Valuing Large Reductions in Individual Mortality Risks

by

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April 23, 2009

Preliminary draft paper prepared for EPA Workshop on Estimating Benefits of Reducing Hazardous Air Pollutants for presentation on April 30, 2009.

DRAFT—Do Not Cite

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1. Introduction

Government estimates of the value of statistical life (VSL) are based on analyses of tradeoffs involving very small risks. The chief source of evidence is labor market studies, and these analyses pertain to risks that workers actually face rather than very large hypothetical risks. Other hedonic studies, such as those of housing markets and product markets, likewise are restricted to risk levels that are observable. Stated preference studies have no such limitation, but these analyses have generally focused on small risks as well. This paper will explore the potential influence of the size of the risk on the pertinent valuation amounts that EPA should use for benefit assessment purposes.

2. Hedonic Labor Market Studies

The main reference point for analyses of the VSL is the wage-risk tradeoff implied by workers' choices among jobs of different riskiness. Labor market evidence is the main source relied upon by government agencies. Following the standard hedonic labor market approach, economists have estimated the average wage-fatality risk tradeoff associated with the market equilibrium generated by the tangency of workers' constant expected utility loci for different wage-risk combinations and the market offer curves available to them.

Figure 1 illustrates the mechanisms at work. Firm 1 has offer curve OC_1, which consists of the set of age-risk combinations that yield the same level of profits. At higher risk levels, the firm can offer greater wages and maintain the same level of profits, thus accounting for the upward slope of OC_1. Similarly, Firm 2 has offer curve OC_2. Because workers value wages positively and risk negatively, they will never select a job that pays less than an alternative

position for any given risk level. Thus, what is pertinent for worker decisions is the outer envelope of firms' offer curves.

What risk level workers will select from the available offers depends on their preferences. As shown in Figure 1, worker 1 selects firm 1 because the risk, wage combination (p_1, $w_1(p_1)$) puts the worker on his or her highest constant expected utility locus EU_1. In terms of the diagram, worker 1 has selected a relatively low risk with a modest risk premium. Worker 2 reaches the highest constant expected utility locus EU_2. That worker has greater willingness to incur fatality risks than does worker 1 and selects risk level p_2, which yields a wage $w_2(p_2)$. For each worker, the slope at the point of tangency of the constant expected utility locus and the market offer curve gives their local wage-fatality risk tradeoff, or their VSL.

The hedonic labor market model estimates the locus of these various risk-wage combinations as shown by w(p) in Figure 1. Even though different workers are sorted along different risk levels, higher risk levels will command greater wages, so that w(p) will be upward sloping. Often the only information generated by a VSL study is some measure of the regression-weighted average slope of w(p), which is the VSL. In some cases, studies have analyzed the curvature of w(p), but before considering that aspect let's first consider what such estimates mean in economic terms.

Suppose that we know the shape of w(p), or the locus of observed risk-wage combinations that workers find attractive. Armed with this functional relationship, what can we say about workers' willingness to accept jobs with much larger risks than the small risk levels considered in hedonic wage analyses? Consider worker 1 who currently incurs a job risk p_1. If that risk level were increased to p_2, then applying the results from the hedonic wage function w(p) would imply that worker 1 would be willing to accept risk p_2 if the wage were increased to

$w_2(p_2)$. However, that wage level will not keep worker 1 on the same constant expected utility locus. A higher wage rate $w_1(p_2)$ is required, where this wage is necessarily greater than that implied by the hedonic wage analysis due to the curvature of EU_1.

By similar argument, one can analyze the worker's willingness to pay for large risk reductions below p_1. As a first approximation, one might wish to assume that the curve w(p) approximates that value. However, as is shown in Figure 1, EU_1 lies above w(p) for risk levels smaller than p_1 so that the willingness to pay values (or the drop in wages that workers are willing to accept) for substantial decreases in fatality risk will be less than that implied by the hedonic wage function.

Hedonic labor market studies of fatality risks of different magnitude will capture two sets of influences. First, because such wage studies are focusing on willingness to accept values for risk, as the risk levels become very large the wage-risk tradeoffs should increase as well, for any given worker. Second, people will sort in the labor market based on their risk preferences and the workers who are at the very high risk jobs have different preferences than those at the more modest risk jobs. Workers who self select into high risk positions will tend to have lower VSL values for any given risk level.

Figure 2 presents the Viscusi and Aldy (2003) results from six different hedonic wage studies that included a quadratic risk term to capture the curvature of the w(p) locus. Although the steepness of the decline in VSL with risk levels varies with the particular study, in every instance there is a downward sloping relationship. The dominant influence is the sorting of lower VSL people into high risk jobs. These w(p) curvature results consequently provide little insight into any particular individual's willingness to accept large risk increases or willingness to pay for large risk decreases because the main factor is the influence of individual sorting based

on risk preferences, not changes in any particular individual's VSL tradeoff along a constant expected utility locus. Put somewhat differently, government agencies looking for guidance in valuing major shifts in risk levels will have to rely on information beyond that conveyed by the hedonic wage function.

3. Labor Market Risk Levels

The fatality risks analyzed in labor market studies all pertain to the incremental risk of death relative to the background risk that the person faces. Thus, the willingness to accept amounts refer to the amount a person requires to incur an additional risk that will be posed by the job. Theoretical models and empirical frameworks often set the background risk level equal to zero, though there are exceptions for high risk groups.

The risk levels analyzed in the hedonic wage studies have varied over time, in part because the workplace has become safer. The highest risk levels analyzed in the literature were in early studies that used the risk information from the Society of Actuaries, for which the average annual risk of fatality is 1/1,000. These risk values are available by broad occupational group, not also by industry. The large risk value is misleading, however, as the data do not distinguish the occupation-specific risk but rather reflect the overall mortality risk from all causes associated with people in particular occupations. For example, in these data, actors have a particularly high risk.

The more meaningful risk measures are those that attempt to isolate the risk associated with the worker's particular job. The first such measures were those based on the early U.S. Bureau of Labor Statistics fatality risk data by industry. These data are based on a sample of

firms and imply an average risk level on the order of 1/10,000 for the time period beginning in the 1970s.

The next wave of studies used data that are believed to be a more comprehensive tally of workplace fatalities. The National Institute of Occupational Safety and Health developed the National Traumatic Occupational Fatality (NTOF) data, which reduced the amount of measurement error in the fatality variable. Notwithstanding the name of the data set, the information is available by industry and by state, and not by occupation. The average risk levels in studies using these data are from 1/10,000 to 4/10,000.

The current gold standard for fatality risk data is the U.S. Bureau of Labor Statistics Census of Fatal Occupational Injuries (CFOI). This data base consists of a complete census of all occupational fatalities rather than a sample. Each fatality is verified with multiple source documents, with four being the average number used. The confidential micro data files can be used to construct risk measures by industry, occupation, industry-occupation, age, gender, race, or other matters of interest. The average annual fatality risk level in the studies using these data is about 1/25,000.

While there are exceptions, for the most part the hedonic wage literature has focused on willingness to accept amounts for risk levels averaging from 1/25,000 to 4/10,000. By most standards, these are comparatively small risks. For such small risk changes, the willingness to pay amounts for EPA benefit assessment should be fairly similar to the willingness to accept amounts. As indicated with respect to Figure 1, for larger non-incremental risk changes, the estimated VSL from labor market studies will overstate the implied VSL based on willingness to pay (WTP) amounts and understate the implied VSL based on willingness to accept (WTA) amounts for large risk changes.

4. A Calibration Example for Non-Incremental Risk Changes

With information on the shape of individual utility functions it is possible to analyze how the willingness to pay amounts and willingness to accept amounts will vary depending on the magnitude of the risk change. We will begin with the general formulation for VSL and then consider specific functional forms. Let u(y) be the utility function of income y when healthy, and let p be the probability of death. For simplicity, suppose that bequests have a value of zero. Then VSL is given by

$$VSL = u(y)/[(1-p)\,u'(y)]. \tag{1}$$

Suppose that the utility function takes a logarithmic form u(y) = a + ln(y). Such utility functions are specified up to a positive linear transformation but the parameters must be set to be consistent with the estimated VSL. Assume that VSL = $7 million and that the worker faces an annual fatality risk of 1/10,000. Also let the value of y = $27,200, which is the current average annual wage income of blue-collar workers in the Current Population Survey. This information is sufficient to pin down the shape of the utility function.

Consider an order of magnitude increase in the size of the risk from 1/10,000 to 1/1,000. The associated risk change is 9/10,000. Based on a VSL of $7 million, the estimated WTA amount would be $6,300. But to keep the worker on the same constant expected utility locus, the required WTA is $6,966. Thus, the WTA is about 10 percent greater than would be predicted based on the local rate of tradeoff.

Similarly, the implied VSL for the discontinuous change in the risk level is greater as well. The additional required wage compensation implies a VSL of $7.7 million based on the

WTA amount. Large risk increases consequently generate a WTA value greater than that implied by the estimated VSL from local tradeoffs, but the changes in the valuations are not stark within this particular range.

Government policies generally involve WTP amounts for decreases in risk rather than WTA values for risk increases. Suppose the starting annual fatality risk is 1/1,000, the starting income is $27,200, and the VSL based on local wage-risk tradeoffs is $7 million. Suppose the risk is reduced to 1/10,000, which based on an extrapolation from the estimated VSL implies a WTP amount of $6,300. Based on the WTP amount that will put the worker on the same constant expected utility locus, the WTP value is $5,825, which is 8 percent less than would be predicted by the local tradeoff rate derived from the hedonic wage relationship. The estimated VSL associated with this non-incremental risk change is $6.5 million.

Large risk changes consequently have a different associated VSL than implied by local rates of tradeoff. The implied VSL amounts for these shifts are greater than the locally estimated VSLs from a WTA perspective and less than locally estimated VSLs from a WTP perspective. For the risk change amounts of 9/10,000 considered here, the WTA values were 10% lower than predicted and the WTP amounts were 8% lower than predicted. That the discrepancy should be greater for the WTP amounts is expected. The WTA and WTP amounts keep the worker on the same constant expected utility locus. As can be seen from Figure 1, the curvature of EU_1 ensures that the WTP-magnitude of risk change relationship will be flatter than the WTA-magnitude of risk change relationship. Thus, to the extent that EPA is largely concerned with WTP estimates than WTA values, the change in the rate of money-risk tradeoffs with large changes in risk is less than would be the case for WTA values.

An interesting application of these results is with respect to a VSL diagram that appeared in Appendix D of the Review of the Revised Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act 1990-2020, Draft report, # EPA-SABCOUNCIL-ACV-XXX-XX, March 5, 2004. Figure 3 is drawn from that report. The risk-WTP combinations r_1 through r_5 indicate the observed results of hedonic wage studies being pooled in a meta analysis. The counterpart VSL amounts for each of these studies assuming a constant linear rate of tradeoff is indicated by VSL-1 through VSL-5. The indicated WTP function in the diagram indicates the estimated WTP function based on a meta analysis. Thus, the WTP value rises with the risk change based on the pooling of results across studies and leads to a flatter WTP function than that implied by any particular estimate.

What is potentially confusing about such discussions, which often refer to labor market estimates as "empirical measures of WTP for risk reductions" is that for hedonic labor market studies they are not WTP measures but WTA measures. In the case of stated preference studies, the reference point usually is WTP values. From a theoretical standpoint, for large risk increases the WTA should be greater than the estimated value based on a linear extrapolation of VSL levels. To the extent that labor market meta analyses are fitting curves such as that in Figure 3, the implied VSL should be steadily rising as the risk change increases. That the estimated VSL does not increase with the level of the fatality risk is a consequence of the self selection of different workers into the high risk jobs, as shown in Figure 2.

To avoid the complicating considerations of multiple studies across different groups, Figure 4 presents the results based on a single study. Linear extrapolation of the estimated VSL for large risk changes will overstate the WTP amounts for very large changes in risk as people have a positive but diminishing willingness to pay for risk reductions. Whether these effects of

major shifts in the risk level are of practical consequence to EPA depends on the magnitude of the risks being considered.

5. Are Large Environmental Risks Big?

Although some environmental risks are relatively large, whether they are large compared to the labor market risks that form the basis of most VSL studies is less obvious. For the labor market reference point, consider the risk levels in the recent BLS CFOI data. These annual fatality risks average 1/25,000, which is smaller than the risk levels in other hedonic wage studies. As a result, focusing on these data will provide an upper bound on the extent to which one should view environmental risks as comparatively large.

EPA benefits assessments typically focus on lifetime risks rather than annual risks. Assuming a 40 year work life, an annual occupational fatality risk of 1/25,000 corresponds to a lifetime job-related mortality risk of 1.6/1,000. For a VSL of $7 million, the annual required wage compensation is $280. The undiscounted lifetime wage premium is $11,200. For benefit assessment purposes, such values should be discounted using a reasonable discount rate such as 3%.

For an example of a large environmental risk subject to EPA regulation, I used the Draft Benzene Case Study (March 2008). This draft Clean Air Act regulation would reduce the lifetime risks of leukemia to the exposed population. The high risk county affected by the regulation is Brazoria County for which EPA estimates that the lifetime leukemia risk would decrease from 2/10,000 to $3x10^{-6}$. This risk change is two orders of magnitude. But whether the decrease is two orders of magnitude or even more is not the key issue because the post-regulation leukemia risk is about zero.

What is consequential is the absolute magnitude of the lifetime risk reduction of approximately 2/10,000. Even this lifetime risk level is not completely outside the range of the annual risk levels that have been considered in hedonic wage studies. How great the risk probability reduction is depends on the nature of the risk exposure. Suppose that the lifetime leukemia risk of 2/10,000 is based on a series of exposures over a ten year period. Then the annual leukemia risk is about 2/100,000. The CFOI annual risk of 1/25,000 is 4/100,000, which is twice as great as this amount. Thus, even using the fatality risk data series posing the smallest risk level, the leukemia risk reduction is of fairly similar magnitude. If the lifetime risk exposure is the result of exposures of even more than ten years, then the annual risk is even smaller.

Whether the environmental risk reduction is large or small depends on how the benefits question is framed. Knowing that there is a lifetime risk reduction of a particular magnitude is not sufficient. Does the risk arise from a one-time exposure that results in leukemia at a particular future date? Or, more reasonably, does the risk arise from a series of exposures over time that produces a future distribution of risk across many future time periods? In all likelihood, focusing on the lifetime risk overstates the risk reduction achieved by the policy in any given year in much the same way as focusing on workers' lifetime risks would overstate their annual fatality risk level.

In the case of the labor market risks, the wage compensation for risks occurs in small annual amounts. Policies often do not involve annual payments but instead may involve substantial fixed costs leading to more costs being incurred up front. How the payment mechanism is structured will matter for survey valuations. Most policies are not in fact funded through actual payments of this type, so it is usually the public finance benefit valuation thought experiment that is pertinent.

6. Latency and Cancer Benefit Issues

Leukemia and other cancer risks involve a substantial latency period. From the standpoint of benefit assessment, the willingness to pay for reducing these risks at some future date should be discounted by a usual government rate such as 3%. An alternative is to incorporate the latency period aspect into a stated preference survey and ascertain individuals' own rates of time preference with respect to cancer. As fascinating as this might be as an academic exercise, it is unlikely to provide meaningful guidance for policy. Decisions involving an intertemporal component are fraught with error. Among the problems identified in past studies is that of hyperbolic discounting whereby individuals display inordinately high rates of discount for the initial period, as shown in Viscusi, Huber, and Bell (2008). Thus, estimated implicit rates of time preference may largely reflect a form of individual irrationality. Decisions involving risk and uncertainty are also potentially fraught with error so that combining a latency period element with a risk valuation task may lead to an overly complex stated preference task.

Even putting aside both the issues of latency and the magnitude of the risk, more refinement of the benefit estimates for cancer risk reduction is needed. The valuations of cancer risk reduction will differ depending on the type of cancer, the associated morbidity effects, and the effect on premature mortality. Some stated preference studies of cancer simply denote the disease as "cancer" with little description of the health consequences. Such studies will not yield meaningful valuations. Unless the respondent knows the characteristics of the health risk being valued and the consequences for personal welfare, the commodity being valued may bear little relationship to what is needed for benefit assessment.

Two studies that have obtained cancer risk valuations after providing a detailed description of the health consequences are Magat, Viscusi, and Huber (1996) and Van Houtven, Sullivan, and Dockins (2008). Each of these studies used a risk-risk methodology whereby respondents determined the personal auto accident risk that would be equivalent to a given risk of cancer. The Magat, Viscusi, and Huber (1996) study presented respondents with detailed descriptions of the health effects of leukemia developed in conjunction with cancer specialists at the Duke Medical Center. One would expect the studies to generate different values because of the different descriptions of the health consequences. However, the extent of the differences is quite large, as Magat, Viscusi, and Huber (1996) found cancer risks occurring without any latency period as having a value equal to auto accident risks, whereas Van Houtven, Sullivan, and Dockins (2008) found that even with a 5 year latency period, cancer risks were valued three times as highly as auto accident risks. Other studies yield different results, as clearly there is a major research need to refine the estimates of cancer valuations.

7. Summary and Conclusions

Labor market estimates of VSL provide the wage-risk tradeoffs for very small risks. The degree to which these values provide guidance for EPA benefit assessment for large risk reductions depends on the magnitude of the risk reduction. For non-incremental risk changes, the tradeoffs implied by the estimated VSL amounts will understate the WTA values and overstate the WTP amounts.

How much of an overstatement or understatement occurs requires either knowledge of individual utility functions or direct elicitation of these values using a stated preference approach. Using a log utility function for illustrative purposes, evaluation of risk changes

between 1/1,000 and 1/10,000 will result in an understatement of the WTA amount by 10% and an overstatement of the WTP amount by 8% for the utility function example I presented. The relatively smaller effect on the WTP, which is the usual pertinent value for policy, stems from the curvature of the constant expected utility locus.

The magnitude of the risks in the hedonic wage literature seem to be comparable to the large risks addressed by EPA regulations. The annual risk levels in hedonic wage studies are usually in the range from 1/10,000 to 1/25,000, but many studies have considered larger risk levels, such as 1/1,000. Using estimates of VSL based on differences in worker risk levels is not particularly useful. An added complication of the hedonic wage studies is that they reflect both variations in the WTA amount with the level of the risk as well as the self selection of workers with different preferences into the higher risk jobs. The sorting effect proves to be more influential than the size of risk effect on WTA.

The appropriate comparison for risk levels targeted by EPA regulations should put the risks on the same temporal basis as the job fatality risks. So if worker risks are on an annual basis, these occupational risk levels should be converted to lifetime risks to be comparable to the EPA lifetime risk estimates. Alternatively, risks could be converted to annual risks, which seems to be more pertinent for benefit assessment purposes so as to take into account the temporal distribution of the risks. Even the very large lifetime risks from benzene exposures in the high risk counties are not out of line with the risk levels in hedonic wage studies.

While additional work is desirable to further explore how the valuation of the risk depends on the magnitude of the risk change, additional research is also needed on the valuation of cancer risk reduction benefits. The effects of cancer on individual well-being are not identical

for all kinds of cancer. Ideally, EPA benefit values should reflect the pertinent morbidity and mortality effects that are being prevented by the risks that are reduced.

References

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Figure 1: Hedonic Market Equilibrium for Fatality Risks

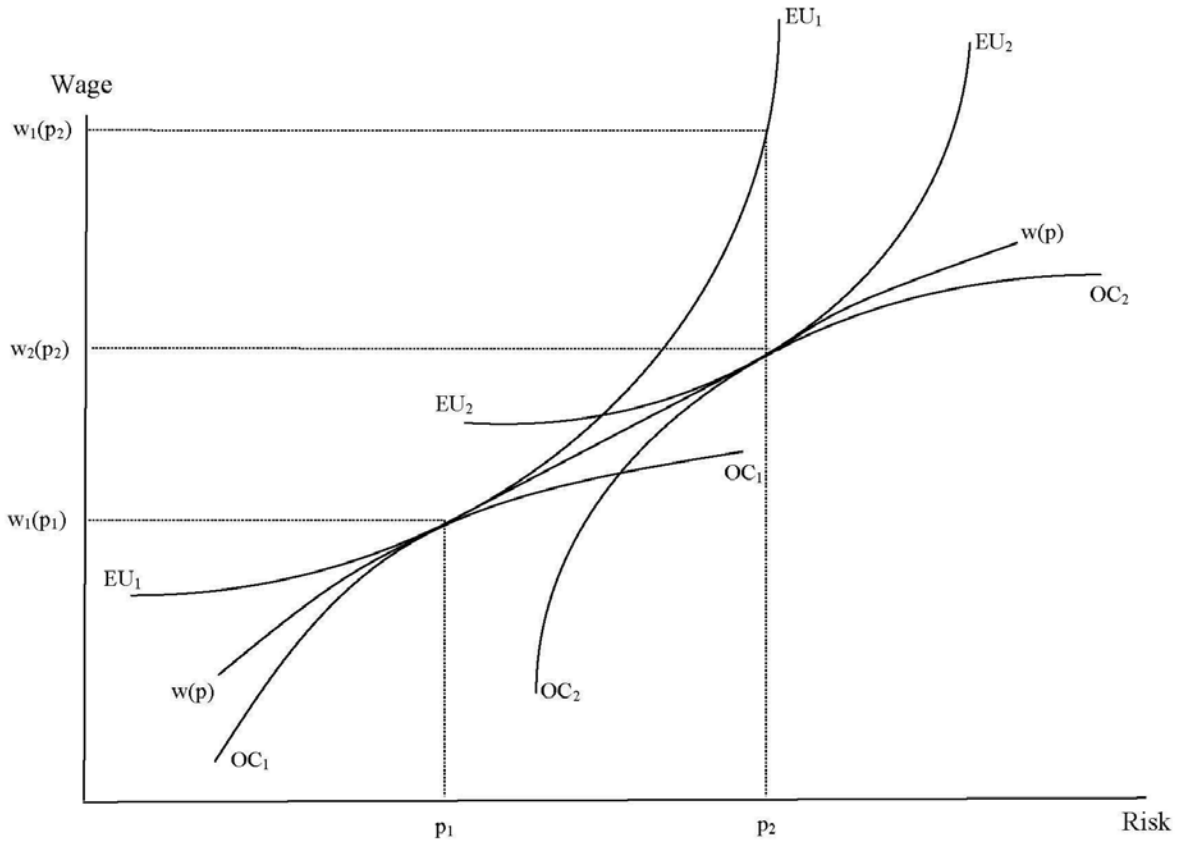

Figure 2: Relationship of Value of Statistical Life to Risk Level in Hedonic Wage Studies

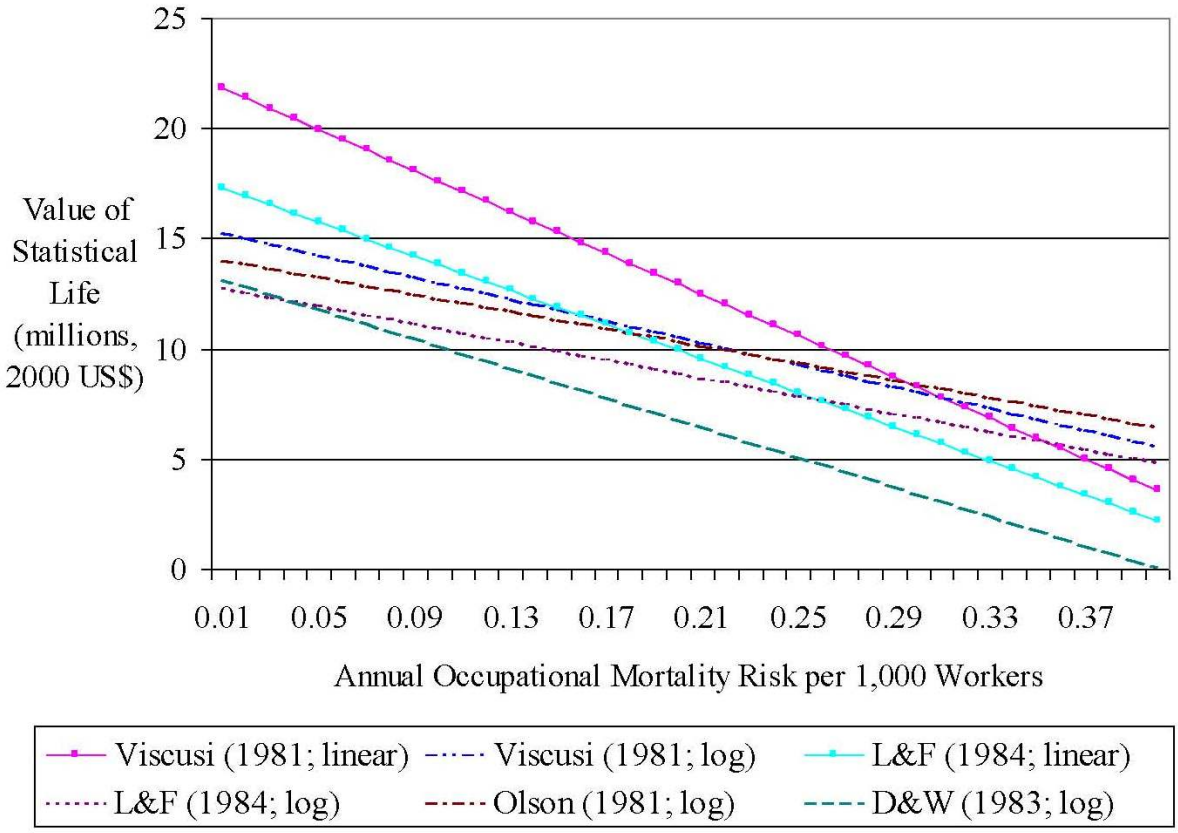

Figure 3: Illustrative Analysis of Meta Analyses

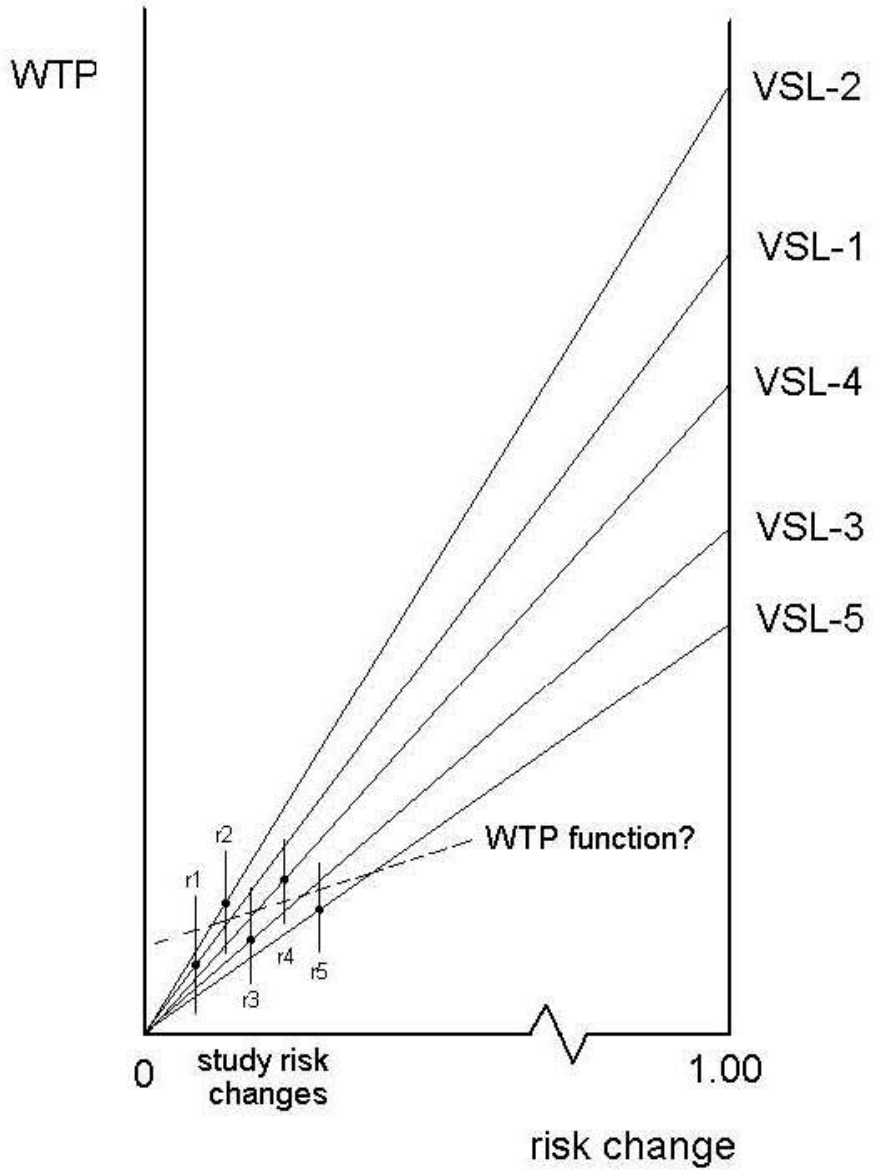
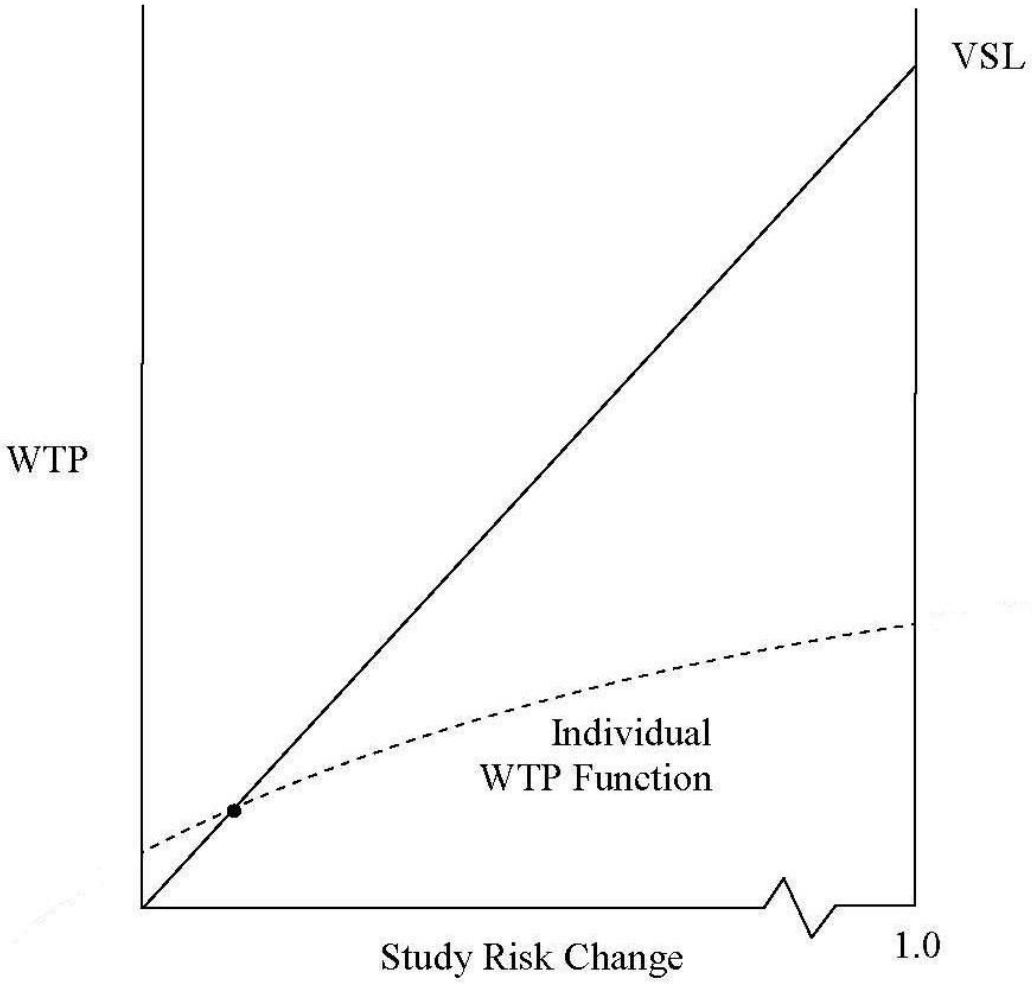
Figure 4: Individual Willingness to Pay as Function of Risk Level