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Revisiting the Environmental Protection Agency's Value of a Statistical Life

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Abstract

The US Environmental Protection Agency (EPA) bases its estimate of the value of a statistical life (VSL) on 17 hedonic wage studies and five contingent valuation studies conducted between 1974 and 1991. We summarize advances in the mortality risk valuation literature since these papers were published, focusing on studies that value risks to adults and were conducted in the United States. We review hedonic wage, other revealed preference, and stated preference studies, identifying papers that satisfy appropriate validity criteria. We conclude that the recent literature is sufficiently rich to permit a revision of EPA's baseline estimate. Importantly, VSL estimates from both the averting behavior and stated preference studies we review reflect the preferences of a wider range of demographic groups than the current VSL, and newer studies better target causes of death relevant to EPA regulations.

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1. Introduction

Reductions in premature mortality are one of the most important categories of benefits provided by environmental regulations. They constitute more than 80 percent of monetized benefits in the United States Environmental Protection Agency (EPA) prospective analyses of the 1990 Clean Air Act Amendments (USEPA 1999, 2011) and are the majority of monetized benefits in most air pollution regulations. Mortality benefits are estimated by linking reductions in exposure delivered by a regulation to changes in mortality, using the epidemiological literature, and then valuing the statistical lives saved, using a value of a statistical life (VSL), which is the sum of what people would pay for small risk reductions that sum to one statistical life.¹

EPA's current estimate of the VSL needs to be revisited. The VSL is based on 26 estimates from 22 studies conducted between 1974 and 1991 (listed in Table 1): 17 hedonic wage studies and five contingent valuation studies.² Simply put, these studies are out of date. The hedonic wage studies predate the availability of data sets that characterize risk of death on the job by occupation as well as by industry—a requirement for a valid hedonic wage study (Cropper et al. 2011; USEPA 2010)—and they do not use modern econometric methods. The contingent valuation studies do not reflect post-1991 updates to survey design and VSL estimation for stated preference studies. The literature, using both revealed and stated preference approaches, has evolved considerably in the three decades since the 22 studies were chosen, and EPA's estimate of the VSL should reflect these improvements.

The VSL estimate should be revisited for other reasons as well. EPA regulations address the risk of heart and lung disease and cancer; however, 18 of the 22 studies that constitute EPA's current VSL value accidental workplace death, which is not directly relevant to EPA regulations. Moreover, 74 percent of the deaths avoided that are attributable to reducing exposures to fine particulate matter (PM_{2.5}) are for persons aged 65 and older (USEPA 2006), whose preferences are not reflected in hedonic wage studies. This raises questions. Do studies published in the past three decades provide credible estimates of the VSL for different causes of death and for all groups affected by EPA regulations, including persons 65 and older? If so, how do these estimates compare with the current VSL?

¹ Other terms have been suggested, (e.g., the value of mortality risk; Cameron 2010) but we focus on the more familiar VSL.

² The 22 studies on which the current VSL is based include 17 hedonic wage studies and five contingent valuation studies, one of which values risks in the labor market. Twenty-one estimates come from the 17 hedonic wage studies and five from the contingent valuation studies (Viscusi 1992). Since determination these estimates have been updated to reflect inflation and, in some cases, increases in income.

EPA has made efforts to update the VSL. Between 2000 and 2016, agency staff reviewed the literature, prepared white papers seeking to revise estimates of the VSL and sought the advice of the EPA Science Advisory Board (SAB 2007, 2011, 2017). The 22 studies, however, remain the basis for EPA's current VSL.

The goal of this paper is to take a fresh look at VSL issues and review advances in the mortality risk valuation literature since the 22 studies were published, focusing on studies that value mortality risks to adults and were conducted in the United States. We address hedonic wage studies, other revealed preference studies beyond those focused on the labor market, and stated preference studies. We suggest criteria for what constitutes an acceptable study and cite studies that satisfy these criteria. We do not propose a new VSL, but we discuss how the agency might proceed in developing new estimates.

2. Revealed Preference Studies

2.1. Overview

Revealed preference studies use observations on behavior in risky situations to infer the trade-offs people make between mortality risk and money. Examples include hedonic wage studies, which estimate the trade-off between risk of death on the job and wages, and averting behavior studies, which examine the trade-off between risk of death and money implied by the purchase of goods that affect mortality risks (cars, houses, and medical services). Safe behavior (buckling one's seatbelt) or risky behavior (driving fast) can also be used to infer trade-offs between risk and money, given the value of time.

Hedonic wage studies form the primary basis for EPA's current estimate of the VSL (21 of the 26 estimates used to estimate the VSL come from hedonic wage studies). More wage studies have been published to estimate the VSL for the United States than either stated preference or averting behavior studies. Although self-protection and averting behavior studies have seldom been used by US federal agencies to estimate the VSL, they offer a rich source of information on the risk-dollar trade-offs people make. And they offer some advantages over hedonic wage studies. Whereas hedonic wage studies value risk of accidental death for working persons, and more than 90 percent of job-related fatalities occur among men (USBLS 2021), the majority of self-protection and averting behavior studies focus on traffic fatalities, which affect people of all ages. Some averting behavior studies value health risks, including the risk of cancer and the risk of death from all causes.

Many revealed preference studies are hedonic studies—they explain the wage or the price of a product (e.g., a car or a house) as a function of job or product characteristics, including risk of death. Many of these studies estimate the hedonic price equation using a semilog functional form, implying that the coefficient on risk

represents the percentage change in the wage (or price) corresponding to a one-unit change in risk. The dollar change in the wage (or price) divided by the risk change provides an estimate of the VSL. Recent revealed preference studies in the traffic safety context have modeled the demand side of the passenger vehicle market to measure the trade-off between risk and vehicle cost. Other approaches used in the self-protection literature are discussed below.

All revealed preference studies, whether compensating wage or averting behavior studies, face similar challenges:

- The researcher must accurately measure fatality risk, which is complicated by the fact that fatality risks are endogenous. The risk facing a worker on the job depends on his skill in avoiding risk, and the risk of a fatal car crash depends on the driver of a particular make or model of car.
- The researcher must control for the fact that nonfatal risks, whether on the job or in a traffic crash, are likely to be correlated with fatal risks.
- The researcher must adequately control for other factors that explain the wage that a worker receives or the price paid for a house or car. Such factors can be difficult to control for in models estimated using a single cross-section of data. This has led to the use of panel data and quasi-experimental approaches in recent studies.

Here we discuss how well the hedonic wage and averting behavior literatures have addressed those concerns, focusing on studies published since 2004. Because the averting behavior literature has not been used by EPA and has not been extensively reviewed,³ we examine it in more detail. We end by reviewing how well studies have addressed the three challenges.

³ A notable exception is Blomquist (2003).

2.2. Hedonic Wage Studies

At least 60 hedonic wage studies using US data have been published since 1970. In a typical hedonic wage model, the logarithm of the wage is regressed on workers' characteristics (e.g., age, education, marital status, race, years in the labor force) and job characteristics (e.g., industry, occupation) as well risk of a fatal accident and risk of a nonfatal injury on the job. Some studies also control for Worker's Compensation. Early studies were estimated using a single cross-section of workers.

At the request of EPA, Black et al. (2003) explored the robustness of hedonic wage studies by assembling 10 worker and risk data sets commonly used in hedonic studies and estimating 40 specifications of the hedonic wage function for men and 40 for women. The estimated coefficient on fatal job risk was positive and statistically significant in only 30 of the 80 models. The researchers attributed the instability of the estimated coefficients to errors in estimating fatal job risk and to correlation between the risk measure and occupation and industry dummies.

The estimates used by Black et al. (2003) measured risk by industry but not by occupation. Measurement of risk of death by occupation as well as industry has become a criterion for an acceptable hedonic wage study, beginning with the use of data from the Census of Fatal Occupational Injuries (CFOI) by Viscusi (2004) and Kniesner and Viscusi (2005). The CFOI provides fatality data for more than 720 industry-occupation pairs (72 industries and 10 occupations), which can be combined with employment data to construct measures of fatal risk.⁴ Hersch and Viscusi (2010), Scotton and Taylor (2011), Kniesner et al. (2012), and Scotton (2013) also measure fatal job risk by occupation as well as industry.⁵

Industry and occupation are important determinants of the wage quite apart from their effect on fatal job risk, and they should be controlled for in estimating a hedonic wage equation, otherwise fatal job risk may capture their effects. Scotton (2013) demonstrates that adding industry and occupation dummies to a hedonic wage equation in which fatal risk is measured by industry and occupation causes the VSL to drop by approximately 60 percent. Industry dummies have a larger effect on the VSL than occupation dummies; however, it is important to control for both.

⁴ As Scotton (2013) points out, the measurement of risk using the CFOI data depends on what data are used to estimate the number of workers employed in each industry-occupation cell and also on whether self-employed workers are included in the estimate. It may also be necessary to average data from several years due to low fatality risks.

⁵ Most studies published after 2003 use CFOI data; however, not all studies measure risk by both industry and occupation. For examples of the latter, see Viscusi (2003), Leeth and Ruser (2003), Aldy and Viscusi (2008), Viscusi and Aldy (2007), and Viscusi and Hersch (2008).

The risk of a nonfatal accident or illness, which is much higher than fatal job risk, is sometimes controlled for in hedonic wage studies.⁶ EPA's 2016 white paper on the VSL (USEPA 2016) cites only five studies that both measure fatal risk by occupation and industry and control for risk of nonfatal injury: Viscusi (2004), Kniesner and Viscusi (2005), Hersch and Viscusi (2010), Scotton and Taylor (2011), and Scotton (2013).⁷ Only the last two studies also include industry and occupation dummies.

Hedonic wage studies since 2004 have also dealt with endogeneity of risk. Notable examples are Kniesner et al. (2012) and Lee and Taylor (2019). Kniesner et al. (2012) use panel data to control for worker-specific unobservable characteristics in estimating a hedonic wage equation. If more-productive workers work in riskier (safer) jobs, the VSL will be biased upward (downward). Kniesner et al.'s estimates, which use CFOI data to measure fatal job risk, control for unobserved worker characteristics and also for occupation and industry, in addition to the usual demographic variables. The authors instrument for risk using lagged risk. Lee and Taylor (2019) address the endogeneity of risk by using randomly assigned safety inspections to instrument for plant-level risks to production workers in manufacturing plants. Because the authors have panel data on US manufacturing plants, they can also control for plant-level fixed effects and industry time trends. Both studies provide credible estimates of the VSL.

2.3. Self-Protection and Averting Behavior Studies

The idea underlying studies of self-protection and averting behavior is that people will engage in a risk-reducing activity or spend money on a risk-reducing product to the point where the marginal cost of the activity or product equals its marginal benefit. If the marginal benefit equals the marginal risk reduction provided times the VSL, then the marginal cost of the activity or product divided by the risk reduction provides an estimate of the VSL. This principle has been applied to reductions in the risk of a traffic fatality and health risks associated with environmental exposures.

⁶In the 2015 CFI data, annual risk of a fatal job accident is approximately four per 100,000 workers. Nonfatal job accidents and illnesses requiring days off from work are approximately three per 100 workers per year.

⁷ Only Viscusi (2004) also controls for Worker's Compensation.

2.3.1. Self-Protection and Averting Behavior in a Traffic Safety Context

Although traffic fatalities are accidental, it can be argued that revealed preference studies of people's willingness to pay for reductions in risk of a traffic fatality have two advantages over hedonic wage studies: (1) they affect a broader age spectrum, including persons over 65; and (2) in some stated preference studies (e.g., Hammitt and Haninger 2010), willingness to pay to reduce risk of death in an auto accident is not significantly different from willingness to pay to reduce risk of death due to natural causes.⁸

2.3.2. Using the Purchase of Safer Vehicles to Estimate the VSL

Many revealed preference studies in the traffic safety literature estimate the VSL by examining the premium paid for safer passenger vehicles and the reduction in fatality risk that they deliver. These studies build on the large hedonic literature on vehicle characteristics (Court 1939; Griliches 1961) by adding the risk of fatal injury to other vehicle characteristics. Whereas earlier studies rely on a single cross-section of data to estimate hedonic models, more recent studies use quasi-experimental methods and include structural models of the demand for passenger vehicles.

Hedonic studies of safer automobiles must address similar issues as hedonic wage models: they must accurately measure risk of death, control for risk of nonfatal injury, and control for vehicle characteristics that are correlated with fatal and nonfatal risks. The risk that a given make and model of vehicle will be involved in a fatal crash can be measured by the number of fatal crashes involving that make and model in a given year, divided by the number of such vehicles on the road in that year. If the drivers of all makes and models had similar driving habits and drove the same number of miles per year, these statistics would accurately measure the safety of the vehicle. Because this is not the case, studies must control for the characteristics of the drivers involved in fatal crashes (by make and model) and differences in miles driven (by make and model). Nonfatal risks are often incorporated by equating a certain number of nonfatal accidents to a fatal one, based on their severity. Vehicle weight, body type, and fuel economy must be accounted for, in addition to other vehicle characteristics, given their correlation with accident risks.

Atkinson and Halvorsen (1990) were the first to estimate a hedonic price function for automobiles to compute the VSL. Using data for 112 models of new (1978) cars, they regress the user cost (including capital and fuel costs and insurance) of each model on vehicle characteristics and the fatality rate per 1,000 new vehicles for the model. Because the observed fatality rate depends on the characteristics of the drivers of

⁸ Early studies in the averting behavior literature used safety devices, such as seatbelts (Blomquist 1979; Blomquist et al. 1996), bicycle helmets (Jenkins et al. 2001), and infant car seats (Carlin and Sandy 1991), to estimate the VSL for children and for adults. Since 2000, few studies have used safety devices to estimate the VSL, primarily because these devices are now commonly required by law and their use is enforced.

each model, Atkinson and Halvorsen add the characteristics of drivers involved in fatal crashes for each model (e.g., age, alcohol consumption, seatbelt use) to the hedonic price function.⁹ They estimate the VSL using the user cost for each model and then weight these estimates by market share. Their final estimate of the VSL is divided by the average number of vehicle occupants.

The subsequent hedonic literature, which uses data on automobile purchases by cross-sections of households, has improved on Atkinson and Halvorsen (1990) in two ways: by incorporating measures of nonfatal injury and by dealing more completely with the trade-offs among vehicle weight, safety, and fuel economy. Dreyfus and Viscusi (1995) significantly advance the automobile safety literature by accounting for nonfatal injury, estimating the importance of fuel economy (operating costs over the life of the vehicle) and using a richer set of vehicle characteristics.

The use of cross-sections of households has also allowed researchers to estimate the VSL by age. Mount et al. (2000) hypothesize that a family equates the weighted VSLs of all family members, times the probability of a fatal crash, to the marginal cost of a safer vehicle. Using a sample of families with different household compositions enables them to obtain a VSL for adults, children, and seniors. O'Brien (2018) uses the 2009 National Highway Travel Survey to estimate a conditional logit model of car choice.¹⁰ Consumer utility depends on vehicle characteristics, annual operating cost of the vehicle, and risk of a fatality. Fatality risk is measured per mile driven and also by age group. He uses the coefficients on car cost and risk to infer the marginal rate of substitution (MRS) between risk and money, and he allows coefficients on both variables to vary by age group. His estimates of the population-weighted VSL are more precise than estimates of the VSL by age group.

Li (2012) uses data on vehicle sales for 20 metropolitan statistical areas for 1999–2006 to estimate a discrete choice model of new vehicle purchases. His focus is on the safety effect of light-duty trucks (SUVs, minivans, and pickups), which accounted for 51 percent of new-vehicle sales by 2000. From the perspective of the driver, SUVs are safer than cars in multiple-vehicle crashes, although not as safe in single-vehicle accidents. Taking into account crash severity (fatal, nonfatal) as well as crash frequency, Li uses the safety difference between light-duty trucks and cars to estimate the VSL.

We return to our three criteria for a good revealed preference study: (1) Do those studies use an appropriate measure of fatal risk? (2) Do they control for nonfatal risks? (3) Do they control for other factors affecting vehicle purchase decisions? All

⁹ If the observed fatality rate, F , depends on the inherent fatality rate for the make and model, R , and the characteristics of drivers involved in fatal crashes, D , then $F = g(R, D)$ can be inverted to yield $R = g^{-1}(F, D)$. Data on F and D are available from the FARS database.

¹⁰ Winston and Mannering (1984) estimate a conditional logit model of vehicle choice to value automobile safety features but do not estimate a VSL.

the studies cited adjust fatality risk for the characteristics of drivers involved in fatal accidents and, with the exception of Atkinson and Halvorsen (1990), for vehicle miles driven. The risk of a nonfatal accident is controlled for by Dreyfus and Viscusi (1995), Mount et al. (2000), and Li (2012) but not by Atkinson and Halvorsen (1990) or O'Brien (2018). All studies control for other vehicle characteristics that may affect the purchase decision. As noted above, failure to control for nonfatal risk need not exclude a study from consideration in revising the VSL: researchers can examine the effect of exclusion of nonfatal injury risk on the VSL using meta-regression and adjust VSL estimates accordingly.

2.3.3. Using Natural Experiments to Estimate the VSL

Some studies have used natural experiments in traffic safety to estimate the VSL. Rohlfs et al. (2015) use purchases of used cars with airbags to trace the demand curve for safety. US cars were required to have driver-side airbags by 1996 and passenger-side airbags by 1997. Some luxury vehicles had airbags before this time, but the fraction of vehicles with airbags increased sharply around the deadline, making it possible for the authors to use a regression discontinuity strategy. In the two years before and after the deadline, other characteristics of a make and model did not change appreciably, nor, presumably, did the characteristics of the drivers involved in fatal crashes. Over this period, increases in the supply of airbags (and reductions in the cost of their manufacture) caused the price to fall. The marginal cost of airbags divided by the risk reduction delivered (the sum of risk reductions over the life of the vehicle) provides an estimate of the VSL.

Another quasi-experiment used to estimate the VSL is the change in speed limits on some rural interstate roads in the late 1980s. In 1987 the federal government gave states the opportunity to increase speed limits on rural interstates from 55 to 65 mph while maintaining the federal speed limit of 55 mph on urban interstates and rural arterial roads. Ashenfelter and Greenstone (2004) compare fatalities on rural interstates in states that raised their speed limits with fatalities on rural interstates in states that did not, before (1982–86) and after (1988–93) the speed limit increase. They also compare fatalities on rural interstates with fatalities on rural arterials in the states that raised the speed limits.

Because a rational individual will choose the speed that minimizes the time plus accident costs of travel, the value of time saved per marginal fatality will equal the individual's rate of substitution between money and risk. The VSL is calculated by estimating equations for travel hours and fatalities. The ratio of the coefficients on the higher speed limit in the two equations provides an estimate of the VSL. Ashenfelter and Greenstone estimate that raising the speed limit on rural interstates saved 125,000 hours per additional death. The money value of the hours saved depends on the value of time and the number of occupants per vehicle.

The recent traffic safety literature provides estimates of the VSL that are a useful addition to labor market estimates. Both literatures value risk of accidental death, but the traffic safety literature captures a broader spectrum of the population. The revealed preference studies based on housing prices and medical expenditures, discussed next, value risks that are more closely associated with environmental regulations.

2.3.4. Self-Protection and Averting Behavior in the Housing Market

If health risks are capitalized into housing prices, the effect of exposure to an environmental risk to the occupants of a house, over the life of the house, can be used to estimate the VSL. Portney (1981) first suggested this idea in the context of air pollution and illustrated it using data from a hedonic analysis of housing prices in Allegheny County, Pennsylvania (Spore 1972), which he combined with an epidemiological study of the mortality effects of air pollution (Gregor 1977). This approach must, of course, address the issues listed at the beginning of this section: the effect of air pollution on housing prices must be estimated controlling for other factors that influence house prices, including the disamenity of being located near sources of pollution. Without further controls, the effect of air pollution on housing prices may reflect the morbidity effects of air pollution, as well as its visual disamenity and effects or fears about other types of pollution exposures (e.g., in drinking water). Two studies of the effect of cancer risks on housing values, Gayer et al. (2000) and Davis (2004), avoid some of these problems by using natural experiments to value statistical cancer cases.

Gayer et al. (2000) relate information about cancer risks at seven Superfund sites in Grand Rapids, Michigan, to the price paid for local houses before and after EPA released studies estimating the magnitude of cancer risks associated with the sites. The authors assume that people have a subjective probability of cancer risk before EPA announces a remediation plan, and they modify this with information on cancer risk after the remediation plan is announced and publicized in newspaper accounts. To estimate the effect of cancer risk on housing prices, Gayer et al. estimate a difference-in-differences model: house price is a function of the lifetime cancer risk associated with the house as estimated by EPA (risk), the interaction of risk with a dummy variable equal to one after EPA's estimate has been announced, and an "after" dummy. The coefficients on risk and risk*after are used to estimate the value of a statistical cancer case. The study convincingly handles the issues associated with hedonic property value studies: cancer risk is carefully measured for the occupants of each house based on groundwater and dermal exposures to Superfund sites; the authors also control for the visual disamenity of living near a Superfund site, as well as for housing and neighborhood characteristics.

Davis (2004) compares housing prices in Carroll County, Nevada, before and after an outbreak of pediatric leukemia with housing prices in a control county to calculate the value of a statistical case of pediatric leukemia. He finds that housing prices fell by 14 percent in Carroll County, relative to the control county, after the cancer cluster

appeared. But the 14 percent drop captures the lifetime cancer risks associated with the house. In hedonic property value studies, it matters how annual risks are discounted when calculating lifetime risk. Raising the discount rate from 3 to 5 percent increases the value of a statistical cancer case by 70 percent.

2.3.5. Using Medical Expenditures to Value Mortality Risks

If people equate their marginal health-care expenditures to the marginal benefits of these expenditures, medical expenditures can be used to value mortality risks. Ketchum et al. (2022) focus on the mortality (rather than the morbidity) component of marginal benefits, assuming that Medicare beneficiaries equate the last dollar of out-of-pocket medical expenditures to the associated change in the probability of survival, multiplied by the VSL. Using data from the Medicare Current Beneficiary Survey, the authors estimate the effect of medical expenditures on survival probability.¹¹ Out-of-pocket expenditures are calculated based on copayment rates. Because the average copay rate is about 20 percent, the VSL calculated by dividing marginal out-of-pocket expenditure by the effect of expenditure on survival probability is about 20 percent of the social VSL—the amount society is willing to pay for the extension in survival probability.¹² One could also argue that some individuals, especially those with much lower copays, might be willing to pay more for the increase in their survival probability than the copay requires.

2.3.6. Assessment of the Revealed Preference Literature

The revealed preference literature has progressed significantly since EPA's original VSL estimate was produced. Compensating wage studies have been able to measure fatal job risk by industry and occupation since the advent of the CFOI data. And studies recognize the importance of controlling for both industry and occupation in explaining variation in wages across workers. Many studies also control for risk of nonfatal injury on the job. But only two hedonic studies using a broad cross-section of US workers measure risk by occupation and injury, include industry and occupation dummy variables, and also control for nonfatal injury: Scotton and Taylor (2011) and Scotton (2013).

Studies using quasi-experimental methods (Lee and Taylor 2019) and panel data (Kniesner et al. 2012) are important additions to the literature, although the latter is based only on male workers and does not control for nonfatal job injury. The importance of controlling for nonfatal injury has, however, been questioned. Mrozek and Taylor (2002) and Kochi et al. (2006) do not find that it has a significant effect on

¹¹ Medical spending is instrumented, following Finkelstein et al. (2016), to control for the fact that 25 percent of Medicare expenditures occur in the last year of life.

¹² Suppose that a Medicare expenditure of \$10,000 increases survival probability by 0.005. Society's VSL (our term) = \$10,000/.005 = \$2,000,000. If the individual pays only \$2,000, his private VSL = \$2,000/0.005 = \$400,000.

the VSL in their meta-analyses. Scotton (2013) reports that it does not significantly affect the VSL in her hedonic analysis. No compensating wage studies satisfying the three criteria above speak to risks faced by workers over 65.

The averting behavior literature represents an important addition to the revealed preference literature. Studies that use the price premium attached to safer automobiles to estimate the VSL must (1) adjust for driver characteristics in estimating fatal crash risk; (2) control for other vehicle characteristics that affect vehicle price; and (3) control for nonfatal accident risk. Studies by Dreyfus and Viscusi (1995), Li (2012), and Mount et al. (2000) satisfy all three criteria. Dreyfus and Viscusi (1995) find that dropping nonfatal accident risk has little effect on their VSL estimates. If the third criterion is relaxed, the set of good studies includes Ashenfelter and Greenstone (2004), Atkinson and Halvorsen (1990), O'Brien (2018), and Rohlfs et al. (2015). Mount et al. (2000), O'Brien (2018), and Rohlfs et al. (2015) also provide information on how the VSL varies with age, including persons over age 65.

Three other averting behavior studies target more closely the disease outcomes relevant to EPA regulations. Gayer et al. (2000) and Davis (2004) apply difference-in-differences methods to housing prices to provide convincing estimates of the value of a statistical cancer case.¹³ Ketchum et al. (2022) estimate the value of reducing mortality risks due to natural causes using data on the medical expenditures of Medicare recipients. This targets the over-65 population and causes of death relevant to EPA.¹⁴ We conclude, therefore that the averting behavior revealed preference literature is an important addition to the wage hedonic literature that underlies EPA's current VSL.

¹³ Alberini and Ščasný (2018) describe the relationship between the value of a statistical cancer case and the VSL.

¹⁴ The top four causes of death for persons 65 and older are heart disease, cancer, stroke, and chronic lower respiratory disease (USCDC 2021).

3. Stated Preference Studies

3.1. Overview: Strengths and Limitations

In revealed preference studies, analysts take information provided by real choices in markets, assume that people understand the risks and trade-offs they face, and try to extract underlying preferences for reducing risks. Stated preference studies, in contrast, are survey-based approaches: researchers have full control over context, parameters, and methods of eliciting preferences. This control enables them to study how willingness to pay (WTP) varies by risk, in public versus private settings, by population characteristics (age, race, gender), and by latency effects. As Alberini (2019) notes, stated preference studies are “true experiments” and can therefore avoid a host of statistical problems, such as endogeneity and correlation of risk attributes.

The hypothetical nature of surveys has been an object of intense focus in the stated preference literature. Issues that stem from the hypothetical nature include how to make respondents take income constraints seriously, how to show whether a respondent considers her answers consequential and sensitive to the size of the risk change being offered, how to elicit WTP in incentive-compatible ways, and how to handle protest bids, yea-sayers, and speed answerers (Alberini 2019). In addressing methodological concerns, researchers have tested a variety of survey forms and structures. In open-ended contingent valuation, respondents may freely state their WTP bids without any restrictions from the researcher. Dichotomous choice contingent valuation prompts respondents to vote yes or no on a bid of specified amount and, if double-bounded, asks for their vote on a follow-up bid contingent on their first answer. Choice experiments prompt respondents to choose between the baseline situation and one or more scenarios where the scenario attributes (e.g., nature of risk, size of risk reduction, cost of risk reduction) may differ from one another and the baseline.

3.2. US Stated Preference Studies to Value Mortality Risks

Over the past 30 years, more than two dozen stated preference studies have been conducted in the United States to value mortality risks. As noted above, five early studies were included in the original EPA analysis leading to the current VSL. In its 2016 review of the mortality risk valuation literature (USEPA 2016), the agency identified nine papers that estimated the VSL for adults based on a general sample of the US population and also passed an external scope test—that is, the WTP for different subsamples increased with the size of the risk reduction valued. These

articles were based on seven surveys conducted between 1996 and 2009.¹⁵ No additional studies satisfying these criteria were published between 2016 and 2021. We review how these studies meet the challenges facing a mortality risk valuation study and address the endpoints valued in EPA regulatory impact analyses (RIAs).

Studies that value changes in risk of death must address four issues:

- defining the commodity valued (the cause of death addressed, the nature of the risk reduction and how it is delivered, the size and timing of the risk reduction);
- communicating baseline mortality risks and the hypothetical risk reductions in ways that the respondent can understand;
- determining how to elicit WTP (using a choice experiment, a dichotomous choice approach, or something else); and
- testing for validity of responses (did respondents understand the magnitude and timing of risks valued?).

All the studies reviewed here follow best practice in addressing those four issues. All value a private reduction in risk of death and make explicit the timing and size of the risk reduction and how it is delivered. They elicit WTP using either a dichotomous choice question or a choice experiment. In testing for validity of responses, all find that respondents pass an external scope test, although only two studies pass a strong external scope test (meaning that WTP is proportional to the size of the risk reduction in split samples).

3.3. Defining the Commodity Valued

The causes of death in the studies we review include automobile fatalities; heart disease and stroke; cancer; noncancerous diseases affecting the bladder, brain, liver, or white blood cells; and death due to unspecified natural causes. Although reductions in risk of death in an auto accident can plausibly occur immediately (e.g., within a year), reductions in risk of death associated with the other causes do not. Stated preference studies must therefore specify when risk reductions are likely to occur. In Alberini et al. (2004), risk reductions are equally spaced over the next 10 years.¹⁶ In Chestnut et al. (2012), risk reductions begin immediately and continue indefinitely. In studies based on the 2002 Cameron and DeShazo survey, Hammitt and Haninger (2010) and Viscusi et al. (2014), the risk reductions occur a specified number of years

¹⁵ Three of the studies are based on a Knowledge Networks survey conducted by Cameron and DeShazo in 2002: Cameron et al. (2010a), Cameron et al. (2010b), and Cameron and DeShazo (2013). Additional results are reported in Cameron et al. (2009).

¹⁶ In Alberini et al. (2006), risk reductions occur over a 10-year period beginning at age 70.

in the future or when the respondent reaches a given age.¹⁷ In all studies, respondents' valuations depend on their subjective probability of surviving to the age at which the risk reduction occurs; it also depends on their subjective rate of time preference.

How the risk reduction is delivered differs among the studies. In Hammitt and Haninger (2010), risk of death is associated with pesticide residues on food; hence, consuming food without such residues reduces risk. In Viscusi et al. (2014), risk of death from bladder cancer is associated with arsenic in drinking water; thus, reducing arsenic concentrations (e.g., by installing a filter) reduces risk of death. Hammitt and Haninger (2010) and Corso et al. (2001) reduce risk of death in an auto accident by installing a safety device in the respondent's car. In studies that posit death due to heart disease and stroke, risks are reduced through a program of testing and administration of medicine. Although risk of death is reduced by different means, it is, in all studies, a private risk reduction.

Death due to a chronic illness is likely to be preceded by a period of morbidity. Except for Alberini et al. (2004) and Chestnut et al. (2012), the studies that value risk of death due to a chronic condition discuss the morbidity that precedes death. Only Cameron and DeShazo (2002), however, explicitly value the morbidity preceding death. In their 2002 Knowledge Networks survey, health states are described in terms of pre-illness, illness, recovery, and life-years lost.

3.4. Communicating Baseline Risks and the Size of the Risk Reduction

The respondent's baseline risk of dying and the risk reduction valued can be communicated verbally or using visual aids. Hammitt and Graham (1999) report difficulties in communicating risks verbally in a telephone survey. Corso et al. (2001) compare four methods of presenting risks in written surveys—colored dots on a grid of squares, a logarithmic scale, a linear scale, and a verbal description—and find that WTP varies in proportion to the size of the risk reduction only when risks are communicated using the colored dots or a logarithmic scale. All studies we review rely on coloring squares in a grid to communicate probabilities, following Corso et al. (2001). Although the size of the risk reduction needs to be clearly communicated, in some cases, communicating baseline risks may be less important, particularly when information about baseline risks is shown to leave WTP unaffected in focus groups and pretesting.

¹⁷ In Hammitt and Haninger (2010), the onset of disease may occur immediately, in 10 years, or in 20 years. Death follows two years after disease onset. In Viscusi et al. (2014), bladder cancer occurs in 10 years.

3.5. Eliciting WTP

The studies we review pose WTP questions in several ways. Corso et al. (2001), Alberini et al. (2004), and Hammitt and Haninger (2010) use double-bounded dichotomous choice methods: respondents accept or reject an initial payment for the stated risk reduction and then accept or reject a follow-up amount. The Cameron and DeShazo studies (Cameron et al. 2009; Cameron et al. 2010a, Cameron et al. 2010b, Cameron and DeShazo 2013) and Chestnut et al. (2012) use choice experiments: the respondent chooses between two risk reduction programs that differ in their characteristics and payments, with the option of rejecting both programs. Viscusi et al. (2014) use an iterative choice approach. In all surveys, payments begin immediately and, with the exception of Hammitt and Graham (1999) and Corso et al. (2001), continue for many years. An important question in estimating the VSL is what discount rate is applied to future payments.

3.6. Testing Validity

Evidence that respondents understand the valuation task is provided in several ways. Tests of scope measure whether WTP for risk reductions increase with the size of the risk reduction valued. This is measured by varying risk reductions within respondents (internal scope test) and across respondents (external scope test). A strong scope test requires that WTP increase in proportion to the size of the risk reduction. Respondents pass a strong external scope test in Corso et al. (2001) and Hammitt and Haninger (2010). WTP increases with the size of the risk reduction—but not proportionately—in Hammitt and Graham (1999), Alberini et al. (2004), Chestnut et al. (2012), Cameron and DeShazo (2013), and Viscusi et al. (2014). WTP should generally also decrease, *ceteris paribus*, with the length of the latency period: payments made today should be lower the farther in time the risk reduction occurs (see Hammitt and Liu 2004 for why there may be exceptions). This holds in Alberini et al. (2006) and Cameron et al. (2009) but not in Hammitt and Haninger (2010).¹⁸ All studies indicate that WTP increases with income, which should hold if risk reductions are a normal good. For other validity tests, see Johnston et al. (2017).

¹⁸ Alberini et al. (2004) and Alberini et al. (2006) are based on the same survey; however, the latter study focuses on WTP for a future risk reduction.

3.7. Relevance of Stated Preference Studies to EPA Analyses

The health outcomes usually valued in EPA's RIAs are reductions in mortality associated with heart and lung disease due to reductions in PM_{2.5}. EPA states that three-quarters of the deaths avoided occur among persons 65 years and older (USEPA 2006).¹⁹ What is needed is an estimate of what people of different ages would pay today to reduce their risk of dying from heart and lung disease, given a specified time path of risk reduction. Reductions in cancer risk must be valued in drinking water RIAs and in rules regulating chemicals under the Toxic Substances Control Act. In the case of cancer (and other diseases), regulations reduce exposure today and risk of death with a cessation lag—the time between reduction in exposure and reduction in risk.

Do existing studies address those risks? Chestnut et al. (2012) provide VSL estimates for reductions in risk of a fatal heart attack. Cameron et al. (2009) simulate their structural model to estimate WTP to avoid immediate risk of death due to heart disease, heart attack, and stroke. Four studies—Cameron et al. (2009), Hammitt and Haninger (2010), Chestnut et al. (2012), and Viscusi et al. (2014)—provide estimates of the value of reduced cancer risks. The cessation lag in Hammitt and Haninger (2010) varies from 0 to 20 years. In Cameron et al. (2009) and Viscusi et al. (2014), it is 10 years. Finally, Alberini et al. (2004) estimate WTP for a reduction in risk of death from an unspecified natural cause over the next 10 years. These five stated preference surveys provide mortality risk valuations directly relevant to endpoints of concern to EPA.²⁰

Four of those studies also provide insights into how cause of death affects the VSL. Hammitt and Haninger (2010), Chestnut et al. (2012), and Cameron et al. (2009) value both cancer and noncancer mortality risks. Hammitt and Haninger (2010) find no significant difference in WTP for cancer versus noncancer mortality for the four organs and tissues studied.²¹ This result is echoed by Chestnut et al. (2012), who find no significant difference in WTP to reduce cancer (site unspecified) and heart attack mortality risks. Cameron et al. (2009) find that WTP for reductions in risk of heart attack or heart disease equals or exceeds WTP to avoid mortality from breast, prostate, or colon cancer, holding the timing of the risks constant. The studies reviewed thus find no evidence of a cancer risk premium.²²

¹⁹ Hammitt et al. (2020) point out that the number of deaths avoided is not statistically identified.

²⁰ Hammitt and Graham (1999) and Corso et al. (2001) value risk of death in an auto accident.

²¹ The organs and tissues are the bladder, brain, liver, and white blood cells.

²² Viscusi et al. (2014) examine WTP to reduce risk of bladder cancer but do not value noncancer mortality risks and therefore cannot measure a cancer risk premium.

All the studies reviewed could be used to estimate the effect of age on the VSL. Some studies emphasize such results (e.g., Alberini et al. 2004). Other researchers have not fully explored the age issue in the published study: Hammitt and Haninger (2010) and Viscusi et al. (2014), for example, report the effect of age only in linear form.

4. Conclusions and Possible Next Steps

The US literature estimating the VSL has improved significantly since EPA identified 26 VSL estimates in the 1990s. It now includes VSL estimates based on compensating wage differentials in the US labor market, and averting behavior studies that use the purchase of safer cars or houses to infer the VSL. When we apply three criteria to revealed preference studies—appropriate measurement of fatality risk, controls for risk of nonfatal injury, and controls for other factors that may be correlated with the value of mortality risks—we find five studies that provide convincing estimates of the VSL for risk of accidental death, and 11 studies if we relax the second criterion. Three other revealed preference studies value cancer risks and risk of death due to unspecified natural causes.

Stated preference studies have also improved: seven stated preference surveys of the VSL based on representative samples of the US population pass a scope test—that willingness-to-pay for a reduction in mortality risk increase with the size of the risk reduction. These studies, identified by EPA in 2016 (USEPA 2016) and discussed in the previous section, provide credible estimates of the VSL.

Do these studies provide reliable estimates of the VSL for a previously neglected demographic: persons aged 65 years and older. Some revealed preference studies—Mount et al. (2000), O'Brien (2018), Rohlfs et al. (2015), and Ketcham et al. (2022)—provide estimates of the VSL specifically for persons over 65.²³ Other averting behavior studies include persons over 65 in the sample of individuals used to estimate the VSL. Stated preference studies with respondents over age 65 can do this as well. We are not suggesting that EPA vary the VSL with age, but it is of interest to include adults of all ages in estimating the VSL.

Do the studies reviewed provide estimates of the VSL for causes of death relevant to EPA. Two studies—Cameron et al. (2009) and Chestnut et al. (2012)—estimate a VSL for heart disease and respiratory disease. Three studies—Alberini et al. (2004), Hammitt and Haninger (2010), and Ketcham et al. (2022)—value death by natural causes. Four studies—Chestnut et al. (2012), Cameron et al. (2009), Hammitt and

²³ Rohlfs et al. (2015) report results for persons 60 years and older.

Haninger (2010), and Viscusi et al. (2014)—estimate a VSL for cancer.²⁴ We are not suggesting that EPA ignore estimates based on accidental deaths, but it is certainly of interest to compare VSL for causes of death relevant to EPA with VSL based on accidental deaths.

A review of the VSL might begin by extracting VSL estimates from each study to construct a new VSL or set of VSLs—a task requiring care and judgment. Should multiple estimates be chosen from a single study? How should estimates be combined? In 2006, EPA convened a meta-analysis expert group to provide advice on just such issues (USEPA 2006b). Approaches range from the simple to the rigorous, with the latter including weighting VSL estimates from various studies in inverse proportion to their standard errors, and meta-regression, in which variation in VSL estimates is explained as a function of population and risk characteristics and study design.²⁵ We note that EPA’s meta-analysis expert group (USEPA 2006b) and the 2007 Science Advisory Board report (SAB 2007) recommended conducting separate meta-analyses for revealed and stated preference studies and then using expert judgment to combine or weight them. The Science Advisory Board’s 2011 report (SAB 2011) also recommended conducting meta-regressions. In terms of process, EPA could follow the Federal Advisory Committee Act process, or use the approach taken by the US Department of Transportation in revising its VSL in 2014 (Robinson and Hammitt 2015; DOT 2016). The Department of Transportation engaged in a structured review, with expert advice, but has not relied on a formal Federal Advisory Committee Act process.

Whatever EPA’s process, reexamination of the VSL is imperative. Newer, better-designed, and analytically rigorous US studies are available in both the revealed and stated preference literatures. Past attempts to revise the VSL have been derailed by reviewers’ observation that new studies are not perfect. The best thus becomes the enemy of the good. The current VSL has been in place for 30 years. It is time to reexamine it.

²⁴ The three studies that estimate a VSL for cancer and a VSL for noncancer natural causes find no cancer premium.

²⁵ See also Banzhaf (2022), who performs a meta-analysis of meta-analyses.

Table 1. Studies Used in EPA VSL Estimation

Stated preference				
Authorship	Title	Year published	Number of estimates	Mean or median
Gegax, D.A., Gerking, S., and Schulze, W.D.	Perceived Risk and the Marginal Value of Safety	1985* (1991)	1	Mean
Gerking, S.D., de Haan, M., and Schulze, W.D.	The Marginal Value of Job Safety: A Contingent Valuation Study	1988	1	Mean
Jones-Lee, M.W.	The Economics of Safety and Physical Risk	1989* (1995)	1	Mean
Miller, T.R. and Guria, C.	The Value of Statistical Life in New Zealand: Market Research on Road Safety Land Transport Division	1991	1	Mean
Viscusi, K., Magat, W.A., and Huber, J.	Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis	1991	1	Mean
Revealed preference/hedonic wage				
Authorship	Title	Year published	Number of estimates	Mean or median
Moore, M.J., and Viscusi, W.K.	Rates of Time Preference and Valuations of the Duration of Life	1989	1	Mean
Butler, R.J.	Wage and Injury Rate Responses to Shifting Levels of Workers Compensation	1983	1	Mean
Cousineau, J., Lacroix, R., and Girard, A.	Occupational Hazard and Wage Compensating Differentials	1992	1	Mean
Dillingham, A.E.	The Influence of Risk Variable Definition on Value-of-Life Estimates	1985	2	Mean
Garen, J.	Compensating Wage Differentials and the Endogeneity of Job Riskiness	1988	1	Mean
Kniesner, T. and Leeth, J.	Compensating Wage Differentials for Fatal Injury Risk in Australia, Japan, and the United States	1991	3	Mean
Leigh, P.	Gender, Firm Size, Industry and Estimates of the Value of Life	1987	1	Mean
Leigh, P. and Folsom, R.	Estimates of the Value of Accident Avoidance at the Job Depend on the Concavity of the Equalizing Differences Curve	1984	1	Mean

Marin, A. and Psacharopoulos, G.	The Reward for Risk in the Labor Market: Evidence from the United Kingdom and a Reconciliation with Other Studies	1982	1	Mean
Moore, M.J. and Viscusi, W.K.	The Quantity-Adjusted Value of Life	1988	1	Mean
Olson, C.A.	An Analysis of Wage Differentials Received by Workers on Dangerous Jobs	1981	1	Mean
Smith, R.S.	The Occupational Safety and Health Act: Its Goals and Its Achievements	1976	1	Mean
Smith, R.S.	The Feasibility of an 'Injury Tax' Approach to Occupational Safety	1974	1	Mean
Smith, V.K.	The Measurement of Mortality Air-Pollution Relationships	1976	1	Mean
Smith, V.K. and Gilbert, C.C.S.	The Implicit Valuation of Risks to Life: A Comparative Analysis	1984	1	Mean
Viscusi, W.K.	Wealth Effects and Earnings Premiums for Job Hazards	1978	1	Mean
Viscusi, W.K.	Occupational Safety and Health Regulation: Its Impact and Policy Alternatives	1981	1	Mean
Herzog, H. and Schlottman, A.	Valuing Risk in the Workplace: Market Price, Willingness to Pay, and the Optimal Provision of Safety	1990	1	Mean

* Years reported in table reflect how they appear in Viscusi (1992). Years reported in parentheses correspond to the available references.

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