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Labor market estimates of the senior discount for the value of statistical life[☆]

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Abstract

This article develops the first measures of age–industry job risks to examine the age variations in the value of statistical life. Because of the greater risk vulnerability of older workers, they face flatter wage-risk gradients than younger workers, which we show to be the case empirically. Accounting for this heterogeneity in hedonic market equilibria leads to estimates of the value of statistical life–age relationship that follows an inverted U shape. The estimates of the value of statistical life range from \$6.4 million for younger workers to a peak of \$9.0 million for those aged 35–44, and then a decline to \$3.8 million for those aged 55–62. The decline of the estimated value of statistical life with age is consistent with there being some senior discount in the Clear Skies Initiative analysis.

JEL Classification: J17; I12

Keywords: Value of statistical life; Job risks; Senior discount; Compensating differentials

1. Introduction

Using the value of statistical life (VSL) to monetize the benefits of risk regulations has long been controversial, particularly outside the professional economics literature. The level of controversy increased in 2003 when the US Environmental Protection Agency (EPA) prepared an illustrative analysis of the Clear Skies Initiative in which it used a VSL estimate for those aged 65 and older that was 37% lower than for those aged 18–64. This unit benefit difference, which became known as the ‘‘senior discount’’ or ‘‘senior death discount,’’

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generated such substantial controversy that EPA eventually abandoned such differentiation in VSL levels for benefit assessment.[1]

While the EPA approach has garnered the most press attention, other countries likewise have used different VSL levels for older age groups. In a 2000 analysis for the Canadian government, the VSL used for the over-65 population was 25% lower than the VSL for the under-65 population.[2] More generally, the European Commission [17] recommended that its member countries value benefits using VSL levels that decline steadily with age.

On a theoretical basis, there clearly is a legitimate role for an adjustment, but the magnitude and direction of the adjustment are unclear. For models in which consumption is constant over the life cycle, such as those with perfect annuity and insurance markets, the VSL declines steadily with age, as shown by Jones-Lee [25,26] and Shepard and Zeckhauser [39].[3] Other models with imperfect insurance and annuity markets, such as Shepard and Zeckhauser [39] and Johansson [24], have presented simulations indicating that there is an inverted U-shaped age–VSL relationship. More recent analyses, such as Johansson [23], Aldy and Viscusi [4], and Ehrlich and Yin [14], have indicated that the age–VSL relationship is ambiguous and could be positive, negative, or zero. In particular, Johansson [23] concludes that whether actuarially fair insurance markets exist or not, VSL could be increasing, decreasing, or have no systematic dependency on age. He also observes that the VSL trajectory will depend on the optimal age pattern of consumption. Empirically, consumption displays an inverted U-shaped relationship over the life cycle.[4]

Previous labor market estimates of the age–VSL relationship have not been sufficiently refined to resolve the theoretical ambiguity. Unlike this article, all previous studies of the age variation in labor market VSLs have used aggregative risk measures, such as the overall fatality risk for the worker's industry, rather than a risk variable that reflects the different risks faced by older workers.

Eight studies of labor markets in Canada, India, Switzerland, and the United States have included an age–mortality risk interaction term in their hedonic wage analysis, which should be negative if older workers value risks to their lives less. Five of these studies estimated a negative and statistically significant coefficient on the age–mortality risk interaction term.[5] Given the constraints of the specification, the log(wage) regression results for these studies imply that there is an inverted U-shaped relationship of VSL and age; however, the results often imply implausibly low VSL levels, with negative VSL amounts beginning at ages ranging from 42 to 60.[6] Smith et al. [42] use a fatality risk measure matched to workers based on their 2-digit industry code, yielding estimated VSLs ranging from \$7.4 million to \$14.2 million that increase with age for the most risk-averse workers between 51 and 65 years of age, but they do not test whether the differences in VSLs are statistically significant. That study also yielded statistically insignificant VSL estimates for those of age 45–60 and VSL estimates for those aged 26–44 that are negative and statistically significant, implying point estimates of VSL ranging from −\$21.1 to −\$22.5 million.[7] Given that there is no theoretical rationale for strongly negative VSLs, this study does not appear to fully resolve the research question of the age–VSL dependency.

Structural life cycle models of labor market and product market decisions adjust the standard hedonic wage models for life expectancy effects and assume a constant value per marginal year of life over the individual life

[1]Among the many articles covering this controversy were the following: "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.

[2]See Hara and Associates [20] for their analysis, which was in the context of cigarette regulation.

[3]The simulation models of Arthur [7], Rosen [36], and Cropper and Sussman [11] likewise have shown a declining VSL with age.

[4]Kniesner et al. [28] examine the inverted U-shaped life-cycle consumption relationship and its effects on the age–VSL pattern.

[5]These studies are reviewed in Section 8 of Viscusi and Aldy [47].

[6]Consider the following results from representative regression models from these studies. The VSL is negative for all workers over age 42 based on Thaler and Rosen [43], at age 48 based on Viscusi [46], at age 49 based on Arnould and Nichols [6], at age 56 based on Meng [31], and at age 60 based on Baranzini and Ferro Luzzi [8]. The other three studies, Shanmugam [37,38] and Meng and Smith [32] found statistically insignificant coefficient estimates.

[7]The Wave 1 Table 3 estimates in Smith et al. report negative and statistically significant VSL levels that we converted to point estimates using the reported coefficients in conjunction with the wage data reported on p. 427 of Smith et al. [42] and an assumption of a 2000-hours work year. The adult respondents in their 20s, 30s, or 40s in the Health and Retirement Study sample are included on the survey on the basis of their spousal or living arrangements with an older individual. Although the survey is intended to be representative of the near-elderly population, it is not necessarily representative for this younger age demographic.

cycle and usually across individuals as well. These studies of US markets indicate that the quantity of life does matter, as they have yielded implicit rates of discount with respect to years of life ranging from 2% to 11–17%.[8]

Survey studies in Canada, Sweden, Taiwan, the United Kingdom, and the United States have also investigated the effect of age on the expressed willingness to pay for mortality risk reduction from hypothetical government programs. Using a quadratic age specification, Jones-Lee et al. [27], Johannesson et al. [22], and Persson et al. [35] all reported survey evidence of an inverted U for the value of a statistical life over the life cycle. The widely cited estimates of the age−VSL relationship from Jones-Lee et al. [27] are based on results from a contingent valuation study for which there is a positive age coefficient and a negative age squared coefficient in a regression of VSL values for traffic safety risks to one's self.[9] Studies with more restrictive formulations in which age enters linearly have found a negative age–VSL relationship, as in Smith and Desvousges [41], Corso et al. [10], and Hammitt and Liu [19]. Several recent survey studies have used age group indicator variables to characterize the age–VSL relationship. In a study of Ontario residents, Krupnick et al. [29] find that VSL is fairly flat until age 70, after which it is lower.[10] In a similar study with an American sample, Alberini et al. [1] did not find that the VSL declines with age, even at advanced ages.[11]

This paper extends the labor market estimates of the age–VSL relationship in several respects. In Section 2, we examine the age-related measures of injury risk and fatality risk. Older workers are among the highest fatality risk groups, and they may be especially vulnerable to serious injury. To capture this possible difference in safety-related productivity, Section 3 sets out the hedonic labor market model in which older and younger workers may be facing quite different market offer curves. The empirical estimates indicate that there is such a difference in the market opportunities locus. Moreover, there is an inverted U-shaped relationship between VSL and age that peaks in the 35–44 age range. We apply these estimates to the Clear Skies Initiative benefit assessments and provide conclusions in Section 5.

2. Job risk variations by age

To characterize the fatality risks faced by workers of different ages more precisely than is possible using average risk values by industry, we construct a risk measure conditional upon age and the worker's industry rather than using an industry basis alone, which is the norm for all previous studies of age variations in workers' VSL. The source of the fatality measures is the US Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI). Beginning in 1992, BLS utilized information from a wide variety of sources, including Occupational Safety and Health Administration reports, workers' compensation injury reports, death certificates, and medical examiner reports to develop a comprehensive database on every job-related fatality. For each death, there is information on the worker's age group and industry that we use in constructing the fatality risk variable.[12]

We structured the mortality risk cells in terms of 2-digit SIC industries and the age groups specified in the CFOI data: $\leqslant 15$, 16–19, 20–24, 25–34, 35–44, 45–54, 55–64, and $\geqslant 65$.[13] To construct the denominator for the mortality risk variable, we used the US Current Population Survey Merged Outgoing Rotation Group files to

[8]Viscusi and Aldy [47] provide a review of those studies, which include labor market and product market studies, such as Moore and Viscusi [33] and Dreyfus and Viscusi [13].

[9]These significant results were for only one question, Question 18(a), as other survey questions regarding risks to one's self or risks to one's self and others usually led to one of the two age coefficients being statistically significant.

[10]The age group indicator variable coefficients imply an inverted U for VSL over the life cycle. Likewise, the results for the US and pooled US−Canada samples also show a modest inverted U-shape in Alberini et al. [1]. Neither paper, however, presents results of statistical tests comparing the estimated VSLs. The authors indicate (Krupnick et al. [29], note 22) that with more stringent data cleaning criteria, they estimate quadratic age regression specifications that yield an inverted U with statistically significant coefficient estimates on the age and age variables.

[11]Recent survey-based research by DeShazo and Cameron [12] also shows that VSL declines with age.

[12]The availability of the CFOI data set has allowed analysts to construct job-related mortality rates in a variety of ways. Viscusi [44] used this occupational fatality data set to construct mortality rates by industry and by industry and occupation, while Leeth and Ruser [30] constructed job-related mortality rates by race, gender, and occupation.

[13]We have omitted the CFOI's $\leqslant 15$ and $\geqslant 65$ age groups in our empirical analyses. Our empirical analysis matches the average CFOI fatality risk for the age 55–64 group to workers in the age 55–62 age range that we consider.

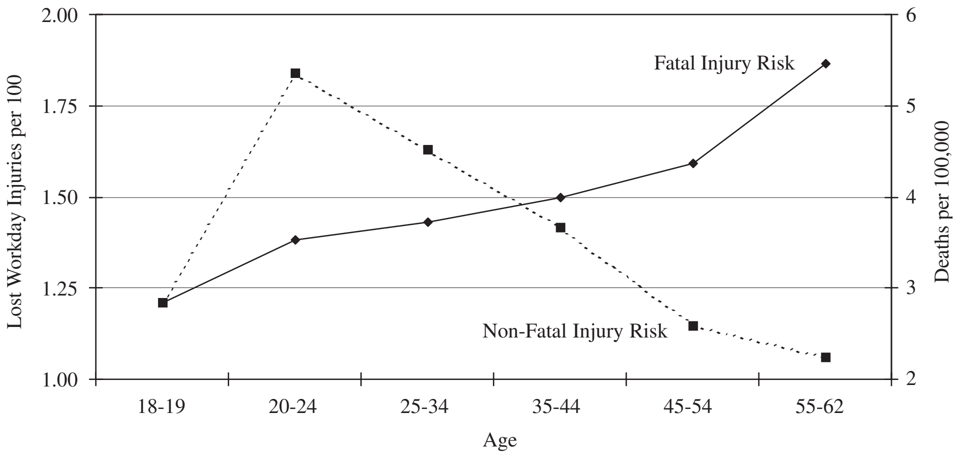

Fig. 1. Age-specific fatal and nonfatal injury risks, 1992–1997. *Notes*: Constructed by authors with mortality risk data from the BLS Census of Fatal Occupational Injuries, 1992–1997, injury risk data for lost workday injuries from the BLS Injuries, Illnesses, and Fatalities Program, 1992–1997, and CPS MORG data files, 1992–1997.

estimate worker populations for each cell in the mortality data. The subsequent mortality risk is averaged over the 1992–1997 period to minimize any potential distortions associated with catastrophic mortality incidents in any 1 year and to have a better measure of the underlying risks for industry–age groups with infrequent deaths.[14] Our injury risk measure also varies by age, and we constructed it in an identical manner for each 2-digit industry and for each of the age groups listed above. The injuries reported for that cell were those that were sufficiently severe to lead to at least one lost workday, or what is usually termed lost workday injuries. For both job risk variables, there are 632 distinct industry–age group risk values, which is among the most refined risk measures used in any hedonic wage study in the literature.

Injury and mortality risks are not constant across a worker's life cycle, making the age adjustment in the risk variables potentially important. Fig. 1 illustrates the general age-related patterns that will be borne out in more refined breakdowns as well. The risk of nonfatal injury rises to a peak for the age 20–24 and declines steadily thereafter. The lowest probability of injury shown in Fig. 1 is for workers aged 55–62. In contrast, the fatality risk per 100,000 workers rises throughout the different age ranges, reaching a peak for the 55–62 age group. Older workers consequently are much less susceptible to injury but, if injured, are more likely to die.

The overall spirit of this age-related pattern is also reflected in industry risk measures. Fig. 2 depicts the injury risks in major 1-digit industries by age group. In almost every industry, the probability of a worker incurring a job-related injury rises until age 20–24 or age 25–34, and then decreases with that worker's age. In the case of manufacturing workers, for example, workers aged 20–24 have an annual lost workday injury frequency rate of 3.3 per 100, as compared to 1.7 per 100 for workers aged 55–62. This declining pattern of risk with age may reflect selection into safer jobs within industries by older and more experienced workers. The injury risk–age relationship may also reflect the benefit of experience that enables older workers to self-protect and mitigate their exposure to accident risks.

The mortality risk age trend by industry follows the same rising pattern as in the aggregative results in Fig. 1. As Fig. 3 indicates, the job fatality risks peak for workers aged 55–62 in all seven major industries presented in this figure.[15] Whereas, lost workday injury risks for manufacturing workers decline steadily with

[14]We have also constructed mortality risk measures based on 3-digit industry for the 1992–1997 period that do not vary by age for comparison purposes.

[15]We have omitted the mining industry from Figs. 1 and 3. Mining risk levels greatly exceed those for the industries shown, and inclusion of mining would obscure the trends in the other industries. For injury risks in the mining industry, the probability of an injury is always decreasing in age. For mortality risks, the probability of death in the mining industry peaks in the early 20s, but is increasing in age for individuals 35–62-years old. We have also omitted the mortality rate for those aged 18–19 in the financial sector in Fig. 3 because the small cell size does not satisfy BLS publication criteria.

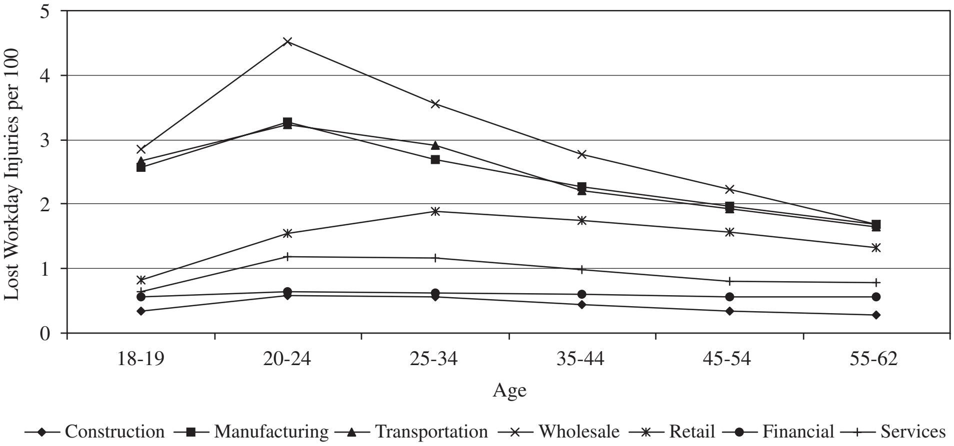

Fig. 2. Lost workday injury risk by age and 1-digit industry, 1992–1997. *Notes*: Constructed by authors with injury risk data for lost workday injuries from the BLS Injuries, Illnesses, and Fatalities Program, 1992–1997 and CPS MORG data files, 1992–1997.

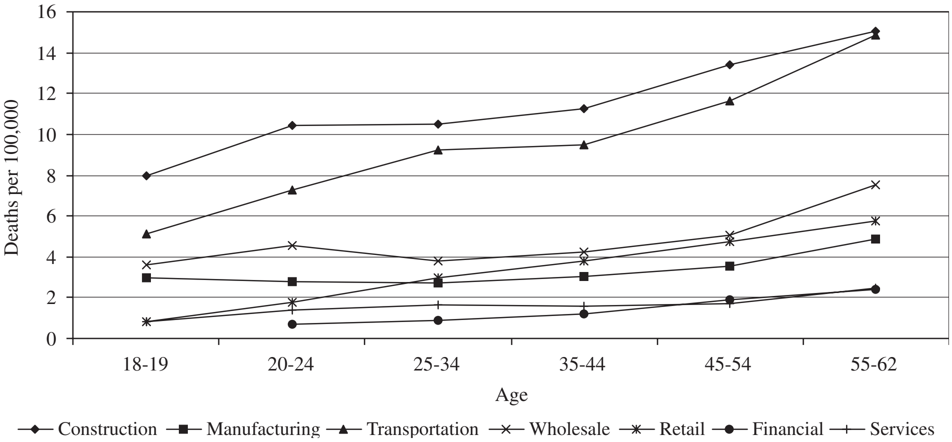

Fig. 3. Mortality risk by age and 1-digit industry, 1992–1997. *Notes*: Constructed by authors with mortality risk data from the BLS Census of Fatal Occupational Injuries, 1992–1997 and CPS MORG data files, 1992–1997. The cell size for the 18–19 age group in the financial sector does not satisfy the BLS publication criteria.

age, the annual fatality risk rate increases with age, as it is 2.8 per 100,000 for workers aged 20–24 and 4.8 per 100,000 for workers aged 55–62. This positive relationship between job-related fatality risks and age is not the result of industry averages failing to reflect accurately the age-related differences within types of jobs. Even within occupations, the mortality risk peaks for workers age 55–62, as shown in Fig. 4.[16] Mortality risks also increase with age for different causes of the injury, such as gunshot wounds, asphyxiation, electrocution, intracranial injuries, burnings, drownings, etc. There is also a positive age–fatality risk relationship based on the type of injury event, such as transportation accidents, falls, fires and explosions, assaults, and exposure to harmful substances. Irrespective of the perspective, job fatality risks are increasing with worker age.

[16]Our subsequent empirical analysis uses an industry–age breakdown of cells rather than occupation–industry–age because the more refined breakdown results in a large number of cells with zero fatalities. Indeed, using 1-digit occupation/2-digit industry/age group breakdowns would lead to approximately 6200 cells to capture an average of about 6600 annual fatalities. We use a risk measure based on age and industry in lieu of age and occupation. This is consistent with most of this literature that usually focuses on industry-aggregated fatality risks. Viscusi [44] reports that an industry-based risk measure yielded stable and statistically significant coefficient estimates for the relevant risk measures, but estimates using occupation-based risk measures were not successful because of the greater measurement error in workers' reporting of occupation.

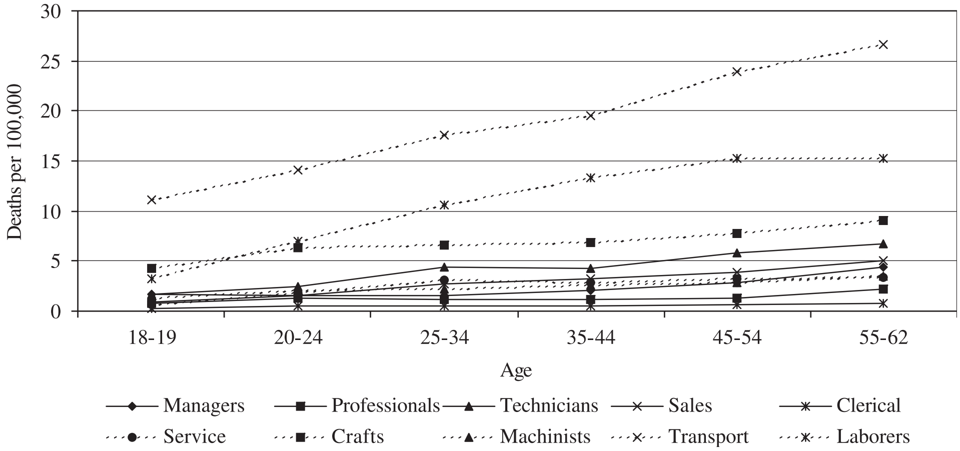

Fig. 4. Mortality risk by age and 1-digit occupation, 1992–1997. *Notes*: Constructed by authors with mortality risk data from the BLS Census of Fatal Occupational Injuries, 1992–1997 and CPS MORG data files, 1992–1997.

Table 1
Age profiles of mortality risk measures by 3-digit industry and by age group by 2-digit industry

Industry	18–19	20–24	25–34	35–44	45–54	55–62
A. 3-digit industry risk measure						
Construction	11.43	11.43	11.43	11.43	11.43	11.43
Manufacturing	3.77	3.47	3.16	3.00	3.13	3.13
Transportation	11.19	10.23	9.96	9.04	8.34	10.04
Wholesale	4.95	4.90	4.70	4.90	5.06	5.23
Retail	2.98	2.97	3.02	3.23	3.13	3.19
Financial	*	1.18	1.23	1.23	1.32	1.37
Services	2.42	1.98	1.63	1.50	1.28	1.34
B. Age group by 2-digit industry risk measure						
Construction	8.00	10.47	10.50	11.27	13.41	15.05
Manufacturing	3.14	3.00	2.82	3.12	3.56	4.83
Transportation	4.98	6.85	8.70	9.04	10.60	14.42
Wholesale	4.11	4.62	3.80	4.27	5.09	7.49
Retail	0.92	1.99	3.01	3.95	4.83	5.92
Financial	*	0.64	0.87	1.13	1.78	2.21
Services	1.05	1.54	1.61	1.55	1.58	2.33

Notes: Panel A estimates constructed by matching 3-digit industry average mortality risk measures for 1992–1997 period to the 1998 CPS MORG sample used in regressions in Section 4. Construction is disaggregated only to the 1-digit industry level in the CPS MORG. Panel B estimates constructed by matching age group by 2-digit industry average mortality risk measures for 1992–1997 period to the 1998 CPS MORG sample used in regressions in Section 4. All measures are mortality rates per 100,000 full-time workers.
*The cell size for the 18–19 age group in the financial sector does not satisfy the BLS publication criteria.

The importance of considering age-specific fatality data is indicated by the data in Table 1, which presents the average worker fatality risk by age and 1-digit industry.[17] Panel A presents occupational mortality risk averaged over workers assigned their risk by 3-digit industry. Panel B presents mortality risk averaged over workers assigned their risk by age group and 2-digit industry. In each instance, the industry fatality risk patterns in Panel A are fairly invariant with respect to age, but the age-specific fatality rates increase with age. This relationship is also borne out in Fig. 5, which presents the age–fatality risk counterpart to Fig. 1 using both the 3-digit industry fatality risk and the risk by age and 2-digit industry. Taking into account the industry

[17]We have omitted the mortality rate for those aged 18–19 in the financial sector in Table 1 because the small cell size does not satisfy BLS publication criteria. We included these risk measures in all regressions presented in this paper.

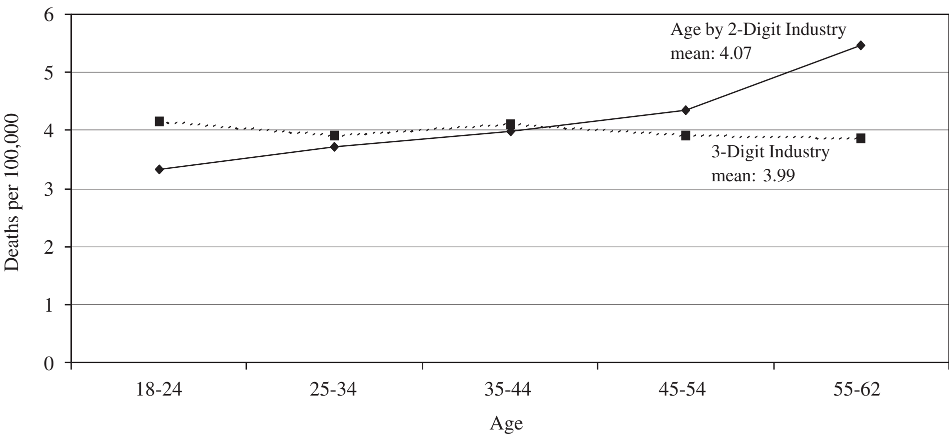

Fig. 5. Mortality risk by age based on 3-digit industry and age group by 2-digit industry risk measures, 1992–1997. *Notes*: Constructed by authors with mortality risk data from the BLS Census of Fatal Occupational Injuries, 1992–1997 and CPS MORG data files, 1992–1997, and matched to the 1998 CPS MORG worker sample used in the regressions presented in Section 4.

mix of workers, but ignoring the age-specific risk within industry, leads to a flat age–risk profile that fails to reflect the substantially increased fatality risk that is found once one accounts for the differential risk faced by older workers.

Older workers are less likely to be injured on the job than younger workers, but given that they are injured, they are much more likely to die from that job-related accident. Older workers apparently are more vulnerable to serious injury from any particular incident. The high fatality rates for older workers consequently do not appear to be the result of older workers sorting themselves into very risky jobs but rather that older workers are more prone to serious injury for any given injury risk level.[18]

These findings are quite pertinent to the question of whether labor market estimates of VSL understate the appropriate benefit measure for EPA policy purposes. The EPA [16] hypothesizes that VSL may not decline with age because older workers are more risk averse and select into safer than average jobs (p. 77). We find that this claim regarding age differences in job fatality risks is not correct. Older workers are not working in jobs that are relatively safer to them than to their younger colleagues. Since older workers are in positions that are more dangerous than the average job, VSL estimates based on a linear representation of occupational mortality risk may *over-estimate*, not under-estimate, older workers' VSLs. Section 4 explicitly addresses this question empirically.

3. Modeling the age–VSL hedonic labor market

Our estimation of wage–risk trade-offs will follow the structure of the conventional hedonic labor market approach, but with one principal exception. Based on the apparent differences in risk vulnerability by age group, the offer curves facing older workers should be different from those for younger workers. This formulation parallels the theoretical development in Viscusi and Hersch [48] for smokers and nonsmokers, where smokers were offered lower wages and faced flatter offer curves than do nonsmokers.[19] The difference here is that because of their higher overall productivity, older workers will receive a higher base wage than younger workers, but because of their lower safety-related productivity they will face a flatter compensating differential gradient. Age is a monitorable personal attribute, so that it is quite feasible to distinguish workers based on that characteristic and provide different offer curves.

[18]Accident rates of the job often reflect similar patterns, as there is an increase in deaths from falls, automobile accidents, and other risks for the most senior age groups. While most fatal accident rates for the elderly are higher than for younger groups, the relationship between age and accidents is not always monotonic. For example, motor vehicle accidents have a U-shaped pattern, with the lowest rate being for 45–64-year olds. Death rates from falls steadily rise with age. See the National Safety Council [34], especially pp. 8–12 for age-related accident statistics.

[19]A similar approach was applied to black and white workers in Viscusi [45].

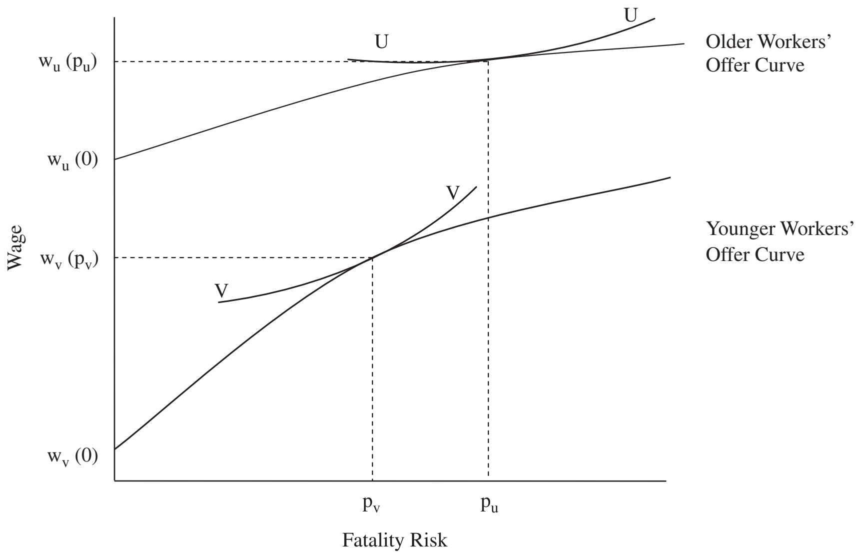

Fig. 6. Compensating differentials for older and younger workers.

Fig. 6 illustrates the nature of the hedonic equilibrium in which older workers and younger workers are segmented into different markets. The market offer curve for each group reflects the outer envelope of the individual firm offer curves. These curves have a positive slope because firms can maintain the same profit level with a higher wage if the level of investment in safety is less. As hypothesized here, the offer curve for older workers begins at a wage $w_u(0)$ for a riskless job. Because older workers have more experience, their offer curve has a higher intercept than that for younger workers, for whom the wage offer for a riskless job is given by $w_v(0)$. The offer curves drawn in Fig. 6 show a flatter slope for older workers. Although older workers receive a compensating differential for increases in fatality risk, the wage–risk gradient offered is less because much of the risk arises due to their greater personal vulnerability rather than the inherent riskiness of the job. Market equilibrium consists of the points on the highest attainable constant expected utility locus for each worker. The optimal job choice for the younger worker is risk p_V and wage $w_v(p_v)$, where VV is the highest achievable constant expected utility locus. The younger worker receives compensating differential $w_v(p_v)$–$w_v(0)$ for risk p_v. Similarly, the older worker reaches the highest constant expected utility locus UU at risk p_u and wage $w_u(p_u)$. The older worker receives compensating differential $w_u(p_u)$–$w_u(0)$ for risk p_u.

The estimate of the VSL is based on the slope at the point of tangency of the market opportunities locus and the constant expected utility locus. Reflecting the joint influence of supply and demand, older workers will exhibit a lower VSL for the situation drawn in Fig. 6. If such a result is observed empirically, it does not necessarily imply that Fig. 6 is an accurate reflection of the market. Because older workers face higher fatality risks than do younger workers, even if their market offer curve was not flatter but was a parallel upward shift of the offer curve for younger workers, they would exhibit a lower VSL because they are farther along on that curve.

As a result, we propose a different, stronger test. In particular, we will examine the compensating differential received by older workers. Since $p_u > p_v$, if the offer curves differed only by a constant intercept shift term, then it will always be the case that

$$w_u(p_u) - w_u(0) > w_v(p_v) - w_v(0). \tag{1}$$

If older workers receive a lower compensating differential for fatality risk $p_u > p_v$, then they must face a flatter wage–risk gradient. Thus, suppose we observe empirically that

$$w_u(p_u) - w_u(0) < w_v(p_v) - w_v(0). \tag{2}$$

If the curves only differed by a parallel upward shift of c to reflect older workers' greater productivity, then

$$w_u(0) = w_v(0) + c \tag{3}$$

and

$$w_u(p_u) = w_v(p_u) + c. \tag{4}$$

Then Eq. (2) becomes

$$w_v(p_u) + c - w_v(0) - c < w_v(p_v) - w_v(0), \tag{5}$$

or

$$w_v(p_u) < w_v(p_v), \tag{6}$$

which contradicts the assumption of an upward-sloping market offer curve, since $p_u > p_v$.

To provide for the possibility of separate market equilibria, we estimate a hedonic wage equation that allows for the coefficient for job risks and other factors to vary across our different age groups. In doing so, we also introduce the new risk measures of age-specific fatality risks and age-specific nonfatal job risks. Otherwise, we adopt the canonical hedonic wage regression approach in which we regress the natural logarithm of the after-tax hourly wage or labor compensation on a set of worker and job characteristics, mortality risk, injury risk, and a measure of workers' compensation. Many studies, however, have been more parsimonious, omitting nonfatal injury risks and workers' compensation because of the difficulty of estimating statistically significant coefficients for three risk-related variables. As a result, we show both sets of results here. The specification takes the following form:

$$\ln(w_i) = \alpha + \sum_{j=1}^{4} \delta_j \text{age}_j + \sum_{j=1}^{5} \text{age}_j H_i' \beta + \sum_{j=1}^{5} \gamma_{1j} \text{age}_j p_i + \sum_{j=1}^{5} \gamma_{2j} \text{age}_j q_i + \sum_{j=1}^{5} \gamma_{3j} \text{age}_j q_i \text{WC}_i + \varepsilon_i, \tag{7}$$

where w_i is the worker i's hourly after-tax wage rate, H is a vector of personal characteristic variables for worker i, age_j are the indicator variables for the five age groups, 18–24, 25–34, 35–44, 45–54, and 55–62, p_i is the fatality risk associated with age–industry cell for worker i's job, q_i is the nonfatal injury risk for the age–industry cell for worker i's job, WC_i is the workers' compensation replacement rate payable for a job injury suffered by worker i, and ε_i is the random error reflecting unmeasured factors influencing worker i's wage rate.

We calculated the workers' compensation replacement rate on an individual worker basis, taking into account state differences in benefits and the favorable tax status of these benefits. We use the benefit formulas for temporary total disability, which comprise about three-fourths of all claims, and have formulas similar to those for permanent partial disability.[20] The terms α, δ, β, γ_1,γ_2, and γ_3 represent parameters to be estimated. The vector of personal characteristics included is quite extensive and is reported in Table A1 of the Appendix A.

It is instructive to compare our estimation equation to that in the study by Smith et al. [42]. The main common feature is that both of our analyses are based on semi-logarithmic wage equations that include age group interactions with the fatality risk variable. Their study used the Health and Retirement Study data so was also able to include a measure of worker risk aversion and controls for sample selection, neither of which is included in our study.[21] Distinctive aspects of our analysis based on the CPS is that we use a different fatality risk variable (the CFOI risk by 2-digit industry and age rather than the earlier BLS 2-digit industry

[20]The procedures for calculating the workers' compensation benefit variable are discussed in more detail in Viscusi [44], which also provides supporting references.

[21]The CPS data that we used did not include variables that permitted us to identify these selection issues. Because we terminate our sample at age 62, retirement and reduced work hours is not a major issue. Indeed, the average hours worked per week for our oldest age group is 42.3, as compared to the sample average of 42.5. The CPS MORG datasets only provide hours worked per week, not hours worked per year or estimates of weeks worked per year. In addition, as Altonji and Blank [5] and others have observed, selection corrections have never had a major effect on wage equations for men and in recent data have not significantly affected the wage equation estimates for women.

risk), we include both a nonfatal risk variable and a workers' compensation variable, and we permit all coefficients to vary with age, not just the fatality risk.

Assuming 2000 hours worked per year and a log-linear specification, the value of a statistical life for the typical worker in age group j is given by

$$\hat{\text{VSL}}_j = \hat{\gamma}_{1j}\bar{w}_j 2,000 \times 100,000. \tag{8}$$

To determine if the VSL estimates are statistically different, we evaluate the following null hypotheses of pairwise VSL comparisons of age groups i and j:

$$H_0^{ij} : \hat{\text{VSL}}_i = \hat{\text{VSL}}_j, \quad i \neq j. \tag{9}$$

We test these hypotheses with a variant of the Wald test:

$$W_{ij} = (\hat{\text{VSL}}_i - \hat{\text{VSL}}_j)^2 \left[\hat{\text{var}}(\hat{\text{VSL}}_i) + \hat{\text{var}}(\hat{\text{VSL}}_j) - 2\hat{\text{cov}}(\hat{\text{VSL}}_i, \hat{\text{VSL}}_j)\right]^{-1}. \tag{10}$$

We estimate the VSL variances accounting for the fact that both the age group wage and the estimated age group mortality risk coefficient are random variables following Goodman [18] and for the covariance among the mortality risk coefficients following Bohrnstedt and Goldberger [9].

4. Regression estimates and implications

Our empirical estimates match the age–industry risk measures with the 1998 US Current Population Survey Merged Outgoing Rotation Group data file. We have employed a number of screens in constructing our sample for analysis. The sample excludes agricultural workers and members of the armed forces. We have excluded workers younger than 18 and older than 62, those with less than a 9th grade education, workers with an effective hourly labor income less than \$4.75, and less than full-time workers, which we defined as 35 hours per week or more. The lost workday injury frequency rate for the sample is 1.4 per 100 and the annual fatality rate is 4.1 per 100,000, each of which is in line with national norms. Appendix A Table A1 summarizes the descriptive statistics of the key variables in our data set.

To account for the influence of occupational injury insurance on the compensating differentials for occupational injuries and fatalities, we have included the expected workers' compensation replacement rate in all regression specifications. We calculated this variable for each individual based on the respondent's characteristics and state benefit formulas. The variable represents the interaction of a worker's injury rate and that worker's estimated workers' compensation wage replacement rate based on the worker's wage, state of residence, and estimated state and federal tax rates. The replacement rate variable accounts for the favorable tax status of workers' compensation benefits. Since the expected replacement rate is a function of a worker's wage, this variable could be endogenous in our regressions although tests for endogeneity were not conclusive.[22] We have conducted two-stage least-squares regressions including an instrumental variables estimate of the expected workers' compensation replacement rate. These specifications yield very similar coefficient estimates, estimated variances, and estimated VSLs to the OLS specifications.

We present estimates of hedonic wage equations in which each specification permits all parameters to vary across these groups. Table 2, Panel A presents the log-linear specification including a fatality risk variable as the only risk variable in the equation, as is common in the literature, while Panel B adds the nonfatal injury risk variable and expected workers' compensation variable. All variables have the predicted signs, with there being compensating differentials for fatal and nonfatal risks, and there is a wage offset for higher expected workers' compensation benefits. The bottom row of each panel gives the estimated VSL for each subsample.

[22] We used the state's average workers' compensation benefit and an indicator variable for whether the state has a Republican governor as instruments. These appear to be valid instruments: they are both statistically significant determinants of the replacement rate (at the 1% level) while controlling for all other explanatory variables in the hedonic wage regression, neither variable offers any statistically meaningful explanation of the log (wage) (statistical significance at the 30% and 45% levels), and a test of overidentifying restrictions indicates that the instruments are not correlated with the error term (test statistic = 0.234). While we have presented these two-stage least squares results, Hausman tests do not support the conclusion of endogeneity. The test statistic for the workers' compensation replacement rate is 1.42.

Table 2
Value of a statistical life based on age–industry job mortality risk, 1998 and age group by 2-digit industry risk measure

	18–24	25–34	35–44	45–54	55–62
A. Mortality risk specification					
Death rate, age–industry	0.00528	0.00484	0.00450	0.00274	0.00211
	(0.00084)*	(0.00049)*	(0.00049)*	(0.00049)*	(0.00065)*
	[0.0011]*	[0.00072]*	[0.00074]*	[0.00066]*	[0.00075]*
VSL	\$8.34	\$11.27	\$12.32	\$7.81	\$5.86
Age group	H_0: pair-wise tests of equality of VSL estimates, F-statistics				
18–24	—	2.81	4.39**	0.078	1.23
25–34	—	—	0.35	3.74†	6.48*
35–44	—	—	—	5.42**	8.24*
45–54	—	—	—	—	0.73
B. Mortality risk, nonfatal injury risk, workers' compensation specification					
Death rate, age–industry	0.00408	0.00288	0.00328	0.00190	0.00137
	(0.0068)*	(0.00045)*	(0.00044)*	(0.00046)*	(0.00058)**
	[0.0093]*	[0.00070]*	[0.00076]*	[0.00072]*	[0.00078]†
VSL	\$6.45	\$6.72	\$8.99	\$5.42	\$3.81
Age group	H_0: pair-wise tests of equality of VSL estimates, F-statistics				
18–24	—	0.032	2.47	0.37	1.87
25–34	—	—	2.02	0.60	2.31
35–44	—	—	—	4.04**	6.67*
45–54	—	—	—	—	0.61

Notes: Dependent variable: natural logarithm of after-tax hourly labor income. VSLs expressed in millions of year 2000 dollars. $N = 120{,}008$. Specification includes nine 1-digit occupation indicator variables, eight regional indicator variables, demographic variables, nonfatal injury risk (by age group by 2-digit industry), and workers' compensation expected replacement rate. Robust (White) standard errors are presented in parentheses and standard errors accounting for within-group correlation are presented in brackets.
*, **, † indicates statistical significance at 1%, 5%, and 10% levels.

For all regression results, we report both White heteroskedasticity-corrected standard errors in parentheses as well as robust and clustered standard errors accounting for potential within-group correlation of residuals in brackets. Assigning individuals in our sample mortality and injury risk variables' values based on 2-digit industry and age group, and the workers' compensation replacement rate variable's values based on 2-digit industry, age group, and state, may result in industry, age group, and/or state-level correlation of residuals in the regressions. The reported within-group adjusted standard errors reflect a grouping of the observations based on 2-digit industry, age group, and state. While this within-group correlation correction generates larger standard errors, and thus larger confidence intervals, they do not change any of the qualitative determinations of statistical significance. Most studies in the hedonic wage literature have not accounted for this within-group correlation, and consequently, may tend to overstate the significance of the risk premium estimates.[23]

The VSL pattern in Panel A of Table 2 rises from \$8.3 million for workers aged 18–24 to a peak of \$12.3 million for workers aged 35–44, and then a steady decline to a value of \$5.9 million for workers aged 55–62. The estimated VSL for the 55–62 age group is statistically different at the 1% level from the estimated VSLs for workers in the 25–34 and 35–44 age groups (F-statistics of 6.48 and 8.24, respectively). The estimated VSL for the 45–54 age group is statistically lower than the 35–44 age group VSL at the 5% level (F-statistic of 5.42). There is also an inverted U-shaped relationship for the more comprehensive specifications in Panel B of Table 2. Inclusion of the two other risk measures reduces the VSL levels somewhat, which rise from \$6.4 million for workers aged 18–24 to \$9.0 million for workers aged 35–44, then decline to \$3.8 million for workers aged 55–62. The oldest age group is again statistically different at the 1% level from the 35–44 age group (F-statistic of 6.67) and the 45–54 age group has a statistically lower VSL than the 35–44 age group at the 5% level

[23] Refer to Hersch [21], Viscusi and Hersch [48], Leeth and Ruser [30], and Viscusi [44,45] as examples of the first papers in this literature that account for this type of correlation.

Table 3
Value of a statistical life based on industry job mortality risk, 1998 and 3-digit industry risk measure

	18–24	25–34	35–44	45–54	55–62
A. Mortality risk specification					
Death rate, industry	0.00346	0.00389	0.00279	0.00305	0.00374
	(0.00067)*	(0.00044)*	(0.00041)*	(0.00048)*	(0.00081)*
	[0.00082]*	[0.00070]*	[0.00061]*	[0.00061]*	[0.00096]*
VSL	$5.46	$9.06	$7.63	$8.69	$10.38
Age group	H_0: pair-wise tests of equality of VSL estimates, *F*-statistics				
18–24	—	5.91**	1.94	3.44†	3.94**
25–34	—	—	0.87	0.045	0.29
35–44	—	—	—	0.35	1.20
45–54	—	—	—	—	0.41
B. Mortality risk, nonfatal injury risk, workers' compensation specification					
Death rate, industry	0.00323	0.00191	0.00167	0.00222	0.00216
	(0.00063)*	(0.00038)*	(0.00035)*	(0.00041)*	(0.00068)*
	[0.00081]*	[0.00063]*	[0.00051]*	[0.00054]*	[0.00080]*
VSL	$5.10	$4.44	$4.57	$6.32	$6.00
Age group	H_0: pair-wise tests of equality of VSL estimates, *F*-statistics				
18–24	—	0.25	0.15	0.62	0.18
25–34	—	—	0.0094	1.62	0.56
35–44	—	—	—	1.32	0.46
45–54	—	—	—	—	0.020

Notes: Dependent variable: natural logarithm of after-tax hourly labor income. VSLs expressed in millions of year 2000 dollars. $N = 120{,}008$. Specification includes nine 1-digit occupation indicator variables, eight regional indicator variables, demographic variables, nonfatal injury risk (by 2-digit industry), and workers' compensation expected replacement rate. Robust (White) standard errors are presented in parentheses and standard errors accounting for within-group correlation are presented in brackets.
*, **, † indicates statistical significance at 1%, 5%, and 10% levels.

(*F*-statistic of 4.04). This inverted U-shape is consistent with several models of life cycle decisions in a world of imperfect capital and insurance markets. These findings also indicate that there is empirical support for a VSL senior discount relative to prime age groups (refer to Aldy and Viscusi [2] for similar empirical results for additional years).

For comparison purposes, Table 3 reports VSL estimates by age group but where the risk measures are specific to the industry only, as in previous studies, rather than being based on age–industry risk measures. These regressions use the fatality risk variable by 3-digit industry group, as in Table 1. These VSL estimates are higher and do not turn down with age. The Panel A results show a rising VSL pattern that increases from $5.5 million for those aged 18–24 to $10.4 million for those aged 55–62. The increase in VSL with age parallels the findings in Smith et al. [42], which used a 2-digit industry level risk measure and, as with the Panel A results, also included only a fatality risk measure. Thus, our findings in Table 2 may differ from their estimates largely due to our use of an age-specific risk measure. In Panel B, the VSL levels vary from $4.4 million to $6.3 million, so that the inverted U-shaped VSL pattern over the life cycle is not evident. The estimated VSL for the oldest age group cannot be statistically discerned from the VSLs of any of the other age groups in either regression specification.

The higher level of the VSL estimates in Panel A of Table 3 is not unprecedented.[24] Moreover, the higher VSL estimates for Table 3 as compared to Table 2 are of interest in their own right, as these findings are consistent with theoretical models by Shogren and Stamland [40], indicating that failure to account for unobserved heterogeneity in safety-related productivity will lead to overestimates of VSL.

The life-cycle structure of VSL in Table 3 differs as well, as it either rises with age or is flat for the regression estimates based on the industry-based fatality risk estimates. This difference arises because the measurement

[24]Viscusi [44] also reports similar high estimates for industry-based estimates.

Table 4
Age-specific job mortality risk and compensating differentials

Age group	Average mortality risk (per 100,000)	Average compensating differential ($ per hour; 2000$)	Average compensating differential ($ per hour; 2000$)
18–24	3.34	0.15	0.12
25–34	3.71	0.21	0.13
35–44	3.99	0.25	0.18
45–54	4.36	0.17	0.12
55–62	5.46	0.16	0.10
Specification		Age–industry mortality risk (Table 1A)	Age–industry mortality risk, injury risk, expected workers' Compensation Replacement rate (Table 1B)

Notes: Average mortality risk estimated from the age group-specific sub-sample of the sample used in this paper. The average compensating differential is based on the age group-specific coefficient estimate on the mortality risk variable and age group-specific average wage.

error in the fatality risk measure is not random. As Figs. 1, 3, and 4 indicate, older workers have a higher job-related fatality risk. Estimates based on the industry level risk are based on a specification in which the value of the risk measure is understated (Fig. 5, Table 1), leading to an overestimate of the fatality risk parameter. Taking into account the age variation in risk levels is not a minor refinement, but has a substantial effect on the level and age pattern of VSL estimates.

To examine whether the lower VSL estimates for older workers imply that they face different market offer curves, one must ascertain whether the total compensating differential for groups with greater risk is higher than for groups facing lower risk, as would be the case if the wage–risk gradient was the same for all groups. Table 4 reports the mortality risk for each age group and the fatality risk compensating differential estimates based on the estimate in Panels A and B of Table 2. The highest risk group is workers aged 55–62, but they receive lower wage compensation for fatality risks than all (three) other age groups with lower risk based on Panel B's (A's) specification. The second highest risk group, workers aged 45–54, also receive wage compensation below that of two age groups with lower risk. No other age group in Table 4 has a higher risk and lower compensating differential than other age groups. These findings show that workers aged 45–54 and 55–62 face flatter wage–risk trade-offs than do younger workers, which is consistent with their greater risk vulnerability.

Our estimated VSL for the 55–62 age group is $3.8 million, as compared to the peak VSL of $9 million for the prime-aged workers (35–44 age group). Assume for the purposes of illustration that the same VSL levels for those aged 55–62 apply to those over 65. There is no reason to believe that the post-65 values will be higher, and they may well be lower so that this illustration understates the extent of the senior discount.

Based on this approach, we have re-evaluated the monetary benefits associated with the mortality risk reduction estimates for the Clear Skies Initiative. We do not assume a discrete drop in the VSL at any arbitrary age, as the EPA did in its alternative estimate.[25] Neither theoretical analysis nor our empirical work justifies a constant VSL until some age, a discrete drop, and then a constant, lower VSL for those older than this threshold age. The senior discount debate should not be cast as simply how much to monetize a change in the elderly's mortality risk. Instead, the benefits transfer should assign willingness to pay for risk reduction to all age groups consistent with what they reveal (or state) in other contexts, such as our labor market analysis. As the first paper to estimate and present age-specific VSLs for most of the life cycle, we can replicate the Clear Skies Initiative analysis with age-specific VSLs starting at age 18.

We apply our age-specific VSLs to estimates of age-specific mortality reduction. For the mortality reduction for those in 18–64 for whom EPA does not provide age-specific change in mortality, we assume that the

[25]EPA [15] applied a "single age adjustment based on whether the individual was over or under 65 years of age at the time of death" (p. 35).

mortality reductions are distributed evenly by age and use the estimated age-specific VSLs for this population. We apply the VSL for the 55–62 age workers to the 65 and older population's reduced mortality, recognizing that doing so may lead to estimates that are an upper bound on benefit values.

Applying our VSL estimates in such a manner to the mortality reduction estimates presented in EPA's 2002 Clear Skies Initiative Technical Addendum on the benefits analysis yields total mortality risk reduction benefits for the 65 and older population that are 40% lower than the EPA's constant VSL analysis and 4% lower than its own senior discount analysis (Aldy and Viscusi [3]). The total mortality risk reduction benefits for the 18–64 population in our re-evaluation of the Clear Skies Initiative differ by less than 1% from the estimated benefits presented by EPA in both its constant VSL and senior discount analyses.

5. Conclusion

While adjusting benefit levels for environmental policies to account for age differences is controversial, from an economic standpoint taking age into consideration has a strong theoretical basis. For policy evaluation generally, the appropriate benefits measure is society's willingness to pay for the risk reduction, and these values may vary with age, as theory suggests is generally the case. While analyses of perfect markets suggest a steadily declining VSL with age, simulations based on imperfect markets have often suggested an inverted U-shaped relationship.

Our empirical analysis focused on labor market estimates of VSL, which has been the principal source of data now relied upon by EPA and other government agencies to estimate VSL more generally. The main innovations of our approach were the use of the first measure of fatality risk and nonfatal injury risk that account for age differences in risk and the estimation of separate hedonic market equilibria by age group. Because of the greater risk vulnerability of older workers, the market offer curves for older workers should be flatter than those for younger workers. Our empirical analysis indicates that older workers do face a different gradient for compensating differentials and that the lower observed VSL reflects the joint influence of different market opportunities as well as their choice of jobs along the market opportunities locus.

While older workers do have lower estimated VSLs than the entire working population, the decline in VSL is not proportional to remaining life expectancy. The VSL for workers aged 55–62 is $3.8 million, which is below the peak estimated VSL of $9.0 million for those aged 35–44, and less than the estimated VSL for the youngest age group of $6.4 million. While these and subsequent other estimates will refine the age−VSL relationship, it is clear that it is important to account for differences in individual productivity in producing safety and that the age−VSL relationship is not flat or steadily declining, but rather follows an inverted U-shape.

Appendix A

Table A1 presents descriptive statistics for the sample.

Table A1
Present descriptive statistics for the sample

Variable	Description	Mean (standard deviation)
Log (wage)	Natural logarithm of after-tax hourly wage or hourly equivalent of salary (2000$)	$2.42 (0.50)
Age	Age of worker in years	38.99 (10.84)
Black	Indicator variable for whether worker is black	0.10 (0.30)
Native American	Indicator variable for whether worker is Native American	0.011 (0.11)
Asian	Indicator variable for whether worker is Asian	0.040 (0.20)
Hispanic	Indicator variable for whether worker is Hispanic	0.087 (0.28)
Female	Indicator variable for whether worker is female	0.45 (0.50)
Education	Number of years of education	14.13 (2.36)
Married	Indicator variable for whether worker is married	0.60 (0.50)

Table A1 (*continued*)

Variable	Description	Mean (standard deviation)
Union member	Indicator variable for whether worker is a union member	0.16 (0.37)
Public sector job	Indicator variable for whether worker is employed in a public sector job	0.062 (0.24)
Urban resident	Indicator variable for whether worker resides in an urban area	0.79 (0.41)
Mortality risk	Annual occupational mortality risk, per 100,000 full-time workers (age–industry measure)	4.07 (5.31)
	Annual occupational mortality risk, per 100,000 full-time workers (industry measure)	3.99 (5.82)
Injury risk	Annual nonfatal injury risk, per 100 full-time workers (age–industry measure)	1.41 (1.26)
	Annual nonfatal injury risk, per 100 full-time workers (industry measure)	1.40 (1.21)
Workers compensation replacement rate	Injury risk × expected workers' compensation replacement rate for the worker in his or her state of residence (age–industry measure)	0.87 (0.82)
	Injury risk × expected workers' compensation replacement rate for the worker in his or her state of residence (Industry measure)	0.86 (0.77)

Notes: $N = 120{,}008$.

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