or years at a diminished functional level? Recent studies suggest that these values are far less than $6.3 million.

Existing VSL estimates also neglect well-known results from the literature on risk perception. Circumstances of the risk such as dreadfulness, voluntariness, and timing matter more to people in valuing risk than simple probabilities. One need only point to the recent public reaction to anthrax risk as an obvious example. Risk perceptions and associated behavior also are subject to well-known cognitive inconsistencies such as risk aversion for gains and risk seeking for losses. Researchers and meta-analysts also must confront the vexing question of whether the comparative advantages and disadvantages of revealed-preference or stated-preference approaches offer the more promising opportunity to explore risk-benefit tradeoffs. It is tempting, but feckless, to dodge these difficult conceptual and empirical problems by simply treating estimates derived from different methods as equally informative and valid raw material for the meta-analysis mill. These two strictly statistical approaches to synthesizing available evidence on VSL do not inspire confidence that the results provide the information needed to improve social resource allocation. It is time for researchers to accept some additional role for carefully reasoned and explicit professional judgment in assessing the usefulness of empirical VSL estimates.

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Question and Answer Period for Session III

Glenn Harrison, of the University of South Carolina, asked Jim Neumann what the difference was between his study and the study of Mrozek and Taylor.[10]

Jim Neumann noted a few differences. First, he said, they looked at a broader set of literature than Mrozek and Taylor. Second, Mrozek and Taylor used a weighted least squares regression technique and they recovered multiple estimates from each study. The study described by Neumann, in contrast, recovered a single estimate from each study. A third difference is that the Neumann study looked at a far smaller suite of potentially important factors for explaining variance, at least within wage risk studies.

Glenn Harrison asked if what the Neumann study had done was to add a couple more studies [*to the Mrozek and Taylor list*]. Neumann replied that they had added estimates from a different literature as well, the CV and the consumer market literature.

Ted Miller, of the Pacific Institute for Research and Evaluation, noted that in the studies by Paul Dorman he ran many models that yielded zeros for the VSL. He asked Ikuho Kochi what happened with those studies in her meta-analysis of VSL studies, because she didn't show any zeroes. What happens, he asked, when the coefficient on the risk (in a wage-risk study) is not significant? What happens when that coefficient is negative in these models?

Ikuho Kochi responded that they excluded those VSL estimates, since they were assumed to be due to specification errors.

Ted Miller objected to this, saying that throwing those zero and negative values out means that their meta-analysis is guaranteed to overestimate, and that, in addition, unreasonably huge values from studies of questionable quality were put into the meta-analysis (exacerbating the problem). He asked Jim Neumann if they did the same thing.

Jim Neumann said that they recovered a single estimate from each of the studies. Ted Miller asked if they had, then, at least included all the studies with zeroes. The issue of what to do with VSL estimates that are zero, negative, or positive but not statistically significant was discussed. Jim Neumann said they included the zeros in their meta-analysis, but could not recall what they had done with the positive but not significant values from the Dorsey study.

Bryan Hubbell corroborated that they (the Kochi meta-analysis) did assume that they would truncate the VSL distribution at zero – that is, they did not include negative coefficients.

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[10] Taylor, Laura O. and Janusz Mrozek, "What Determines the Value of Life: A Meta-Analysis," forthcoming in *Journal of Policy Analysis and Management.*

The issues of which estimates to include and which to exclude in a synthesis of VSL estimates, and what selection criteria to apply, was discussed. Glenn Harrison asked Bryan Hubbell if they had included two different VSL estimates (one corresponding to an objective risk and the other to the subjective risk) from the same study in their meta-analysis. One is right, he said, and the other is wrong.

Bryan Hubbell said that, at this point yes, they did because they are engaged in a multi-stage project, and the initial effort was to try to use all the available estimates. One of the things they want to do, he said, is apply more stringent criteria to individual estimates from the studies, because there are situations where people have published multiple articles on the same data set and it is not clear which is the correct estimate to take.

Glenn Harrison responded that in such cases you put controls in for why they get different numbers.

Bryan Hubbell agreed and said that this was going to be their next step. At this point, he said, they are developing a way to get Bayesian estimates. And the next step, he said, referring to a paper by Hammitt and Spengler (and some other authors, including Levy), is actually taking the Bayesian mean, the pooled estimate, and decomposing it into a regression analysis. But what Ikuho Kochi presented at the workshop was the first step, on which they are trying to get some feedback before moving further.

Glenn Harrison asked whether anyone has taken into account publication bias.

Jim Neumann said that they had not incorporated any specific adjustment for publication bias.

Ted Miller reiterated that they do need to put the zeroes back in their meta-analyses. He also noted that before versus after tax can make a big difference, and he did not see anything about this in their analyses. In the wage risk studies, he noted, the tax gets multiplied by the risk aversion, so you wind up with a 15 to 20 percent higher value in a before-tax wage risk study based on nominal wages than an after-tax based on after-tax wages. Finally, he asked how they adjusted VSLs, particularly from the foreign studies. Do they inflate them and then adjust them to U.S. dollars, or do they adjust them to U.S. dollars and then inflate them with U.S. adjusters? That makes a huge difference in the values, he said.

Jim Neumann said they do the latter: they convert them first and then inflate them. Bryan Hubbell and Ikuho Kochi said they do the same thing.

Ted Miller then asked what adjuster they used, and commented on the lack of debate about this. Jim Neumann responded that they used GDP in prior work, but in this case they used CPI.

Ted Miller suggested that it is possibly the Employment Cost Index or the GDP that is appropriate, but that it was not clear, and that we ought to be thinking about what difference it might make.

With regard to the before tax-after tax question that Ted Miller asked earlier, Jim Neumann noted that it was one of the issues they considered. He said they tested a series of specifications. Although he thought they had not yet done the runs that look at whether the estimate is based on before tax or after tax, their approach would be essentially to take the estimates as they emerge, in terms of what the author recommends as the preferred estimate, and then include a control in the meta-analytic regression, to see whether that has an effect on the overall results.

Alan Krupnick, of Resources for the Future, commented that, if we think that VSL or the willingness to pay for risk reduction is sensitive to context and risk characteristics and population characteristics and so on, then it's hard to justify mixing the CV and the CM [*consumer market*] together with the wage risk studies. He opined that the right way to do it is to just use the wage risk studies, of which there are a large number. When you mix these other studies in there, he continued, you just don't know what you have. He counseled just dropping the CV studies entirely and focusing on the wage risk studies.

Tom Crocker, of the University of Wyoming, noted that the meta-analyses and the empirical Bayes treatments both presume that the data are drawn from a structure that is similar or identical across studies. That is, that the decision processes involved are the same. There are techniques, he said, developed by Bruno de Finetti and Arnold Zellner, to test in these empirical Bayes contexts whether the structures are the same across studies. That is, one need not treat them as the same; one can test that. He said they found in the hedonic property value studies they looked at that if one is dealing with structural attributes, one could treat the studies as coming from the same market. However, if one is dealing with fixed locational attributes, they found, then one is dealing with different markets, and it is not appropriate to combine such studies in the same meta-analysis or empirical Bayes-type framework. In terms of the underlying economic theory, he noted, it is quite obvious as to why this is the case. One can arbitrage the structural attributes across locations. There is a market for these attributes, and people shift resources from one location to another, all according to relative prices. However, with respect to specific locations where environmental quality is exogenous insofar as the individual is concerned, then you are basically dealing with different markets, and it is not appropriate to pool studies. He suggested that we might think about what features of these VSL studies are "arbitrage-able."

Matti Vainio, of the European Commission's Environment Directorate-General, offered what he called a very practical suggestion: as a recommendation or even as an outcome of this workshop, develop a list, perhaps annexed to the proceedings, specifying the minimum requirements of what should be reported in a study. If researchers do not provide the data, he said, at least they can provide enough descriptive statistics that one could get some notion of what is going on. Returning to the question of taxes, he asked for clarification about what wages people were talking about – people's own wages that they receive net of tax? Or the gross wage? Or the gross wage including the employer's compensation for health-related expenditure, pensions, and so on?

Jim Neumann replied that it varies, noting that what Ted Miller was referring to is the extent to which researchers actually apply these adjustments to look at income net of taxes in their use of the population data when they match the population data to the risk data in a wage risk study.

Laura Taylor, of Georgia State University, who identified herself as "one half of Mrozek and Taylor," asked Bryan Hubbell and Ikuho Kochi what paper the $87.5 million, at the high end of their range, came from.

Ikuho Kochi replied that it is from a study done in the United Kingdom, by Arabsheibani in 2000 [Arabsheibani and Marin, 2000].

Ted Miller commented that he is worried when people use studies with obvious errors in them. He referred to a study by Moore and Viscusi, in which they estimated the discount rate and the value of a life year simultaneously, but then when they calculated the value of life, they forgot to apply the discount rate. He asked Jim Neumann if he just took their best value that they stated.

Jim Neumann responded that the Moore and Viscusi estimate is not in their set, and that Viscusi said he did not think those studies (with Moore) were applicable for policy analysis.

Ted Miller cited another study, Siebert and Wei, in which they were supposed to multiply by the mean wage, but they have the mean of the natural log of wage, so they just exponentiated. He points out that, unfortunately, the mean of the natural log is not the natural log of the mean, so they wind up with a wrong value. He asked Jim Neumann if he included that study in his analysis.

Jim Neumann said that they had, and that he was not sure whether they had made the adjustment or not. Miller replied that it was not possible to make an adjustment, that they do not give you the data. They did not happen to have the mean wage, he said; they only had the mean of the natural log of wage.

Robin Jenkins, of the EPA, directed her question to Jim Neumann. She noted that the more recent studies were more disparate in terms of their estimates, and wondered if that is possibly because more sub-populations have been covered in the more recent studies, and there is been greater variation in the methodologies used. She asked if he noticed whether that could possibly explain why the VSL estimates are becoming more disparate.

Jim Neumann replied that it is testable hypothesis, but that they have not looked at it.

Glenn Harrison asked if the EPA is funding any other meta-analyses.

Bryan Hubbell noted one project, in which OAQPS (*EPA's Office of Air Quality Planning and Standards*) is working with RTI (*Research Triangle Institute*), and Kerry Smith as a consultant. The project is working on preference calibration methods for developing estimates of VSL, using the existing literature to calibrate the utility functions using extensions of Kerry Smith's approach. He said that is the extent to which OAQPS is funding any kind of efforts.