DISCUSSION PAPER

Valuing Mortality Risk Reductions

Progress and Challenges

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RESOURCES
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Abstract

The value of mortality risk reduction is an important component of the benefits of environmental policies. In recent years, the number, scope, and quality of valuation studies have increased dramatically. Revealed preference studies of wage compensation for occupational risks, on which analysts have primarily relied, have benefited from improved data and statistical methods. Stated preference research has improved methodologically and expanded dramatically. Studies are now available for several health conditions associated with environmental causes, and researchers have explored many issues concerning the validity of the estimates. With the growing numbers of both types of studies, several meta-analyses have become available that provide insight into the results of both methods. Challenges remain, including better understanding of the persistently smaller estimates from stated preference than from wage differential studies and of how valuation depends on the individual's age, health status, and characteristics of the illnesses most frequently associated with environmental causes.

Key Words: value of a statistical life, mortality risk reduction, hedonic wage studies, stated preference studies

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Contents

Valuing Mortality Risk Reductions: Progress and Challenges

Maureen Cropper, James K. Hammitt, and Lisa A. Robinson[*]

1. Introduction

The value of mortality risk reduction is a major determinant of the benefits of environmental policies and regulations. The quantified benefits of environmental improvements have long been dominated by the effects of reduced air pollution, with reductions in mortality risks accounting for more than 90 percent of quantified benefits of the 1990 Clean Air Act Amendments (U.S. EPA 2011). Mortality risk reductions also contribute significantly to the benefits of drinking water regulations and other environmental policies. Regulations often affect risks of heart and lung disease and several types of cancer. Environmental programs reduce mortality risks to persons of all ages, but the largest risk reductions are often enjoyed by older people, who face greater baseline risk: more than 80 percent of the life years gained as a result of the Clean Air Act Amendments accrued to individuals age 70 and older (U.S. EPA 2011). Risk reductions accruing to infants and children are generally smaller, but also of concern to decisionmakers.

Over the past decade, the research available to support valuation of environmental risk reductions has evolved significantly. This paper discusses important methodological improvements in both revealed and stated preference research, summarizes key findings, and notes areas in need of additional work. It explores current standards of methodological acceptance that reflect the evolution of this literature.

Historically, the U.S. Environmental Protection Agency (U.S. EPA) and other agencies have estimated the value of mortality risk reduction primarily using compensating wage differentials—wage premia that workers receive for risks of fatal injuries in the workplace (Robinson and Hammitt 2011). These estimates are based on actual transactions in the labor market; however, they must be inferred from observational data by holding other job and worker characteristics constant. For valuing environmental risks, they have two primary drawbacks: they

are based on risk of accidental death rather than environmentally related disease, and the workers whose preferences are assessed are generally younger than 65 years. Moreover, valuation of occupational and environmental risks may differ if occupational risks are perceived as more voluntary and individually controllable.

Interest in valuing nonaccidental mortality risks has led to growing use of stated preference studies, in which respondents are asked directly about mortality risk reductions. Stated preference studies can be tailored to value risks of specific diseases by populations that are not represented in hedonic wage studies. However, respondents may have less incentive to consider their responses than in more consequential settings. From the perspective of environmental risk valuation, the important questions are the extent to which stated preference results are valid, reliable, and should replace or supplement hedonic wage estimates.

This paper is organized as follows. Section 2 reviews the concept of mortality risk valuation—how much money an individual will substitute for a change in his risk of dying. This is usually expressed as the value per statistical life (VSL)—that is, the rate of substitution between wealth (or income) and risk. In Section 3, we discuss hedonic wage studies, outlining the methods used and discussing what distinguishes a well-conducted study. We summarize briefly the resulting empirical estimates. Section 4 describes stated preference studies. We describe the methods used, discuss methodological improvements, and summarize empirical findings. Section 5 concludes by evaluating the empirical literature, proposing criteria for methodologically acceptable studies, and suggesting further research.

2. The Value per Statistical Life

Analyses of the health benefits of environmental policies generally begin with a risk assessment that estimates the change in mortality risks likely to be experienced by the affected population. These assessments do not predict which individuals might die if pollution is not abated; they estimate only the change in mortality risk over a defined period for members of the affected population. These changes in mortality risk are often summarized as the expected number of "lives saved" or "premature fatalities averted"—that is, the sum over affected individuals of the risk change.

By convention, the value of these risk changes is expressed as the value per statistical life (VSL), which is defined as the marginal rate of substitution between money and mortality risk in a defined time period. In other words, it is the local slope of an indifference curve between risk and wealth, not the value of saving an individual's life with certainty (see Hammitt 2000). This

means that if an individual is willing to pay $700 for a 1 in 10,000 decrease in his risk of dying during the year, his VSL is $700 divided by the risk change, or $7 million. The VSL can also be viewed as the sum of what a group of individuals would pay for risk reductions that sum to one statistical life.[1]

The VSL concept is illustrated in Figure 1. Wealth is plotted on the vertical axis, and the probability (p) of surviving a specified period is plotted on the horizontal axis. The curved line represents an individual's indifference curve. For each change in survival probability (Δp), individual willingness to pay (WTP) or willingness to accept (WTA) compensation is measured by the vertical distance between the two points on the indifference curve. The VSL can be calculated as the individual's WTP or WTA divided by Δp.[2]

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[1] Because the term is often misinterpreted (Cameron 2010), U.S. EPA is considering using *value of risk reduction* (VRR).

[2] Strictly speaking, VSL is the limit of WTP/Δp and WTA/Δp as Δp tends to zero.

Figure 1. The Trade-Off between Wealth and Survival Probability

$$VSL \approx \frac{WTP}{\Delta p} \approx \frac{WTA}{\Delta p}$$

Indifference curve

Wealth

WTP (for risk decrease)

WTA (for risk increase)

Δp

Δp

0   Survival probability (= 1 - risk)   1
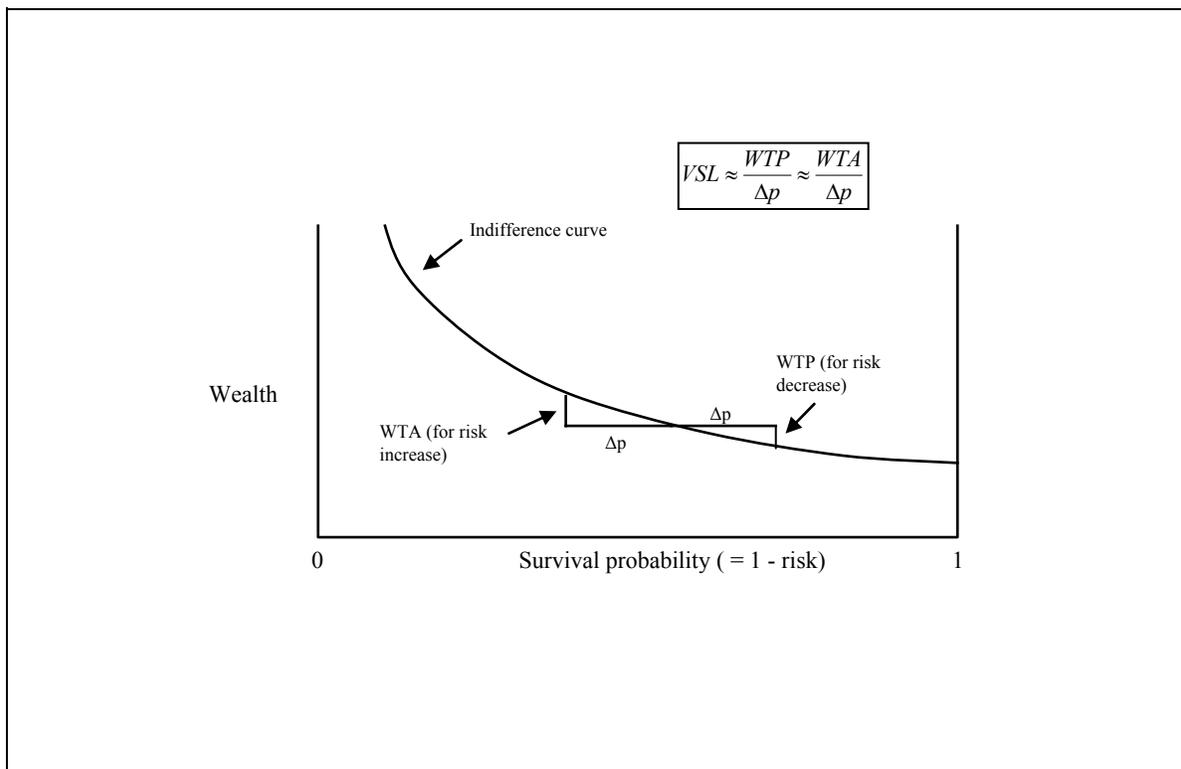
Intuitively, one expects that individual WTP and WTA will increase as the size of the risk reduction increases. For small risk changes, the relationship of WTP and WTA to the risk change should be nearly proportional (i.e., the indifference curve is smooth). Proportionality is not expected for large risk changes because wealth constrains the amount one could pay for a large risk reduction (e.g., one could pay $7 to reduce risk by 1 in 1 million but not $700,000 to reduce risk by 1 in 10). Under standard assumptions, economic theory suggests that individual WTP will decrease (and WTA will increase) with each incremental increase in the risk reduction (see Hammitt 2000; Hammitt and Treich 2007).

The relationships illustrated in Figure 1 may be influenced by other factors, such as income, wealth, age, life expectancy, and current and potential future mortality risk and health status. In addition, individuals may place different values on risks with different characteristics. Some of these characteristics are physical attributes (such as whether the risk is latent or involves significant morbidity prior to death); others are psychological (such as whether the risk is perceived as voluntarily incurred or under an individual's control). There is no single VSL: different people may have different preferences and, for an individual, the value of a 1 in 10,000 risk reduction may depend on whether death results immediately from injury or from a lingering

illness, whether it is caused by a hazard viewed as particularly fearsome, whether one is rich or poor or old or young, and other factors. Given these differences, analysts are often faced with challenges related to the match between the available research and the characteristics of the risks and populations of concern in particular environmental contexts.

3. Hedonic Wage Studies

Historically, the VSL literature has been dominated by revealed preference studies that estimate the trade-off between wages and job-related risks.[3] In hedonic wage studies, researchers compare wages of workers in different occupations or industries who face different levels of on-the-job mortality risk, using statistical methods to control for other factors (such as education or nonfatal job risks) that affect wages. Although these studies are often seen as more credible than stated preference studies, they have two weaknesses: compensating wage differentials must be inferred statistically, rather than being observed directly, and estimates of VSL based on hedonic wage equations assume that the measure of job risk used by the researcher matches workers' risk perceptions.

The premise underlying compensating wage differentials is that jobs can be characterized by various attributes, including risk of accidental death. The association between wages and occupational risks observed in the market is determined jointly by workers' preferences and firms' costs of reducing job risks. If workers are well informed about risks of fatal and nonfatal injuries and if labor markets are competitive, riskier jobs should pay more, holding worker and other job attributes constant. Empirically, wages are described as a function of worker characteristics (age, education, human capital) and job characteristics, including risk of fatal and nonfatal injury (Viscusi 1993). In theory, the difference in wage associated with a small change in risk equals the amount of compensation a worker requires to accept the risk and the income he would forgo for a safer job.

A few hedonic wage studies have used workers' perceived risks (elicited by survey) in place of conventional actuarial risk estimates (e.g., Gerking et al. 1988; Gegax et al. 1991;

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[3] Studies of risk-averting behavior (or demand for consumer-safety products) and residential-property values have also been used to estimate VSL (see reviews by Viscusi and Aldy 2003 and Blomquist 2004). Researchers often argue that these studies are less suitable for valuation than hedonic wage or stated preference studies because of difficulties in estimating actual or perceived risks, the need to make assumptions about key factors such as time costs (in some product studies), whether cancers are likely to be fatal (in some hedonic property value studies), and other factors.

Viscusi and Moore 1991; Liu and Hammitt 1999). These studies yield similar VSL estimates to studies using actuarial risk estimates, as confirmed by meta-analysis (Mrozek and Taylor 2002).

A typical hedonic wage equation is of the form (1), in which the log of the wage is regressed on fatal and nonfatal job risk, worker characteristics (including age, race, education, years of experience, and union status), and job characteristics (including industry and occupation).[4]

$$\ln w_i = \alpha + \sum \beta_m x_{im} + \gamma_0 r_i + \gamma_1 q_i + \gamma_2 q_i WC_i + u_i \ (1)$$

where

w_i : worker i's wage rate

α : constant

x_{im} : personal and job characteristics, worker i

r_i : fatal job risk, worker i

q_i : nonfatal job risk, worker i

WC_i : worker's compensation

u_i : random error term

Because γ_0 represents the proportionate increase in the wage for a one-unit change in fatal job risk, VSL is calculated by multiplying γ_0 by the average wage and dividing by a one-unit change in risk.[5]

3.1. Econometric Issues

The econometric difficulties encountered in estimating the labor market price of risk include obtaining accurate estimates of risk of death on the job; the sensitivity of estimates of γ_0 to what other variables are included in the equation—in particular, to the inclusion of industry and occupation dummies and a measure of nonfatal job risk; and correlation between job risk and variables omitted from the equation. The last problem can take several forms. If higher-risk jobs

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[4] The extent to which industry and occupation dummy variables can be included is limited by the nature of the risk data. If fatal job risk is estimated at the three-digit industry level, then two-digit industry dummy variables can be included in the equation, but not three-digit dummies, to avoid exact collinearity among right-hand variables.

[5] The change in wage and risk must be calculated for the same time period, usually annual.

have undesirable characteristics not measured by the researcher, the risk variable will tend to capture these characteristics, biasing γ_0 upward. Unmeasured worker characteristics could bias the coefficient of risk in either direction. If worker productivity is measured imperfectly and more productive workers accept safer jobs, this will bias γ_0 downward (Hwang et al. 1992). Unmeasured differences in workers' ability to reduce job risk will tend to bias γ_0 upward (Shogren and Stamland 2002).

The magnitude of the econometric difficulties associated with early wage risk studies is documented by Black et al. (2003) and by Black and Kniesner (2003). At the request of U.S. EPA, Black et al. estimated hedonic wage equations using 10 combinations of worker and risk data sets that are commonly used in hedonic wage studies.[6] Four specifications of equation (1) were estimated for each data set: (a) a basic set of covariates (model 1)[7]; (b) the basic set with state dummies (model 2); (c) model 2 with occupation or industry dummies (model 3); and (d) model 2 with both occupation and industry dummies. The authors found the estimated coefficient on fatal risk varied widely; it was positive and significantly different from zero in only 16 (of 40) cases for men and 14 (of 40) for women. They attribute the instability of estimated VSLs to errors in measuring fatal job risk, which may be correlated with worker attributes, and to collinearity between the risk measure and occupation and industry dummies. The authors concluded, "Collectively, these findings lead us to have severe doubts about the usefulness of existing estimates to guide public policy."

Over the past 10 years, the data and methods used in U.S. hedonic wage studies have improved significantly. We discuss the availability of improved risk data, attempts to control for confounding factors, and methods for dealing with the endogeneity of job risk. We document progress in dealing with these econometric challenges and areas that remain open for future research. Section 3.2 provides examples of recent studies and meta-analyses.

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[6] The data sets are obtained by combining either the March Current Population Survey, the Outgoing Rotation Groups of the Current Population Survey, or the National Longitudinal Survey of Youths with risks by industry or by occupation from either the Bureau of Labor Statistics Survey of Working Conditions or the National Institute of Occupational Safety and Health estimates from its National Traumatic Occupational Fatality survey.

[7] The basic set of covariates differs between data sets but includes a quartic function of age, education, union and marital status, race, and ethnicity. Some data sets also include firm size, workers' experience, tenure, score on the Armed Forces Qualification Test.

Measurement of Job Risk

Accurate measurement of fatal job risk requires estimates that vary by both occupation and industry and, because of the infrequency of deaths on the job, are based on a large sample of workers. Random errors in measuring fatal job risks tend to bias estimated coefficients toward zero, understating compensating wage differentials. Most studies prior to 2000 used data from either the Bureau of Labor Statistics (BLS) Survey of Occupational Injuries, reporting deaths by three-digit industry classification, or the National Institute of Occupational Safety and Health (NIOSH), reporting risks by one-digit industry and state, resulting in significant measurement problems.[8] Clearly, workers in different occupations within the same industry are subject to different risks—an office worker in a mining company faces less risk than a miner. There is also evidence that the early BLS data understated fatal job risks.

Recent studies (Aldy and Viscusi 2008; Kniesner et al. 2010; Viscusi 2004) have made significant advances in the measurement of job risk by using the BLS Census of Fatal Occupational Injuries (CFOI) and distinguishing risks by occupation and industry.[9] The CFOI is a census rather than a sample and is based on comprehensive review of multiple records, including death certificates and workers' compensation reports. These studies generally use risks for 720 occupation-industry cells (10 occupations and 72 two-digit industries) based on three-year averages of deaths.

Sensitivity to Equation Specification and Omitted Variables

The sensitivity of estimates of the price of risk to equation specification has been noted by many authors, including Black et al. (2003), Hintermann et al. (2010), Leigh (1995), and Mrozek and Taylor (2002). Failure to control for either worker or job characteristics that are correlated with job risk will render estimates of the coefficient γ_0 biased and inconsistent. Estimates are especially sensitive to inclusion of dummy variables for occupation and industry and to inclusion of nonfatal job risk and replacement of wages through workers' compensation programs (e.g., Viscusi 2004). Occupation dummies are often included in equation (1) to proxy job characteristics, which, apart from injury risk, are seldom included in compensating wage

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[8] Some studies from the 1970s and 1980s (e.g., Thaler and Rosen 1976, Brown 1980) used data from the Society of Actuaries, which measured total death rate by occupation including nonjob-related deaths. Dillingham (1985) is a notable exception of an early study that measured risks by occupation and industry.

[9] Available at http://www.bls.gov/iif/home.htm.

studies.[10] Interindustry wage differentials may occur for reasons unrelated to job risk—for example, because of differences in capital-labor ratios (Krueger and Summers 1988)—suggesting that industry dummies should be included in hedonic wage equations.

Correlations between fatal job risk and industry or occupation make estimates of the price of risk sensitive to their inclusion. Leigh (1995) and Dorman and Hagstrom (1998) argued that the estimated price of risk actually captures interindustry wage differentials, since the coefficient on risk often becomes insignificant when industry dummies are included. In their meta-analysis, Mrozek and Taylor (2002) find that studies that include industry dummies obtain significantly lower estimates of the price of risk than studies that exclude them. Viscusi (2004) finds that controlling for both industry and occupation risk reduces the estimated VSL by half compared with controlling for industry only.

Correlation between industry and occupation and fatal job risk is a problem of collinearity. A similar problem arises when including risk of nonfatal injury in the hedonic wage equation. Nonfatal job risk is generally correlated with fatal job risk, making it difficult to disentangle the effects of the two variables. A possible solution is to find data sets that exhibit less collinearity between these variables.

Endogeneity of Risk

The level of occupational fatality risk a worker faces results not from random assignment of workers to jobs but from a sorting process in which workers choose among jobs for which they are qualified. Moreover, workers may differ in their ability to manage occupational risks, such that even workers in the same job face different risks (Shogren and Stamland 2002).

Correlation between risk and unobserved job or worker characteristics can be handled using instrumental variables or panel data. Finding a good instrumental variable for job risk has proved difficult. Arabsheibani and Marin (2000, 2001) attempt to treat risk as endogenous but find that collinearity between their instrument and other covariates makes precise estimation difficult. Kniesner et al. (2010) and Hintermann et al. (2010) use past risk levels as instruments

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[10] Some studies distinguish or include only blue-collar jobs, or include measures of physical exertion and other working conditions. Deliere et al. (2009) use detailed occupation characteristics from the Dictionary of Occupational Titles to characterize jobs.

for the change in worker risk in their studies.[11] Another possibility is to find a natural experiment, such as a government program to reduce traffic fatalities, that causes variation in fatal job risk and is exogenous to both unmeasured job and worker characteristics.

When panel data are available, estimation of equation (1) using first differences or worker fixed effects will eliminate worker characteristics that change slowly over time from the error term.[12] Kniesner et al. (2011) and Hintermann et al. (2010) use panel data sets to estimate compensating wage differentials for the United States and the United Kingdom, respectively. Kniesner et al. note that most of the variation in risks over time comes from job changes rather than changes in risk, holding job constant. There is sufficient within-worker variation in risk in the Panel Study of Income Dynamics to obtain precise estimates of VSL.[13] The authors also note that controlling for unobserved worker heterogeneity reduces estimates of VSL by about 50 percent from estimates obtained using a single cross-section of data. In contrast, Hintermann et al. do not find statistically significant estimates of VSL when using panel data, although they do find significant results when estimating equation (1) by ordinary least squares.

The econometric issues discussed here suggest that one must be careful in interpreting published studies—especially those conducted prior to 2000—as providing unbiased estimates of the price of risk in the labor market. Although more sophisticated econometric methods are now being used, estimates currently applied in policy analysis are based primarily on earlier literature. With this caveat, we briefly summarize the findings of the empirical literature.

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[11] The use of first differences in risk helps to attenuate measurement error in the risk variables, as does the use of instrumental variables for risk. Black and Kniesner (2003) note that instruments are useful in addressing classical measurement error, but that improved methods are needed to address the non-classical error found in the older hedonic wage studies.

[12] These characteristics may include risk preferences, unmeasured job productivity, and unmeasured safety-related productivity. An alternate approach to dealing with unmeasured worker productivity is to estimate a Roy sorting model (see Deliere et al. 2009).

[13] These estimates are obtained omitting industry dummies.

3.2. Empirical Estimates of the Price of Risk in the Labor Market

Meta-Analyses of Hedonic Wage Studies

The hedonic wage literature includes several dozen studies that have been summarized in a series of meta-analyses, of which the four listed in Table 1 provide U.S. estimates.[14] Each of these meta-analyses constructs a "best estimate" of VSL. The first three use meta-regression to see how VSL estimates from individual studies vary with study and respondent characteristics. The fourth, Kochi et al., uses a Bayesian approach to adjust estimates for within and between study variability. Though all four meta-analyses include VSL studies of non-U.S. populations (almost entirely populations in high-income countries), we focus on the authors' preferred estimates for the United States. About 30 to 40 U.S. hedonic wage studies are included in each meta-analysis (the exact number varies across model specifications). The resulting U.S. estimates range from $2.0 million to $11.1 million (2009 USD).

Table 1. U.S. Estimates from Recent Hedonic Wage Meta-Analyses[a]

	Publication dates of underlying studies[b]	*Highlighted VSL estimate*	
Meta-analysis		*As reported (dollar year)[c]*	*Inflated to 2009 USD[d]*
Miller (2000)	1974–1990	$3.7 million (1995 USD)	$5.2 million
Mrozek and Taylor (2002)	1974–1995	$1.5 million to $2.5 million (1998 USD)	$2.0 million to $3.3 million
Viscusi and Aldy (2003)	1974–2000	$5.5 million to $7.6 million (2000 USD)	$6.9 million to $9.5 million
Kochi et al. (2006)	1974–2002	$8.9 million (2000 USD)	$11.1 million

a. These meta-analyses also provide estimates that include other countries. Miller and Kochi et al. also consider stated preference studies.

b. U.S. hedonic wage studies only.

c. Mean or median estimate(s) for the United States, highlighted by the authors in their abstracts or discussions of alternative models.

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[14] Several other meta-analyses focus on estimating VSL for countries other than the United States. Liu et al. (1997), Hammitt and Liu (1997), and Bowland and Beghin (2001) include only hedonic wage estimates; Kluve and Schaffner (2008) and De Blaeij et al. (2003) include both revealed and stated preference studies; the latter is a meta-analysis of road safety studies.

d. Adjusted for inflation using the Consumer Price Index, All Urban Consumers. Not adjusted for income growth over time.

A more recent meta-analysis of both revealed and stated preference studies from around the world, Bellavance et al. (2009), includes U.S. hedonic wage studies published between 1974 and 2004 along with other studies and uses a mixed-effect regression model. The weighted average of their estimated VSLs is $5.86 million (with a 95 percent confidence interval of $4.7 million to $7.1 million) in 2000 USD, or $7.3 million in 2009 USD. The best estimates obtained by each meta-analysis vary because of the choice of studies and estimates to include in the meta-analysis, as well as the modeling approaches and covariates included. The meta-regressions conducted by Miller (2000), Mrozek and Taylor (2002), and Viscusi and Aldy (2003) explain variation in VSL estimates across studies as a function of study and population characteristics. These include variables such as mean worker income, mean occupational risk, the proportion of workers unionized, and whether the study included controls for interindustry wage differentials or nonfatal job risk. All the meta-analyses find that VSL increases with the average income of workers in the study, although the rate of increase varies. Mrozek and Taylor (2002) find that studies that fail to control for interindustry wage differentials report larger VSLs.

Unfortunately, almost all studies included in these meta-analyses were completed before the improved CFOI data became available and do not reflect recent advances in econometric modeling.[15] There is no published meta-analysis that covers the newer hedonic wage literature; the most current includes studies published only through 2004.

Effects of Worker Age and Risk Characteristics[16]

Most hedonic wage studies estimate an average price of risk in the job market and do not measure how compensating wage differentials vary by risk or worker characteristics. Some studies have examined how the price of risk varies with worker age and cause of death.[17] We summarize examples of recent results here, focusing on attributes that are most relevant to valuing environmental risks.

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[15] U.S. EPA (2010) identified 15 studies that use the CFOI data, of which 8 use the data in original hedonic wage analyses. The earliest of these was published in 2003.

[16] VSL increases with income, though the rate of increase is uncertain. See Hammitt and Robinson (2011) for a review.

[17] A few studies have estimated how compensation varies with other worker characteristics. For example, Viscusi and Hersch (2001) find that smokers accept smaller compensation for nonfatal injury risk than do nonsmokers, and Viscusi (2003) finds that blacks receive less compensation for risk than whites.

Age. Aldy and Viscusi (2008) examine the effect of age on VSL using occupational risk data that vary by worker age and a minimum-distance estimator that controls for cohort effects (younger workers were born later and have greater lifetime income). They find that VSL follows an inverted-U pattern with age, peaking at approximately $8 million (2000 USD) at age 46, then declining to $5 million by age 62. This inverted-U relationship has been found in other hedonic wage studies (Aldy and Viscusi 2007).

Risk characteristics. Nearly all hedonic wage studies estimate compensation for risk of fatal injury and exclude risks of fatal disease (which are much more uncertain). An exception is Lott and Manning (2000), who estimate compensation for risk of fatal cancer. The authors use several indicators of worker exposure to carcinogens at the two-digit SIC level in place of a standard fatality risk measure and estimate the corresponding wage premium. They provide "rough" estimates of VSL using a range of assumptions about the fatality risk of occupational exposure that range from $1.2 million to $12 million (1984 USD), or $2.5 million to $24.8 million in 2009 dollars.

Recent work by Scotton and Taylor (2011) suggests that hedonic wage estimates may mask significant heterogeneity in the value of different types of risks. Using risk rates that vary by cause of injury, they find that wage premia are much higher for workplace homicides than for other job-related risks. Although their results are not directly applicable to illness-related risks from environmental causes, they suggest that more work is needed to understand how different fatality risks are valued.

4. Stated Preference Studies

Stated preference studies, which survey respondents about how they would act in hypothetical situations, have become increasingly common as a means of valuing mortality risk reductions. The scenario presented to respondents can be tailored to specific environmental risks (e.g., pesticide residues or air pollution) and causes of death (e.g., cancer or heart disease). Risks may affect persons of all ages, including children and the elderly, and the researcher is at liberty to specify the size of the risk reduction. The disadvantage of stated preference studies is that individuals may give spurious answers because they face no real consequences. An indication of problematic responses is that estimated WTP often fails to increase in proportion to the size of the risk valued, and thus estimates of VSL decrease sharply as the stated risk reduction increases. Furthermore, estimates from stated preference studies are sensitive to assumptions made in the econometric analysis.

Most stated preference studies are either contingent valuation (CV) studies or choice experiments. In both cases, the respondent is presented with a scenario (often a product or program) that would reduce his mortality risk and information about his baseline risk (without the program). The researcher must define the magnitude of the risk reduction delivered by the program, the time period over which it will be delivered, the amount and form of payment (e.g., product price or additional taxes), and other relevant information. The respondent is asked to make a choice: in the case of CV, whether he would choose the program and pay the stated cost; in a choice experiment, which of several programs he would choose. Studies usually include multiple valuation questions plus debriefing questions to determine whether the respondent understood and accepted the choices offered.

4.1. Choices in Study Design

Nature of the Risk Valued

An important issue in survey design is whether respondents should value reductions in risk of death due to a specific cause (e.g., heart disease or cancer) independently of its link to the environment, or whether the risk of death should be linked to an environmental concern, such as air pollution or hazardous waste sites. The danger with the latter approach is that respondents may not accept the scenario: they may not believe that the environmental problem could result in the stated health effect, they may be unwilling to pay to reduce the risk because they did not cause it, or their values may reflect a desire to modify some other feature of the problem.[18] A danger associated with asking about a more abstract risk reduction that is not linked to a specific hazard and program for amelioration is that the respondents may not find the scenario credible and would reject it out of hand. Because environmental programs often benefit the community at large rather than solely the respondents, it is important to understand whether the respondents are valuing only their own risk reduction or the reductions provided to the larger community.

A recent Organisation for Economic Co-operation and Development (OECD) review of the international stated preference literature (Lindhjem et al. 2010) identified 75 VSL surveys, of which 18 focused on environmental causes, 28 on health risks from unspecified causes, and 29 on traffic safety. Examples of environmental and health-related studies include those focused on

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[18] In a study of pesticide residues on foods, Hammitt and Haninger (2010) found that 32 percent of respondents thought their personal risk was overstated in the survey and 12 percent thought it was understated.

the risk of cancer from pesticide residues (Hammitt and Haninger 2010), the risk of death from exposure to hazardous waste (Alberini et al. 2007), and the risk of death due to chronic heart and lung disease (Krupnick et al. 2002).

How Risks Are Communicated

A critical component of any mortality risk survey is how baseline risks and risk changes are communicated. Baseline risk is the respondent's risk of dying without the program or product, usually from all causes. The risk changes are typically on the order of 1 in 10,000 or 1 in 100,000 per year. Lay people have difficulty comprehending small probabilities, which may lead them to report values that are not logically related to the size of the risk reduction (Hammitt and Graham 1999).[19]

Methods for communicating risk changes depend on survey mode. For in-person, mail, and Internet surveys, risks are often communicated by coloring squares on a grid, a method that has been found to yield responses to valuation questions that are more consistent with theory (Corso et al. 2001). Krupnick et al. (2002) show respondents their baseline risk of death (i.e., risk of death in the absence of the program) over the next 10 years by darkening squares on a grid of 1,000 squares. The risk reduction that the respondent is asked to buy is communicated by changing red squares to blue. Other devices used to communicate small probabilities include risk ladders, which compare the risk in question with other risks using a linear or logarithmic scale. In telephone surveys, individuals are sometimes told that without a program "x people will die out of 10,000"; with the program "y people will die out of 10,000." A disadvantage of this approach is that it focuses attention on the change in risk to a population rather than to the individual respondent (who may perceive that he will not benefit). Lindhjelm et al. (2010) describe trends in survey mode and reports that the use of Internet and computer-based surveys is increasing rapidly and that most surveys now use some sort of visual aid.

Elicitation of WTP

How respondents are asked to value a risk reduction affects the quality of the data obtained and how responses are analyzed. Before the mid 1990s, most mortality risk valuation surveys used open-ended valuation questions. Respondents were asked, "What is the most you

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[19] Hammitt and Graham (1999) found that 39 percent of telephone survey respondents did not correctly answer which is the larger number: 1 in 10,000 or 5 in 100,000.

would pay for the risk change?" This has the advantage of providing a point estimate of each person's WTP but is a difficult question to answer and may elicit a strategic response (e.g., people are conditioned not to report their maximum WTP in negotiations).

In the majority of contingent-valuation studies conducted since the mid-1990s, dichotomous-choice methods are used, following the recommendation of the U.S. National Oceanic and Atmospheric Administration (NOAA) expert panel on contingent valuation (NOAA 1993). Respondents are asked a neutral question about whether they would pay a stated amount for the risk reduction ("If the risk reduction cost $z, would you purchase it or not?") and the "bid amount" z is varied randomly across respondents. The question is often followed by a second question to more closely bound the respondent's WTP. For example, if the respondent accepts the program when the bid is $100, he is asked whether he would accept or reject it if the bid were $200. If he rejects $200, his WTP is assumed to be between $100 and $200; if he accepts $200, it is assumed to be greater than $200 with no explicit upper bound.[20] Although dichotomous choice questions do not invite strategic response, they provide only interval estimates of each respondent's WTP. The precision of the final estimate is sensitive to the bids chosen. In principle, one might like to have bids distributed over the entire WTP distribution, but those in the tails (which almost all respondents accept or reject) provide little information about the shape of the distribution.[21]

For benefit-cost analysis, analysts usually seek to measure mean WTP because population benefits can be calculated as the product of mean WTP and the number of people affected. Mean WTP for a risk change can be calculated easily from open-ended responses but may be sensitive to outliers, some of which may be invalid "protest responses" in which the respondent reports zero or a very large number as a way of rejecting the premise of the question. In the case of a single dichotomous choice question, the proportion of people willing to pay $z provides a point estimate of the cumulative distribution of WTP. Plotting raw responses against bid amounts provides an estimate of the distribution of sample WTP. A lower-bound estimate of

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[20] Payment cards that list alternative WTP amounts are sometimes used. Respondents are asked to circle the amount that most closely matches their WTP or to circle the two numbers that bracket their WTP. A disadvantage is that responses are sensitive to the range of values displayed on the card (a result that is well known to charities that suggest specific donations).

[21] See Alberini (1995) for more discussion of optimal bid design.

mean WTP may be obtained from these responses using a Turnbull estimator, which assumes each individual's WTP is equal to the largest bid he accepts (Turnbull 1974).

In practice, mean WTP is estimated from dichotomous choice data by assuming that WTP is a function of covariates (i.e., $WTP_i = X_i\beta + \varepsilon_i$, where ε_i is an error term) and estimating the parameter vector β making assumptions about the distribution of $\{\varepsilon_i\}$. For example, in the case of a single dichotomous choice question, if $\{\varepsilon_i\}$ are independently and identically normally distributed with zero mean and standard deviation σ, the probability that the respondent will not pay more than z_i is $\Phi(z_i/\sigma - X_i\beta/\sigma)$ where Φ is the standard normal distribution function. By estimating a probit model with z and X as independent variables (Cameron and James 1987), one obtains estimates of $1/\sigma$ and β/σ. Mean WTP (conditional on X) is computed as $X\beta$.[22] This approach also makes it possible to estimate the relationship between covariates (such as age and income) and WTP. Because WTP is usually assumed to be non-negative and the distribution is often skewed, with a long right tail, asymmetric distributions like lognormal and Weibull are frequently used. With these distributions, the mean is sensitive to the weight of the right tail, which is not well estimated (because few respondents are in the tail). As a result, median WTP is often reported even though the mean is more relevant for benefit-cost analysis.

4.2. Issues with Responses and Data Analysis

Hypothetical Nature of Responses

A major concern with stated preference studies is that respondents may give different answers than they would if facing real consequences. They may not take questions seriously (i.e., they may not give thoughtful responses), or they may say yes to payment questions to please the interviewer (yea-saying) or say no to protest the scenario offered (nay-saying). If respondents do not have to pay, they may not seriously consider their budget constraints.

One method of addressing these concerns is to compare actual with stated WTP for identical risk changes. There is a large literature comparing actual with stated WTP for other commodities. For example, several experiments comparing hypothetical and actual WTP for hunting permits have found no statistically significant difference (Dickie et al. 1987; Mitchell and Carson 1989). Few such studies address mortality risks. Lanoie et al. (1995) conducted a CV

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[22] Maximum likelihood techniques can likewise be used to estimate the parameter vector β in the case of double-bounded dichotomous choice questions, given assumptions about the distribution of the error term.

survey in Montreal and collected the information needed to develop hedonic wage estimates. They found that the two approaches yielded different results but suggest that their sample may be too limited to permit general conclusions. Hakes and Viscusi (2007) compared the VSL implied by seatbelt use data with the VSL from a stated preference study and found no statistically significant difference.

Tests of internal validity, which are now a standard part of most CV studies, are another way of addressing concerns about the hypothetical nature of stated preference surveys, as are debriefing questions asked at the end of the survey.[23] Internal validity can be evaluated by testing whether estimated WTP is sensitive to factors that should affect it (such as the magnitude of the risk change that is valued and the respondent's income) and insensitive to factors that should not affect it (such as small differences in baseline risk). WTP should increase with income. Indeed, the income elasticity of WTP should exceed the coefficient of relative risk aversion (Eckhoudt and Hammitt 2001; Kaplow 2005). In most stated preference studies, WTP increases with income but the income elasticity is less than one (Hammitt and Robinson 2011).

It is standard practice to debrief respondents at the end of a survey to see whether they interpreted the questions as the researcher intended. For example, respondents in a mortality risk survey may consider the morbidity that precedes death as well as mortality per se, even if no mention was made of morbidity. Or they may believe that the risks associated with an environmental contaminant are higher or lower than stated in the survey. Respondents are often asked how confident they are in their responses. This information can be used to adjust WTP either by removing some respondents from the sample or by statistically controlling for respondent reactions.

Failure of WTP to Increase with the Size of the Risk Reduction

Mortality risk survey designers often conduct scope tests by determining whether WTP to reduce risk increases with the magnitude of the risk reduction. External scope tests compare WTP between subsamples of respondents presented with different risk changes. These are preferred to internal scope tests that compare WTP by the same respondents, as internal tests can be influenced by respondents' efforts to provide self-consistent responses. As described in Section 2, WTP should increase approximately in proportion to the size of the risk reduction, implying that VSL remains constant. External scope tests are usually interpreted as testing both

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[23] It is possible to test for "yea" and "nay" saying (Alberini 2005), although this is rarely done.

whether risk changes are interpreted by respondents in an objective fashion and whether responses accord with theory.[24]

Although many studies show that WTP increases with the size of the risk reduction, WTP often fails to increase proportionately. Hammitt and Graham (1999) identified 25 studies that estimated WTP for numerically specified health risk reductions published between 1980 and 1998. Of the nine studies that included external scope tests, WTP was significantly associated with risk change in six but was never proportional to risk change. In a more recent review of studies that examined the effect of age on VSL, Krupnick (2007) reports that 20 of the 28 studies that conducted scope tests show sensitivity to the size of the risk change but does not discuss the extent to which the changes were proportional. Corso et al. (2001) tested the sensitivity of WTP to risk change using several visual aids and external scope tests. They found that WTP was proportional to the risk change using one visual aid and nearly so using another. However, even in studies using these techniques, WTP often fails to increase in proportion to the size of the risk reduction. For example, Alberini et al. (2004) found that mean WTP of U.S. respondents for a reduction in risk of death of 5 in 1,000 over 10 years was about 1.6 times the WTP for a risk reduction of 1 in 1,000.

We believe that it is important that for stated preference studies to test for respondents' sensitivity to the size of the risk reduction, both within and across groups of respondents. Passing at least a weak form of the external scope test, in which WTP increases with risk reduction, should be a criterion for an acceptable study. We note that in a recent data set of stated preference studies compiled by U.S. EPA (2010), only about half the estimates were subject to a scope test; of these, 90 percent of the VSL estimates passed a weak form the external scope test but only 15 percent passed a strong form of the test (which requires that WTP be nearly proportional to the risk reduction).

Sensitivity of Results to Econometric Analysis

Although it is always possible to report the distribution of WTP responses based on raw data, most articles report WTP estimates based on distributional assumptions. The nature of these assumptions can have profound effects on estimates of mean WTP and on estimates of the

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[24] Note that similar tests are not conducted in hedonic wage studies. To identify how respondents' preferences vary with the size of the risk change would requiring estimating workers' bid functions (as in Biddle and Zarkin 1988) but without imposing assumptions that restrict their shape.

association of covariates with WTP (Alberini 2005). When WTP is assumed to have a normal or logistic distribution, predicted WTP may be negative for a significant fraction of the sample and can result in a mean WTP that is negative. This is handled sometimes by computing WTP based on the positive portion of the WTP distribution (Johannesson et al. 1997) but more often by assuming that WTP has a lognormal or Weibull distribution. Alberini (2005) illustrates the effect of alternative distributional assumptions on estimates of mean WTP. For example, mean WTP based on data from Johannesson et al. (1997) ranges from –2100 Swedish krona (SEK) using a normal distribution to 2.9 million SEK using a Weibull distribution. The sensitivity of WTP to distributional assumptions should be tested in all studies.

4.3. Empirical Estimates of VSL from Stated Preference Studies

Over the past 10 years, the number of stated preference studies estimating VSL has increased significantly. The 26 VSL estimates provided in U.S. EPA's 2000 guidance include only 5 from stated preference studies. In contrast, the recent OECD review (Lindhjem et al. 2010) identified 68 stated preference VSL studies (incorporating 75 surveys) that have been conducted since 1970. More than half of these studies were completed in 2000 or later.

Meta-Analysis of Stated Preference Studies

With the increase in stated preference research, new meta-analyses are emerging that consider them separately. In Table 2, we summarize the meta-analyses that include only stated preference studies or provide results separately for stated and revealed preference studies. As noted earlier, Kochi et al. use a Bayesian approach, as do Dekker et al.; the Lindhjem et al. study is based on meta-regression. These meta-analyses do not provide estimates solely for the United States, although most studies were conducted in high-income countries. Each combines studies that address environmental, health, and traffic risks; although traffic risks dominate the older studies, an increasing number of studies now address other causes of death.[25] The resulting VSL estimates range from about $2 million to $8 million (2009 USD).

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[25] We exclude the de Blaeij et al. (2003) meta-analysis from this discussion because it focuses exclusively on traffic safety.

Table 2. Stated Preference Meta-Analyses

Meta-analysis	Publication dates of underlying studies (number of studies)[a]	Highlighted VSL estimates	
		As reported (dollar year)[b]	Inflated to 2009 USD[c]
Kochi et al. (2006)	1988–2002 (14)	$2.8 million (2000)	$3.5 million
Dekker et al. (2011)	1983–2008 (26)	$2.4 million–$7.5 million[d] (2004)	$2.7 million–$8.5 million
Lindhjem et al. (2010); OECD (2011)	1973–2008 (68)	$2.9 million[e] (2005)	$3.2 million

a. Stated preference studies only. Kochi et al. also consider revealed preference studies.

b. Dekker et al. and Lindhjem et al. estimates are taken from the discussion of values for benefit transfer. For the latter study, these estimates are reported in OECD (2011).

c. Adjusted for inflation using the Consumer Price Index, All Urban Consumers. Not adjusted for income growth over time.

d. Range reflects mean estimates for road safety ($2.4 million), air pollution ($4.4 million), and general health ($7.5 million) scenarios (2004 USD).

e. Median recommended in OECD (2011) for OECD countries.

In contrast to results valuing environmental quality, stated preference studies of the value of mortality risk reduction tend to yield smaller estimates than hedonic wage studies. For example, Kochi et al. (2006) use Bayesian methods to compare the distributions of estimates from hedonic wage and CV studies. They estimate the mean value of the hedonic wage distribution as $9.6 million, significantly larger than the $2.8 million mean for the CV studies (2000 USD).

Lindhjem et al., as well as a European study by Kluve and Schaffner (2008),[26] find that studies focused on traffic and environmental risks tend to yield higher VSLs than studies focused on health risks. In contrast, Dekker et al. find similar results for air pollution and unspecified causes and lower values for road safety. Although these diverse findings result in part from differences in the underlying studies as well as differences in statistical approach, they also suggest substantial VSL heterogeneity.

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[26] Kluve and Schaffner (2008) are excluded from Table 2 because they include only European studies.

Each of these meta-analyses, as with the hedonic wage meta-analyses discussed earlier, differ in the universe of studies they consider and in the criteria they apply to select studies and estimates for their analyses. Kochi et al. and the older hedonic wage meta-analyses build on criteria originally developed by Viscusi (1992); some of the newer studies apply more limiting criteria. Lindhjem et al. include the largest number of estimates and test the effects of different exclusion criteria as well as different model specifications.

The Impact of Age and Cause of Death on VSL

Age and cause of death are two important features of mortality risk whose effect on VSL can, in principle, be studied in stated preference studies. Such studies can measure the effect of respondent characteristics on WTP, assuming there is sufficient variation in these characteristics in the sample. To measure the effect of age independently of income or wealth, these variables must be measured in the survey and included in the final model. A good study allows age to enter the WTP function in a flexible form and demonstrates that results are robust to alternative specifications of the error term.

Age. Based on a review of 26 studies, Krupnick (2007) concludes that stated preference studies provide little evidence of a sharp decline in VSL with age; however, few studies provide clear tests of the effect of age on VSL. Ideally, the effect of age on VSL would be tested by using a series of dummy variables or other flexible specification rather than by imposing a linear or quadratic form on age. Few studies report results using a flexible functional form. Moreover, to measure the effect of age per se, studies should control for variables that may affect WTP and are likely to be correlated with age, such as income and wealth. No studies of which we are aware control for respondent wealth because these data are difficult to collect.

Stated preference studies that address risks to children suggest that reducing these risks may be valued more highly than reductions for adults (e.g., Hammitt and Haninger 2010). However, Blomquist et al. (2011), in a stated preference study of the value of preventing asthma risks, find that the relationship of VSL to age is complex, declining from age 4 to 30, increasing from 30 to 66, and declining over older ages.

Cause of death. An important issue in valuing environmental risks is whether a different VSL should be used when valuing risk of death from different causes (e.g., different diseases). European Union and United Kingdom guidance for impact assessment prescribe using a larger VSL for cancer because of the dreaded nature of the disease (European Commission 2000; H.M. Treasury 2003). In stated preference studies, the effect of cancer is studied by varying the cause of death across valuation questions, holding other aspects of the risk constant. Risk-risk trade-off

studies, in which the respondent chooses between options offering different changes in risk of death from various causes, also provide relevant information.[27] A salient issue in valuing the effect of cancer is the timing of the risk. If a latency period precedes the development of cancer, then any discounting may be confounded with the cause of death. The survey must also make clear whether the respondent should consider the morbidity that precedes death.

The empirical evidence on the effect of cancer on VSL is mixed. In a telephone survey in Taiwan, Hammitt and Liu (2004) elicited WTP to reduce risk of a cancer or noncancer disease presenting the same symptoms and prognosis. The authors found that respondents were willing to pay 30 percent more, on average, to reduce the risk of cancer than of the noncancer disease. Van Houtven et al. (2008) conducted a risk trade-off study in which respondents were asked to choose among residential locations presenting different risks of several types of latent cancer and motor vehicle fatality. They found that respondents valued the cancer risks more than the motor vehicle risk with a differential that decreased with latency of the cancer from a factor of 3 for a 5-year latency to a factor of 1.5 for a 25-year latency.

In contrast, neither Hammitt and Haninger (2010) nor Adamowicz et al. (2009) find a cancer risk premium in recent stated preference studies. Hammitt and Haninger (2010) find similar values for mortality risks from cancers, other diseases, and auto accidents. Adamowicz et al. (2009) find that the value of reducing cancer risks is slightly smaller than that for microbial risks (although the differences are often statistically insignificant), noting that this might reflect how respondents interpreted characteristics implicit in the scenarios.

5. Conclusions

In the United States, the benefits of mortality risk reductions from environmental programs traditionally have been valued using VSL estimates primarily from hedonic wage studies. In recent years, the number of stated preference studies has increased dramatically, providing additional options for valuation. In this article, we review the methodological

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[27] In a typical risk-risk study, respondents are asked whether they would prefer to live in a city with a risk of death from cancer of x and a risk of death in a traffic accident of y, or in an otherwise identical city with a risk of death from cancer of w and a risk of death in a traffic accident of v. The rate of substitution between the two risks can be estimated by varying the risk levels across respondents or by adjusting the risks until a respondent is indifferent between the two cities.

challenges faced by these studies and discuss the features that distinguish well-conducted research, as summarized below.

Over the past 35 years, dozens of hedonic wage studies have been conducted in the United States and other high-income countries; however, many of the older studies suffer from both data and econometric problems. Chief among these are reliance on older and less accurate sources of risk data, the sensitivity of the coefficient on risk to inclusion and omission of other variables, and the endogeneity of job risk. For the United States, the first problem has been effectively addressed in recent years through creation of the Census of Fatal Occupational Injuries, which because it is a census rather than a sample has substantially improved confirmation of the data. The initial hedonic wage study relying on these data was published in 2003.

Progress has also been made on the second and third issues. Newer studies often control for both occupation and industry, as well as for nonfatal job risk and worker's compensation. However, collinearity continues to be a challenge, motivating a continuing search for data sets where this is less problematic. The emergence of studies that use panel rather than cross-sectional data is an important advance. Use of instrumental variables and data from natural experiments may also aid in addressing the endogeneity of risk.

The more recent hedonic wage literature has not yet been synthesized in a meta-analysis. The meta-analyses available generally include studies that date back to the early 1970s; they have not analyzed the more recent and methodologically superior studies. At minimum, hedonic wage studies should use CFOI risk data and control for both industry and occupation as well as nonfatal risks.

Although hedonic wage studies are limited in the types of risk and populations included, they provide insight into the magnitude of VSL and its variation with age. Recent studies suggest an inverse-U relationship between VSL and age for working-age adults. Some newer studies attempt to distinguish different types of job-related risks, suggesting heterogeneous values. However, irresolvable differences remain between the populations and risks addressed by hedonic wage studies and those affected by environmental programs. The importance of these differences, as well as possible adjustments, cannot be determined without turning to the stated preference literature.

The stated preference literature now includes many studies that address deaths associated with environmental hazards (cancers, heart disease, and respiratory disease), supplementing earlier studies that often focused on traffic safety. An increasing number of studies address

populations older and younger (and potentially in poorer health) than the working-age individuals included in hedonic wage studies. However, respondents' difficulty in dealing with small risks continues to pose challenges. Researchers have developed a better understanding of how best to present risk concepts and elicit WTP. In addition, increased emphasis on validity tests is improving our understanding of the results.

The growing number of stated preference studies has allowed the increased use of meta-analysis. However, the meta-analyses that focus on stated preference studies conducted to date vary in the extent to which they exclude methodologically deficient studies and lead to conflicting results about the value of environmental risk reductions compared with other risks. The set of studies that satisfy reasonable criteria for relevance and quality remains small. At minimum, stated preference studies should demonstrate that WTP is sensitive to the size of the risk change.

Overall, VSL estimates from stated preference studies appear consistently smaller than those estimated from hedonic wage studies. To some extent, these differences may result from the populations and types of risks each addresses. However, these differences may also reflect the strengths and weaknesses of each approach; they require more exploration.

Although the effects of age on VSL have been considered in some studies, significant uncertainty remains, particularly for the very old and the very young. Given that older populations are often disproportionately affected by mortality risks from environmental causes and that children are often of significant concern for policymaking, greater focus on the values appropriate for these age groups is needed.

Finally, although an increasing number of stated preference studies focus on cancers, heart disease, and respiratory conditions, the results are not yet conclusive. More attention should be directed to how these illnesses are defined and compared, as well as to addressing other challenges faced in stated preference research.

Research on VSL has come a long way in recent years. Revealed preference research has exploited new data sets and new statistical methods, and stated preference research has expanded its coverage to different populations and types of risks. However, these types of research remain challenging. Given the importance of the value of mortality risk reductions to understanding the benefits of environmental policies, further research is warranted.

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