Symposium:
Mortality-risk Valuation and Age

Age Differences in the Value of Statistical Life: Revealed Preference Evidence

Joseph E. Aldy* and W. Kip Viscusi**

Introduction

There are no explicit markets for mortality risk reduction. An individual cannot purchase "mortality risk reduction" per se. However, individuals implicitly reveal how much they value mortality risk reduction in many decisions they make. Spending more to buy safer products or driving above the speed limit to save time are examples of risk tradeoffs. This paper, which is part of a broader symposium on Life Valuation and Age, examines the implications of revealed preferences embodied in labor market decisions. The fatality risk-money tradeoff is known as the value of statistical life (VSL). In the case of the labor market, the VSL is the wage-fatality risk tradeoff revealed by workers' decisions about how much extra pay they require to induce them to accept jobs that pose additional risk.

A strident and continuing controversy with respect to the value of life has been whether the benefit of reducing risks to the old is less than for younger age groups. In particular, should there be a so-called "senior discount" when assessing the value of reduced risks to life? This question has drawn the attention of policymakers in a number of countries. In 2000, Canada employed a VSL for the over 65-year-olds population that is 25 percent lower than the VSL for the under 65-year-olds population (Hara Associates Inc. 2000). In 2001, the European Commission recommended that member countries use a VSL that declines with age (European Commission 2001). In 2002, the US Environmental Protection Agency (EPA), which has traditionally employed a constant value of a statistical life to monetize the benefit value of mortality risk reductions irrespective of the age of the affected population, conducted analyses of the Clear Skies initiative that included a "senior discount."[1] This effort to apply such a discount generated a political firestorm and

*Fellow, Resources for the Future, 1616 P Street NW, Washington, DC, 20036, USA; aldy@rff.org.
**University Distinguished Professor, 131 21st Avenue South, Vanderbilt Law School, Nashville, TN 37203, USA; kip.viscusi@vanderbilt.edu.

[1]In the "senior discount" analyses, the EPA provided two alternatives to account for age. One approach was based on a standard value of a statistical life-year approach (VSLY) that explicitly accounts for life expectancy. The second approach assumed that individuals over age seventy had a VSL equal to 63 percent of the value for those under seventy.

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ultimately led to abandonment of any age adjustments in benefit values assigned by the EPA.[2]

This article reviews and assesses the considerable literature on age variation in VSL levels as revealed through market decisions, rather than the emerging literature on stated preferences, which are elicited through surveys.[3] We focus on labor market evidence, although we address some similar results from product market decisions. More specifically, we examine hedonic, or quality-adjusted, wage studies and hedonic price studies. These analyses use econometric tests to analyze the effect of risk on wages or prices, while controlling for other aspects of the job or product.

The next section provides background on the VSL issue and an overview of the theory and methods that underlie the revealed preference literature on willingness to pay for mortality risk reduction. The third section discusses efforts to construct age-specific estimates of the benefits of risk reduction through VSLY measures that are derived from labor market and product market analyses. The fourth section reviews the literature on how labor market compensation for occupational mortality risk varies with age. This discussion is followed in the fifth section by a description of the recent empirical literature that has employed age-specific occupational mortality risk measures in the labor market analysis. The sixth section assesses the policy implications of employing these age-specific VSL measures, focusing particularly on how using different VSL measures affects evaluation of the Clear Skies initiative. The final section concludes.

Background, Theory, and Methods

Because of the availability of large individual datasets on workers' job characteristics, a literature of more than a hundred "revealed preference" studies of the labor market has examined the wage premiums workers receive for risk.[4] The wage premium per unit of fatality risk has come to be known as the VSL. Our concern is how VSL varies with age. Do older workers make labor market choices that indicate a steadily declining VSL, as would be the case if they were willing to accept lower wages for a given risk as they age? Although concern with age variations in VSL is a recent policy development, labor market studies have addressed this issue for more than two decades.

Our focus on the labor market is consistent with the central role of labor market evidence in setting VSL estimates for environmental policy. In the policy lexicon, the analyst transfers the estimate of the fatality risk-money tradeoff from the labor market context to the environmental policy context. For more than a decade, the EPA has used a benefit measure

[2]For a sense of the political reaction and EPA's decision to discontinue the use of an age-based value of statistical life, see "EPA Drops Age-Based Cost Studies," *New York Times*, May 8, 2003; "EPA to Stop 'Death Discount' to Value New Regulations," *Wall Street Journal*, May 8, 2003; and "Under Fire, EPA Drops the 'Senior Death Discount,'" *Washington Post*, May 13, 2003.

[3]See Krupnick (2007), which appears in this volume, for an assessment of the stated preference literature.

[4]Refer to Viscusi and Aldy (2003) for a detailed review of the revealed preference literature on mortality risk valuation.

for mortality risk reduction based on 26 studies, 21 of which focus on income-risk tradeoffs in labor markets (Environmental Protection Agency 1997; Viscusi 1993).

The transfer of an estimate of willingness to pay for risk reduction from the market context to the environmental policy context is appropriate when the populations have similar risk preferences, and the risk reduction magnitudes are comparable across both contexts. In this case, the benefit to an individual from a small risk reduction can be aggregated to a population-level estimate. For example, if the average person would be willing to pay $500 to reduce the probability of dying by one in ten thousand, then a population of ten thousand individuals would be willing to pay $5 million to prevent one member of that population from dying prematurely. The $5 million figure is the VSL. Because it is not possible *ex ante* to identify the person whose life will be saved, this prevented mortality is considered a statistical life.

There are several reasons for the prominence of issues pertaining to the transfer of VSL estimates from labor market contexts to environmental policy contexts. First, the benefits estimates for major environmental regulations, especially air quality benefits, are dominated by mortality risk reduction. Eighty percent of the more than $22 trillion estimated benefits of the Clean Air Act over 1970–1990 resulted from the mortality risk reduction associated with declining particulate matter and lead emissions (Environmental Protection Agency 1997). If the vast majority of the benefits of environmental policy reflect mortality risk reduction, then it is important to use credible and robust VSL estimates. Second, there is substantial debate about how the age of populations affected by environmental policy should influence benefit values. The elderly benefit disproportionately from air quality regulations that reduce particulate matter emissions. For example, EPA's 1999 Tier 2 regulation of the sulfur content of gasoline pursuant to the Clean Air Act generated estimated mortality risk reduction benefits of $23 billion annually. The average age of the population that received these benefits was estimated to be over seventy years old (Environmental Protection Agency 1999). The effect of environmental health risks on children has also drawn recent scrutiny at the EPA.[5] The concentration of benefits at the two tails of the age distribution raises questions about applying VSL estimates based on the preferences of the working population, who are on average thirty-five to forty years old in the relevant studies.

VSL over the Life Cycle: Theoretical Foundations

Why should the willingness to pay for a mortality risk reduction vary with age? Researchers have developed an array of theoretical and simulation models to address this question. The original models generated results consistent with some basic intuition. Older individuals should be willing to pay less for a reduced mortality risk because they are purchasing fewer additional years of life expectancy. An individual at age forty is expected to live another 40 years, but an individual at age sixty is expected to live only another twenty-three years

[5]For example, Executive Order 13,045 directs regulatory agencies to consider it a high priority to identify, assess, and address environmental health and safety risks that disproportionately burden children.

(Arias 2004).[6] The forty-year-old should value a mortality risk reduction more than the sixty-year-old, *ceteris paribus*, because there are seventeen more expected years at stake for the younger individual.

The decision to invest in risk reduction is comparable to an individual's decision to consume or invest current income. By foregoing some current consumption now in order to invest in risk reduction, the individual increases the probability of enjoying consumption in future years. Because the 40-year-old expects to have more years of future consumption than the 60-year-old, the 40-year-old is willing to forego more current consumption and pay more to reduce mortality risk than the 60-year-old. There is a higher return on the investment in risk reduction for the 40-year-old than the 60-year-old.

Taken to the extreme, this analysis suggests that an individual's willingness to pay for mortality risk reduction peaks at birth and declines throughout life. This result also holds for models that find that individuals borrow and save to ensure that they consume the same amount during every year of life. These models arrive at this conclusion by assuming that individuals have access to perfect markets for borrowing and annuities (Jones-Lee 1976; Shepard and Zeckhauser 1984). This consumption-smoothing result makes it very transparent that willingness to pay for risk reduction should increase with more years of life expectancy, because each year is characterized by the same amount of consumption. Unfortunately, perfect markets do not exist for borrowing or annuities, and resources as well as consumption levels vary considerably over the life cycle.

Shepard and Zeckhauser (1984) first explored the effects of imperfect borrowing and annuities markets on the VSL relationship in their so-called "Robinson Crusoe" analysis. Their model assumes that an individual can save money and consume later out of the savings, but cannot borrow against future income or invest in annuities that would pay out during retirement. Their numerical simulation suggests that the willingness to pay for a risk reduction increases with age among young adults, peaks around age 40, and then declines throughout the rest of life. This inverted-U shape of willingness to pay for risk reduction over the life cycle is also evident in theory and simulation models by Johansson (1996) and Ehrlich and Yin (2005). Recent work by Aldy and Smyth (2007) shows that this inverted U relationship can also hold when adult workers cannot insure against labor income shocks.

The temporal trajectory of VSL implied by these models is consistent with Johansson's (2002) finding that the willingness to pay for risk reduction should track the life-cycle pattern of consumption. For the United States, consumption is strongly linked to labor income for young adults, and increases as job compensation increases, until the late 30s or early 40s when adults begin to accumulate wealth through saving. Labor income begins to decline in the mid-50s and declines substantially after retirement, when individuals draw down their pensions, and consumption begins to slowly decline as individuals continue to age. So the increasing part of the inverted U reflects the low consumption individuals have as young adults, and their increasing consumption with age increases their willingness to pay for risk reduction. Once their consumption begins to flatten out as they start

[6] The small chance of death between ages 40 and 60 makes up the difference between a 40-year-old expecting to live to age 80 and a 60 year old expecting to live to age 83.

saving, the increase in willingness to pay for risk reduction slows down and eventually peaks. At this stage of the life cycle, the phenomenon that fewer remaining years of life expectancy explains willingness to pay for risk reduction begins to dominate. Elderly individuals, who consume less with each year, may reduce their willingness to pay even faster with age.

Hedonic Model Frameworks

Individuals reveal their willingness to pay for lower mortality risk in labor markets by making decisions that involve tradeoffs between wages and risk.[7] This notion dates back to Adam Smith (1776), who observed that "the wages of labor vary with the ease or hardship, the cleanliness or dirtiness, the honorableness or dishonorableness of the employment" (p. 112). To assess this phenomenon in real-world labor markets requires more than a casual comparison of wages and salaries and occupational mortality risk. The safest jobs tend to be the highest paid because of the positive income elasticity of the demand for safety and because the safest jobs tend to require more skills and education. The pertinent economic question is how much extra pay a worker requires to bear extra risk for a given set of job opportunities.

The hedonic market equilibrium is the result of market offers of wages for jobs of different risk and the choices of workers from among the available set of opportunities. Consider first the set of opportunities available to the worker. A firm's offer curve reflects the costs borne by an employer for making a work environment less risky. For any given level of profit, a firm must offer a worker less compensation if it invests in improved safety. This means that the offered wage will decline as the risk level declines.

For a given worker, there is a variety of combinations of wage and occupational mortality risk over which the worker is indifferent. Which firm the worker will choose and which combination of wages and risk will be most desirable will depend on the worker's willingness to bear risk. The market equilibrium for each worker is at the best attainable combination of wage and risk from the choice set available to the worker. The observed combinations of wage and risk chosen by different workers all reflect the optimal choices for each worker from the available choice set.

The set of observed market equilibria for a large number of workers yields a set of wage-fatality risk combinations in the labor market, or a relationship between the wage w and risk p given by w(p). The slope of this w(p) curve represents workers' willingness to pay for a marginal reduction in risk as well as firms' marginal cost for providing more safety. The curve w(p) does not reflect the wage-risk tradeoff for a particular individual but rather the average rates of wage-risk tradeoffs across people. It is neither a demand curve nor a supply curve, but rather reflects the joint influence of supply and demand.

This wage-risk relationship is usually estimated through a regression analysis of a standard wage equation, where the wage rate is a function of the worker's personal and job characteristics and the occupational fatality risk for the worker,

$$\ln(w_i) = \alpha + H_i'\beta_1 + X_i'\beta_2 + \gamma p_i + \varepsilon_i, \tag{1}$$

[7]Individuals, likewise, reveal their income-risk preferences in product markets, and this discussion is applicable to hedonic product market analysis as well.

where $\ln(w_i)$ is the natural logarithm of the worker i's wage rate, H is a vector of the worker's personal characteristics, X is a vector of the worker's job characteristics, p_i is the occupational fatality risk for this worker, and ε_i is the random error reflecting unmeasured factors influencing the worker's wage rate.[8] The terms α, β_1, β_2, and γ are parameters estimated through regression analysis. The personal characteristics typically include measures of human capital, such as education and experience, and other factors, such as union status. The job characteristics often include indicators for whether the job is blue-collar, white-collar, management, etc. The estimated coefficient on the occupational mortality risk variable reflects the willingness to pay to reduce mortality risk.

Many of the advances in the literature have involved refinements in the specification of this regression equation. Considerable attention has been focused on the fatality risk variable. As better data have become available, researchers have made the risk values age-specific. Recognition of the theoretical dependence of VSL on life-cycle consumption has led researchers to incorporate measures of consumption into the worker's personal characteristics. At a more fundamental level, there have been explorations of whether the equation is different for workers of different ages. Do older workers face different offer curves as well as exhibiting different preferences?

Recent research has investigated the existence of a single market equilibrium versus multiple equilibria for wage-risk tradeoffs (Viscusi and Aldy 2007). Because the willingness to pay varies with age, a 40-year-old may require higher labor compensation for a given level of occupational mortality risk than an otherwise equivalent 60-year-old. Thus, as a worker ages, he may change his location along this wage-risk curve. In addition, empirical evidence indicates that older workers are more likely to die on the job than younger workers (Viscusi and Aldy 2007). Firms may respond to older workers' lower safety "productivity" in the work environment by adjusting compensation relative to "safer" younger workers. Because firms can easily monitor the ages of their workers, they can offer wage-risk combinations that vary according to this age-related safety productivity. Thus, both workers' expected utility curves and firms' offer curves vary with the age of workers, which means that different wage-risk market equilibria for different age groups could emerge. Section 5 reports on empirical analyses of this age-specific willingness to pay to reduce mortality risk in labor markets.

Estimating the Value of a Statistical Life-Year (VSLY)

An intuitively appealing and seemingly neutral approach to the variation in VSL with age is to assume that each year of life has the same value. Based on this formulation, it is possible to construct models from the basic theory described above in which the researcher estimates the VSL as well as the worker's rate of time preference, r. These estimates can then be used to derive the VSLY based on how the worker values the discounted years of remaining life. In addition to assuming that each year of life over the life cycle has the same value, this general approach assumes that the VSL can be expressed as the present discounted value of these annual amounts. Changes in wealth levels, family responsibilities, health status, and

[8]Some papers in this literature also include measures of nonfatal injury risk and workers' compensation benefits. Refer to Viscusi and Aldy (2003) for more details.

other aspects of one's life cycle are among the factors that in practice will lead to differences in how one values survival at different ages. How reasonable the VSLY approach is depends on how the value of each year of life actually changes over the life cycle.

The specific model developed by Moore and Viscusi (1988) is a simple quantity-adjusted value of life in which the VSL tracks this series of annualized values. Let VSLY be the value of a statistical life year. The VSL is the present value of all the VSLY levels throughout the remainder of the person's life. If people lived forever, then VSL would equal the discounted present value of an infinite stream of constantly valued annual VSLY levels. With a finite life expectancy, it is necessary to account for the fact that the stream of VSLY amounts is not infinite, as VSL will not include the VSLY values after the person's expected future lifetime.[9]

The VSLY estimation approaches used in this context have all involved different variants of hedonic wage equations. The main difference between the simplest VSLY models and standard VSL estimates is that the fatality risk variable in the wage equation is replaced by the remaining discounted years of life. This formulation leads to empirical estimates of a value per discounted year of life and the rate of discount implied by workers' valuations. The valuation per discounted year of life lost and the rate of time preference that workers reveal through their willingness to risk future losses in life expectancy due to hazardous work are both estimated as part of this methodology.[10]

The most plausible labor market estimates involve VSLY values in the $300,000 range. The models differ in their sophistication, as several of the studies impose quite complex theoretical structures on the estimation process. This complexity comes at a price, as many of these studies yield surprisingly high estimates of VSLY due to the high estimated rates of time preference.[11]

How would one use the VSLY results for policy assessment purposes if one selected a VSLY level of $300,000 based on these results? Let us suppose the policy context is an environmental risk reduction that decreases the mortality risk to people of different ages. For those with one year to live, a reduction in their risk of death would have a VSL equal to VSLY, or $300,000. For those with 2 years of remaining life expectancy, the pertinent VSL is $300,000[1 + 1 / (1 + r)]$, where r is the worker's rate of time preference. One could, similarly, construct the VSL levels by age for all age groups.

The results of such a procedure for ages zero to 100 are shown in figure 1, which illustrates the strong dependence of these VSL levels on age. The life tables used for these calculations are based on average age-specific values for the entire US population. With all such life tables, one's remaining life expectancy decreases with each year of age but by less than one year.[12] The expected continuous, dramatic decline in VSL with age

[9]Thus, there is a deduction for a finite lifespan so that $VSL = \frac{VSLY}{r} - \frac{1}{(1+r)^L}\left[\frac{VSLY}{r}\right]$. Alternatively, it is possible to solve this equation for VSLY as a function of the estimated rate of discount r, leading to $VSLY = r(VSL) / [1-(1+r)^{-L}]$.

[10]Appendix Table A1 summarizes five papers that have followed this general approach.

[11]The outlier nature of several of these studies also may be due to the idiosyncratic character of the Panel Study of Income Dynamics (PSID), which often leads to unusually large VSL estimates.

[12]In making those calculations, we used a discount rate of 3 percent, which is consistent with recommended Office of Management and Budget (OMB) policy (OMB Circular A-4).

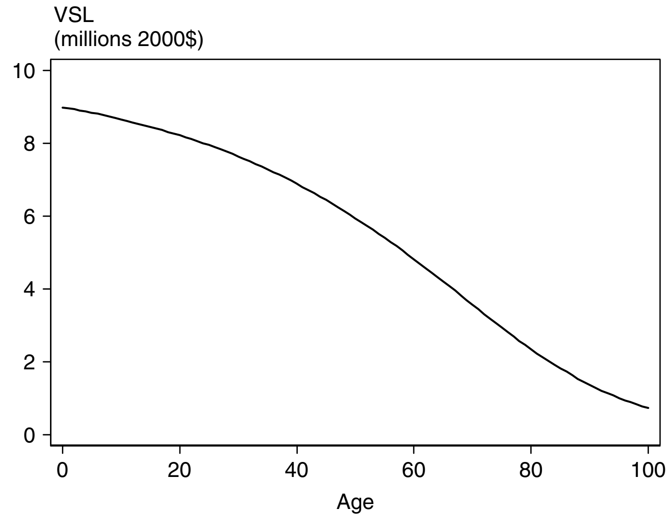

Figure 1. Age–VSL pattern over the life cycle based on VSLY. Notes: The age-specific VSLs are constructed by the authors assuming a VSLY of $300,000, a discount rate of 3 percent, and age-specific life expectancy based on the 2002 US Life Tables (Arias, 2004).

resulting from the VSLY approach is borne out in the results in figure 1. As was discussed above, while there are some theoretical models that predict steadily declining VSLs with age, particularly if there are perfect capital markets and annuity markets that one can access at birth, most models predict the inverted U pattern in which VSL may rise as well as decline with age. Consequently, it is essential to test empirically whether the strong assumptions of the VSLY approach do in fact hold. We address this issue in the subsequent sections.

Literature on Age Variations in VSL

There is a considerable literature that has examined wage equations that include an age-dependent VSL in the analysis. This section considers several wage models that include an industry-wide or occupation-wide job risk variable, which enters the wage equation (Equation (1) above) after being interacted with various age variables.[13] The simplest of these models employ interactions of fatality risk with age or age squared, while others use a series of age group categories.

Age-fatality Risk Interactions

The earliest approach to age-dependent VSL in the literature involved the interaction of the fatality risk variable with age. If the VSL declines with age, then the coefficient on the age-risk variable should be negative. If the age-VSL relationship is more complex (e.g., an

[13]All the studies we discuss pertain to developed countries. However, there have been similar labor market studies for developing countries as well.

inverted-U shape), then the age dependence may not be evident in a model with a simple age interaction, and a more flexible interactive form is required.[14]

Beginning with the study by Thaler and Rosen (1975), who analyzed age interactions with fatality rates of people in different occupations, the estimated age interactions found in the literature are consistently negative and significant.[15] The lone exception in this literature is Meng and Smith (1990), who found an insignificant effect with Canadian data. However, Meng (1989) found a significant negative effect for an earlier Canadian data set. The property value study by Portney (1981) also found a negative age-risk interaction and a declining VSL with age. Each of the labor market studies yields implausible negative VSLs for some of the older workers in their samples, indicating that the simple age-risk interaction may constrain a more complex underlying relationship between age and VSL. The specification used by Aldy and Viscusi (2003) results in an inverted-U shape, but the peak occurs relatively early in the life cycle, at age 29.

These interactive age effects are suggestive but do not resolve the age-VSL dependence issue. There are three principal caveats. First, all these studies assign the same fatality risk variable to all workers in an industry or occupation irrespective of age. Suppose that the jobs of older workers within a given industry are safer on average. If older workers have the same willingness to bear risk and VSL as younger workers, as exemplified by their fatality risk-wage tradeoffs, wage premiums for older workers will be lower. Because the aggregate risk variable overstates their age-specific risk, the econometric evidence will indicate a declining VSL with age. Thus, lower VSLs for older workers could arise from measurement error that biases the results by age. Second, the age-fatality risk interactions impose a rigid linear structure on the age-VSL dependence. The actual relationship may be nonlinear, including rising and falling segments that will be smoothed out by a simple age interaction. Third, hedonic estimates do not capture worker preferences alone, but reflect the joint interaction of the age-dependent market offer curves of firms and the age-dependent worker indifference curves. There also may be important age differences in safety-related productivity. Both supply and demand for risky jobs may vary with age. So, ideally the estimation should be sufficiently flexible to accommodate these variations.

Fatality Risk Coefficients by Age Group

A more recent set of studies of age did not resolve all the complications arising from the influence of age on the labor market equilibrium but did permit the estimation process to have a greater degree of age variation in VSL. Smith et al. (2004) included a series of interactions with age group categorical variables for ages 26 to 44, 45 to 50, 51 to 55, 56 to 60, and 61 to 65. Using Bureau of Labor Statistics (BLS) data by industry[16] matched to workers in the Health and Retirement Study,[17] Smith et al. (2004) found intriguing and somewhat surprising age-VSL results. For the age groups 24 to 44 and 45 to 50, they found

[14]Appendix Table A2 summarizes the results of studies that include an age-fatality risk interaction term.
[15]Viscusi (1979) finds a statistically significant and negative result for the interaction of age with workers' subjective risk beliefs.
[16]These BLS data were the precursors to the more recent Census of Fatal Occupational Injuries (CFOI).
[17]For more information about the HRS, refer to http://hrsonline.isr.umich.edu/.

negative and significant effects that implied quite large negative VSLs, on the order of minus $20 million. The large negative VSLs are inconsistent with economic theory. Smith et al. (2004) also found positive and statistically significant effects for older workers aged 61 to 65, with a quite large VSL of $14 million in 1999 dollars. Taken at face value, the results suggest that the VSL rises rather than falls with age. The authors attribute this result to the lower risk tolerance of older workers.

In a related paper, Evans and Smith (2006) use the Health and Retirement Survey coupled with BLS risk data to explore age variations in risk beliefs, such as longevity expectations. Although the authors do not report VSL estimates, they do analyze the variation in risk beliefs with age. They conclude that the process of forming risk beliefs varies with age and may account for their earlier results concerning the estimated age dependence of VSL.

Kniesner et al. (2006) recast the hedonic wage equation in terms of its theoretical foundations. A main theoretical determinant of the VSL variation with age is its dependence on the pattern of life-cycle consumption. As a result, the authors include food and housing consumption or total consumption in the wage equation and analyze VSL over the life cycle. The data used are the PSID coupled with refined fatality risk data using the new BLS CFOI.[18] Using these newly available fatality risk data, the authors were able to construct a refined job risk variable calculated for a set of 720 industry-occupation categories. Though the risk measure is not explicitly age-dependent, to the extent that older workers are in safer occupations within a given industry, the variable will reflect age differences in risk.

Their estimated overall life-cycle pattern of VSL reflects an inverted-U shape, which is consistent with theoretical models in which capital markets are not perfect. The main novelty of this analysis is that including consumption flattens out the age-VSL relationship for the older age groups. Thus, the VSL rises with age, peaks in one's early fifties, and remains fairly stable but a bit lower thereafter. These results do not suggest a steadily rising VSL pattern as in Smith et al. (2004). Nor do they indicate that the rise in VSL is followed by a steep downturn. Rather, there is a plateau that is just below the peak VSL level.

Age-VSL Relationship Using Age-specific Occupational Mortality Rates

The studies discussed in the previous section all employ standard measures of occupational mortality risk based on the industry or occupational affiliation of workers. In these studies, a 20-year-old manufacturing worker is assumed to face the same probability of dying on the job as a 60-year-old worker in the same manufacturing industry. Two recent papers develop a more refined measure of mortality risk that varies by industry affiliation and worker age (Aldy and Viscusi, 2006; Viscusi and Aldy, 2007). This age-specific risk measure allows for a more specific matching of mortality risks to workers and can improve the estimation of the age-VSL relationship. These papers also employ more flexible statistical models that better reflect how the VSL changes over the life cycle.

[18]For more information about the CFOI, refer to: http://www.bls.gov/iif/home.htm.

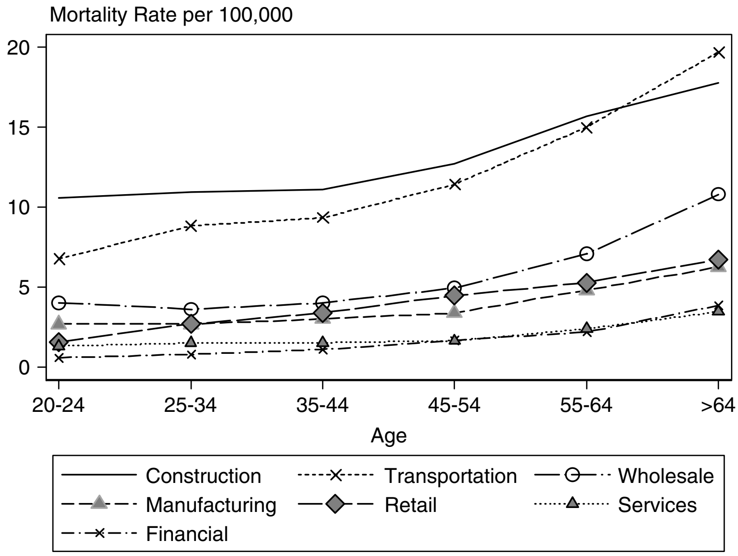

Figure 2. Mortality risk by age and 1-digit industry, 1992–2000. Notes: Constructed by authors, with mortality risk data from the BLS Census of Fatal Occupational Injuries, 1992–2000 and CPS MORG data files, 1992–2000.

Age-specific Fatality Rates by Industry

In Aldy and Viscusi (2006) and Viscusi and Aldy (2007), we match the occupational mortality risk measure constructed from the BLS CFOI to full-time workers in the Current Population Survey (CPS)[19] by 2-digit industry affiliation and one of six age groups. We do the same for a comparably constructed nonfatal injury risk measure. The overall industry levels follow expected patterns: workers in the construction and transportation industries face higher mortality risks than those in the financial sector or in service jobs. Within industries, workers are less likely to suffer a nonfatal injury on the job as they age, which is consistent with workers sorting themselves into safer jobs as their wealth increases with age. This age effect also may reflect the benefit of experience and learning how to mitigate occupational injury risks. The surprising result is that if older workers are injured, the injuries are likely to be more severe and they are much more likely to die on the job than younger workers. As a result, the job-related fatality rate is higher for older workers than younger workers.

Figure 2 illustrates how job fatality risks change with worker age for several major industry groups.[20] The rising pattern of fatality risks by age is widespread throughout the economy. The average 60-year-old manufacturing worker is 80 percent more likely to die on the job than the average 30-year-old. Across virtually every industry, on-the-job mortality risk

[19]The CPS is the federal government's monthly survey of labor market participation by approximately 60,000 households that is used, *inter alia*, to estimate the unemployment rate. Using the CPS provides a much larger sample than typically used in such analyses, and facilitates our age-specific analyses.

[20]Mining is omitted because the mortality risk is off our risk scale. The age pattern for mining sector mortality rate peaks in the 18–24 age group, declines until age 35–44 age group, and then increases with age thereafter.

Table 1 Age-group-specific values of a statistical life (VSLs), annual cross-sections, 1993–2000

Year	18–24 Age Group ($)	25–34 Age Group ($)	35–44 Age Group ($)	45–54 Age Group ($)	55–62 Age Group ($)
1993	0.64	9.92	8.36	2.04	2.36
1994	3.97	7.73	7.75	3.86	4.87
1995	4.87	7.31	6.16	5.02	4.46
1996	5.13	8.08	8.45	4.67	3.39
1997	4.60	8.08	8.98	5.64	4.47
1998	5.65	6.76	8.61	4.69	4.55
1999	2.18	7.18	8.41	8.35	3.95
2000	3.16	9.03	9.85	7.97	3.77

Notes: VSLs are expressed in millions of year 2000 dollars based on age-specific wages.

increases with age and peaks for those over the age of 55. This same pattern of rising risks with age holds, whether considering workers within occupational age groups or by industry affiliation. This does not appear to be the product of the increase in all-cause mortality with age. The increase in occupational mortality risk with age, which is less than a doubling of risk between ages 30 and 60, is much smaller than the nearly ten-fold increase in the probability of dying from all causes over this 30-year period of the life cycle (Arias 2004). Moreover, the occupational mortality data do not include heart attacks and other causes of death that may occur at the workplace but are unrelated to the job.

This age-occupational mortality pattern, however, does not hold for nonfatal injuries: the probability of a lost-workday injury declines with age for most industries (Viscusi and Aldy 2007). An older worker is, on average, less likely to be injured. But if he is injured, he is much more likely to die than a younger worker. Thus, the age-pattern of fatalities appears not to reflect older workers' decisions to take riskier jobs, but rather the greater probability that a workplace accident will be severe for older workers.

This variation by age in the safety productivity of workers is important in the context of the wage determination process presented in the second section of this paper. An employer can easily observe a worker's age. If an older worker is more susceptible to costly, life-threatening occupational accidents in a given job, an employer can adjust the offered labor compensation to account for this difference in safety productivity. Similarly, older workers may demand less compensation for mortality risks than otherwise equivalent younger workers because they have fewer years of life expectancy. The shifts with age of both labor supply and labor demand can result in not one hedonic market equilibrium for labor compensation and job mortality risk, but a series of market equilibria for different age groups.

Age and Cohort Effects

To investigate this possibility, in Aldy and Viscusi (2006) we estimate and compare age-specific VSLs using the CPS over most of the 1990s. In particular, we estimate VSLs for five age groups—18–24, 25–34, 35–44, 45–54, and 55–62—over the 1993–2000 period. As shown in Table 1, there is substantial heterogeneity in the VSL with respect to age, but there are also common trends across years. The VSL always peaks for either the 35–44 age group (6 times) or the 25–34 age group (twice). This pattern reflects an inverted-U relationship between age and the VSL, as the 18–24 and 55–62 age groups have VSL estimates that are always substantially lower than and, in most years, statistically distinct from the higher VSLs for the 25–34 and 35–44 age groups. The workers in the oldest age group in our sample have, on average, VSLs that are half of the peak VSL.

Comparing a 30-year-old worker's VSL to a 60-year-old worker's VSL in a cross-sectional analysis may capture differences in VSLs across generations, but it may not accurately reflect the VSLs for a given cohort or age group as it ages through the life cycle. For example, a 60-year-old may have a lower VSL than a 30-year-old, in part because the fairly steady increase in economic growth over the years suggests that an average worker born in 1970 should expect greater lifetime income than an average worker born in 1940. The higher lifetime income would positively influence how much workers in the younger cohort would be willing to pay to reduce mortality risk. In addition, with improvements in health care over time, a worker born in 1970 may expect to live longer than a worker born in 1940.

To complement the cross-sectional analyses presented in Table 1, we have also estimated age-VSL relationships that account for the year of birth of the workers in our sample (Aldy and Viscusi 2006). These results show that the VSL does increase with year of birth, consistent with the notion of incomes and life expectancy increasing over time. The age-VSL relationship still follows an inverted-U shape, but accounting for year of birth effectively rotates the shape so that younger workers now have a lower VSL; the curve peaks a little later in life (at age 46), and older workers now have a higher VSL. The oldest worker in our sample (age 62) has a VSL that is 35 percent lower than a 46-year-old worker's VSL, the peak value in this analysis. This approach allows us to distinguish pure age effects from age-related cohort effects such as income and life expectancy.

The decision about whether to account for age variation in on-the-job mortality risk influences both the statistical analysis of labor market compensating wage differentials and applications of the estimated VSLs to policy evaluation. Viscusi and Aldy (2007) compare age group VSLs based on the standard 3-digit industry measure of mortality risk and the novel 2-digit industry risk measure by age group. The choice of the job risk measure does not substantially affect estimates of the average compensating wage differential for the entire sample of workers aged 18–62 years, but it does affect the variation in VSL by age. As previously noted, the age-specific industry risk measure results in VSLs that increase with age until they peak for workers when they are in their late 30s or early 40s, and then decrease thereafter. The industry-only risk measure applies a lower risk measure to most older workers than does the age-specific industry risk measure and results in VSLs for 55 to 62-year-olds that are higher than for workers in the 25–34 age group. Using the average mortality risk for the industry introduces systematic error into the statistical analysis—it results in younger workers having a higher risk measure and older workers a lower risk measure than what they typically experience. This means that VSLs will be overestimated for older workers and underestimated for workers in their 30s and 40s.

Policy Implications of Labor Market Age-specific VSLs

The studies discussed in the previous sections have several key policy implications for monetizing the benefits of mortality risk reduction. First, choice of the cross-sectional age-VSL function versus the cohort-adjusted age-VSL functions depends on the policy evaluation task. An economic analysis of a policy that reduces mortality risks across the population today should employ the cross-sectional age-VSL function. The cross-sectional relationship reflects the current tradeoffs between mortality risk and income for the current population. However, if a risk reduction policy generates benefits over a long period of time, such as with a two-decade latency period for cancer risks, it may be more appropriate to apply the cohort-adjusted VSLs for today's young adults who will become the future's older individuals. Our analysis rejects the assumption underlying the current widespread approach of the US government, which is, that VSL is constant across the population irrespective of age.

Second, using these age-specific VSLs to monetize the benefits of environmental policies does have a significant effect. An instructive illustration of the influence of age adjustments and the "senior discount" for VSL can be found in the analysis of the Clear Skies initiative prepared by Environmental Protection Agency (2002). The EPA's use of a senior discount for VSL in an exploration of the sensitivity of the benefit estimates to different assumptions vaulted the age adjustment issue into policy prominence. We have applied our estimates of the VSL-age relationship to EPA's analysis of the Clear Skies initiative and compare the results to the estimates developed by EPA (see Table 2). We recognize that the illustrative estimates presented here may be refined in subsequent studies in much the same way as the original VSL estimates have become refined through dozens of studies in the literature. This comparison shows that one's decision to apply the average VSL of all workers, a fixed fraction of the average VSL of all workers (EPA's original "senior discount"), the average VSL for workers aged fifty-five to sixty-two, or the VSLY derived from an average VSL to individuals 65 and older has a significant impact on the estimated benefits of mortality risk reduction.[21]

Table 2 presents a summary of the key risk benefits information based on the VSLs estimated by both EPA and Viscusi and Aldy (2007). EPA prepared two sets of mortality risk estimates—base estimates based on a long-term exposure assumption and alternative estimates based on short-term exposures. In each case, the analysis distinguished reduced mortality effects for two different age groups, those eighteen to sixty-four and people aged sixty-five and older. As is indicated by the first column of reduced fatalities, most of the reduced fatalities are among the sixty-five and over population, so the application of any kind of senior discount will have a potentially substantial effect on benefits. The second column of estimates values the reduced fatalities using a constant VSL of $6.3 million. The main basis for this EPA estimate is an assessment of labor market estimates of VSL, so in that respect our analysis of age variations in VSL is quite germane to the EPA benefits assessment (see Environmental Protection Agency 1997; Viscusi 1993). The constant VSL estimates and subsequent calculations assume that the willingness to pay for fatality risk reductions does not vary with the quality of life and life expectancy of those being protected. In practice, that may not be the case if, for example, people with advanced respiratory ailments are the main beneficiaries of the policy. The EPA senior discount estimates do not affect the assessed benefits for those under age sixty-five, but do alter the benefits for the sixty-five and older population. EPA assumed a 37 percent reduction in VSL for those seventy and

[21] Simulation studies from Shepard and Zeckhauser (1984) through Aldy and Smyth (2007) show that the VSL of those 65 and older is lower than the average of all workers and the average of the 55–62 age group.

Table 2 Summary of Clear Skies initiative benefits based on EPA VSLs vs VSLs estimated by Viscusi and Aldy (2007)

Age group		**Benefits of reduced mortality (2000$, billions, undiscounted)**				
	Reduced annual fatalities in 2010	**Constant value of life (EPA, 2003)**	**Senior discount (EPA, 2002)**	**Value based on age-industry fatality risk VSL estimates**	**Value based on industry fatality risk VSL estimates**	**VSLY based on EPA's constant VSL**
Base estimates—long-term exposure:						
Adults, 18–64	1,900	12.0	12.0	11.9	10.1	11.5
Adults, 65 and older	6,000	37.8	23.8	22.9	36.0	15.9
Alternative estimates—short-term exposure:						
Adults, 18–64	1,100	6.9	6.9	6.9	5.8	6.7
Adults, 65 and older	3,600	22.7	14.3	13.9	21.6	9.5

Notes: Environmental Protection Agency (2003) provides the reduced annual fatalities in 2010 data (p. 64) and the constant value of life of $6.1 million (1999 dollars; p. 34). Environmental Protection Agency (2002) provides the senior discount conversion factor of 0.63 (p. 35). The calculation of the benefits for adults aged 18–64 assumes that the reduced mortalities are equally distributed by age. Age-specific VSLs, based on the results presented in the specifications in Tables 1B and 2B of Viscusi and Aldy (2007), are applied to the estimated mortalities by age and these are aggregated to yield the 18–64 benefits estimates. The VSLs for the 58–62 age group estimated in Tables 1B and 2B of Viscusi and Aldy (2007) are applied to the 65 and older mortalities to estimate the benefits for the elderly. The VSLY estimates are based on a discount rate of 3 percent and age-specific life expectancy from the 2002 US Life Tables (Arias, 2004).

over, reducing the total long-term exposure benefits assessment for this group from $37.8 billion to $23.8 billion. This change reduces the overall policy benefits by 28 percent.

To illustrate the effect of using our results, we assume that the mortality reductions for the under-sixty-five population are distributed evenly by age, that the pertinent VSL is the estimated age-specific VSL for this population, and that the VSL for ages fifty-five to sixty-two is the same as that of the older group affected by the policy. This approach leads to a negligible reduction in the EPA's estimate of long-term exposure benefits for those under sixty-five, from 12.0 to $11.9 billion, and it reduces the sixty-five and older benefit value to $22.9 billion. Thus, these labor market estimates imply a reduction in benefits of only 5 percent relative to that obtained by EPA in its senior discount analysis. Benefits to those sixty-five and older comprise about two-thirds of the total benefits in the senior discount analysis and our age-specific VSL analysis, as compared to 76 percent with a constant VSL. The VSL estimates by age that use industry job fatality estimates, but do not account for the influence of age differences on risk, yield much higher benefit estimates.

To estimate the risk reduction benefits using the VSLY approach, we have annuitized EPA's $6.3 million VSL using a discount rate of 3 percent, which yields a VSLY of about $275,000. Applying VSLYs to the age-specific risk reductions based on 2002 life expectancy has a modest impact on the under-65 benefits—a decline from $12 billion to $11.5 billion. In contrast, VSLYs have the lowest risk reduction benefits for the 65 and older population, with an estimate of less than $16 billion.

We do have some reservations about the VSLY approach. First, as we note above, an age-invariant VSLY holds only under the strong assumption of constant consumption over the life cycle. Second, our age-specific VSLs are consistent with an inverted-U pattern for VSLY with respect to age (Aldy and Viscusi 2006). EPA and other government agencies have previously monetized risk reduction benefits based on the number of life-years saved. However, the statistical tests in our work reject this notion of a constant, age-invariant VSLY as used in prior government analyses and in EPA's assessment of the Clear Skies initiative.

This exercise has illustrated the sensitivity of various options for benefits transfer. For example, applying a VSL for the 55–62 age group to an older age group may overestimate the benefits, based on the life-cycle pattern for 18–62-year-olds estimated in Aldy and Viscusi (2006) and simulation work by Shepard and Zeckhauser (1984) and Aldy and Smyth (2007). This policy evaluation exercise also shows the differences between the standard benefits transfer, based on the average VSL of the entire population, and an application of a near-elderly VSL to the affected elderly population.

Age differences in the pertinent VSL for benefit assessment first emerged in a policy context for environmental policies. Because many EPA programs reduce risks at the tails of the population distribution, it is not surprising that the senior discount issue surfaced with respect to environmental policies rather than, for example, occupational safety regulations. The fact that benefits to senior citizens comprised the lion's share of the policy benefits for the Clear Skies initiative instigated this controversy.

Heterogeneity in VSL levels is expected from a theoretical standpoint, but making the VSL for a group systematically lower, as EPA did in its analysis of the Clear Skies initiative, introduces distinctions that will surely be controversial even if well founded. The negative direction of the change in valuation of older people's lives, rather than the recognition of heterogeneity in VSL, may have accounted for the public uproar that the benefit assessment created. If EPA had instead placed a premium on the lives of children whose risks would be reduced by the policy, it is likely that few would have objected.

Conclusion

Whether the VSL should vary by age is not a matter of equity or political expediency. Rather it should be grounded on estimates of how people's willingness to pay for risk reduction varies with age. As we age, our life expectancy shortens, but our economic resources vary as well, giving rise to a theoretical indeterminacy in the age-VSL relationship.

The implicit valuations of risk revealed through labor market decisions resolve some, but not all, outstanding issues. First, it is clear that VSL does vary with age. The labor market VSL increases with age, peaks in mid-life, and subsequently declines. The decline, later in life, appears to be flatter than the early-adult life increase for models that recognize either cohort effects or life-cycle consumption patterns. Second, the popular perception that the VSL must be less for a 60-year-old than for a 20-year-old because of the differences in life expectancy is not borne out. However, a 60-year-old does appear to have a lower VSL than a 30 or 40-year-old. Third, the assumption of a constant value per year of life that underlies the VSLY approach can be rejected, as VSLY also rises and then subsequently declines over the life cycle. Finally, applying a VSL for those in their late 50s and early 60s to an even older population would appear to introduce less error than the current practice of applying the average VSL for the entire population; age-specific VSLs have little impact on total under-65 mortality risk reduction benefits, but have a substantial influence on the benefits for the 65 and older population.

Pinpointing the VSL at different ages will require further research, including evidence other than market-based revealed preference studies. However, the broad outlines of the age-VSL relationship are clear. Developing this research agenda can further inform and improve the evaluation of mortality risk reduction policies across government agencies. Understanding how willingness to pay to reduce risk varies with age will facilitate better prioritization of risk reduction efforts for populations of various ages. Proper recognition of the heterogeneity of VSL can promote the goal of securing the greatest social benefit for a dollar of investment in reducing mortality risk.

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Appendix

Table A1 Summary of VSLYs and estimated discount rate studies

Year	Author (Year)	Type of study	Sample	Implicit discount rate (%)	VSLY (2000$)
1988	Moore and Viscusi (1988)	Labor Hedonic with Reduced Form Discounting Model	QES 1977	9.6–12.2	269,000–305,000
1989	Viscusi and Moore (1989)	Labor Hedonic with Structural Markov Model	PSID 1982	10.7	1,085,000–2,261,000
1990	Moore and Viscusi (1990a)	Labor Hedonic with Structural Life Cycle Model	PSID 1982	2.0	739,000
1990	Moore and Viscusi (1990b)	Labor Hedonic with Structural Integrated Life Cycle Model	PSID 1982	1.0–14.2	950,000
1995	Dreyfus and Viscusi (1995)	Automobile Hedonic	1988 Residential Transportation Energy Consumption Survey	11–17	415,000–560,000

Notes: In cases in which the authors reported VSLs and not VSLYs, we annuitized the reported VSL based on an assumption that the average age of the sample was 35 years old and used the reported discount rate. We converted all values to year 2000 dollars with the CPI-U deflator.

Table A2 Results of hedonic studies using age-risk interaction specifications

Author (Year)	Age × risk variable coefficient	Average VSL (millions in 2000 US$)	VSL at given age (millions in 2000 US$)		
			25	40	55
Thaler and Rosen (1975)	Significant (5%), negative	1.0	1.9	0.2	−1.4
Portney (1981)	Integrated air pollution mortality risk estimates with hedonic housing model	1.0	–	1.5	0.3
Arnould and Nichols (1983)	Significant (1%), negative	0.5, 1.3	24.0	9.0	−6.0
Meng (1989)	Significant (10%), negative	3.9–4.7	8.3	4.5	0.69
Baranzini and Ferro Luzzi (2001)	Significant (1%), negative	6.3, 8.6	12.7, 17.2	7.3, 10.7	1.9, 4.1
Aldy and Viscusi (2003)	Significant (1%), negative	4.7	6.2	5.1	1.5

Notes: The Portney results are for female homeowners under the age of 45 and for those between 45 and 64 years of age. Male homeowners have a similar downward trend with age but with lower magnitudes. Meng and Smith (1990) and Shanmugam (1996/1997, 2001) report statistically insignificant coefficient estimates for age-risk interaction terms. Dillingham et al. (1996) find a positive and statistically significant effect of the length of impaired work life from a nonfatal occupational injury on the wage. Refer to Table 10 of Aldy and Viscusi (2003) for more details on these studies. We converted all values to year 2000 dollars with the CPI-U deflator.

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