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ADJUSTING THE VALUE OF A STATISTICAL LIFE FOR AGE AND COHORT EFFECTS

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Abstract—To resolve the theoretical ambiguity in the effect of age on the value of statistical life (VSL), this article uses a novel, age-dependent fatal risk measure to estimate age-specific hedonic wage regressions. VSL exhibits an inverted-U-shaped relationship with age. In the year 2000 cross section, workers' VSL rises from \$3.7 million (ages 18–24) to \$9.7 million (35–44), and declines to \$3.4 million (55–62). Controlling for birth-year cohort effects in a minimum distance estimator yields a peak VSL of \$7.8 million at age 46, and flattens the age-VSL relationship. The value of statistical life-year also follows an inverted-U shape with age.

I. Introduction

INTUITIVELY one might expect that older individuals may value reducing risks to their lives less because they have shorter remaining life expectancy. The commodity they are buying through risk-reduction efforts is less than for younger people. Carrying this logic to its extreme, the value of a statistical life (VSL) would peak at birth and decline steadily thereafter. For models in which consumption is constant over the life cycle, Shepard and Zeckhauser (1984) and Jones-Lee (1989) showed that the VSL should decrease with age.[1] Based on an assumption of constant consumption levels over time, the VSL can be annuitized to create an age-invariant value of a statistical life-year (VSLY). Whether consumption will in fact be time-invariant in such models depends critically on the presence of perfect capital and insurance markets. Empirically, consumption is not constant, as it rises then falls over the life cycle.

Numerous theoretical studies have shown that the age variation in VSL becomes more complex once changes in consumption over time are introduced into the analysis. Changes in consumption levels and wealth over the life cycle influence risk-money tradeoffs in a complex manner. Johansson (2002) concluded that the theoretical relationship between the VSL and age is ambiguous and could be positive, negative, or zero. Other theoretical models that have imposed additional structure on the analysis imply either that there is an inverted-U-shaped relationship between the value of statistical life and age or that VSL decreases with age. The simulations by Shepard and Zeckhauser (1984) show a steadily declining value of life if there are perfect annuity and insurance markets, and an inverted-U age-VSL relationship in an economy with no borrowing or insurance, as do Johansson (1996), Ehrlich and Yin (2005), and Aldy and Smyth (2007).

Empirical evidence based on labor market data may be instructive in resolving the theoretical ambiguity in the age-VSL relationship. Viscusi and Aldy (2003) review eight studies of labor markets in Canada, India, Switzerland, and the United States that included an age-mortality risk interaction term in their hedonic wage analysis. In these studies, labor income (typically hourly wage or hourly equivalent of salary) is regressed on on-the-job mortality risk and its interaction with age, among other determinants of labor compensation. Five studies estimated statistically significant coefficient estimates for the age-risk interaction and all found a negative effect indicating that older workers value risks to their lives less.[2] These results imply implausibly low VSL levels, with negative VSL amounts beginning at ages ranging from 42 to 60.

A series of papers have derived estimating equations from theoretical models of the value of a statistical life that assume workers smooth their lifetime consumption and have constant VSLY over their lifetime. For example, Moore and Viscusi (1988) estimate implicit discount rates on the order of 10% and VSLYs of about \$300,000 from labor market data. Dreyfus and Viscusi (1995) estimate a hedonic automobile model based on a similar structure and find slightly higher discount rates and VSLYs of about \$500,000. The literature deriving these empirical VSLY results assumes that VSLY is constant and that VSL declines monotonically with age.[3]

A third line of research has examined how VSL varies with age using specifications in which VSL can vary over the life cycle in a more flexible manner. The study by Smith et al. (2004) used industry-level Bureau of Labor Statistics (BLS) mortality risk data and estimated fatality risk coefficients for different age categories. They found that VSL increased with age and measures of risk aversion for workers 51–65 years of age. Kniesner, Viscusi, and Ziliak (2006) used BLS Census of Fatal Occupational Injury (CFOI) data for 720 industry-occupation cells in conjunction with a hedonic wage model that incorporated variations in life cycle consumption levels. They found an inverted-U-shaped age-VSL relation that was relatively flat for those 51–65 once changes in consumption over the life cycle are recognized. Viscusi and Aldy (2007) used BLS CFOI fatality risk

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[1] Rosen (1988), Arthur (1981), and Cropper and Sussman (1988) also present simulation results with VSL decreasing with age.

[2] These studies are reviewed in section 8 of Viscusi and Aldy (2003).

[3] Refer to Aldy and Viscusi (2007) for a more detailed review of the empirical literature of how VSLs and VSLYs vary with age.

data by age and industry to estimate VSL levels for different age groups and found an inverted-U-shaped pattern over the life cycle.

Efforts to resolve the age-VSL variation have consequently focused not only on the econometric structure but also on the fatality risk data. With the exception of our companion paper (Viscusi & Aldy, 2007), all labor market studies used fatality risk data that are based on industry averages or industry-occupation averages rather than age-specific values, causing potential biases, where the magnitude of the bias varies with age. If, for example, average industry fatality risks for workers of all ages overstate the risks faced by older workers, the estimated implied VSL amounts for older workers will understate the wage-risk tradeoffs that are actually being made. Our analysis will use fatality risk data by age and industry, creating a more pertinent matching of job risks to worker characteristics.

Our use of a pooled series of cross sections also will provide a different perspective than all previous papers assessing age variations in VSL, which have employed cross-sectional survey data. By using a single cross section, such approaches confound the cohort-specific influence and age-specific effects on the estimated compensating differential. The cohort influence based on the year of birth should have an unambiguous effect on VSL. The VSL has a positive income elasticity of 0.5 to 0.6.[4] Younger workers belong to a later cohort with higher lifetime incomes, so that they will tend to be willing to pay more for a given risk reduction, implying a higher VSL. The pure age effect is less clear-cut. As a worker ages, there are fewer years of remaining life expectancy, implying lower benefits for a given risk reduction, which should reduce the worker's willingness to pay to reduce risk. This effect is unambiguous if capital markets are perfect. In a world with imperfect capital markets, however, lower-income younger workers will not be able to borrow against higher future expected earnings or efficiently insure against idiosyncratic labor income shocks. This influence will depress their VSLs at young ages until borrowing constraints become less stringent, resulting in an age-related VSL trajectory similar to the inverted-U shape of life cycle consumption patterns. Extending the traditional analysis to a pooled series of cross sections will enable us to distinguish age effects from cohort effects. Two separate questions can then be considered: (i) How does the value of life vary with age across the population? and (ii) How do differences in cohorts influence this relationship?

This article extends the previous literature in several respects: (i) use of an age-specific job mortality risk and nonfatal injury risks in our hedonic wage analyses; (ii) estimates of VSL changes over the life cycle by pooling eight years of cross-sectional data; (iii) use of a minimum distance estimator that controls for cohort effects based on year of birth; and (iv) calculation of the variation in VSLY by age rather than imposing an assumption of a constant VSLY. We find that the VSL rises and then falls across the population and over the life cycle, but the shape of the trajectory is different after accounting for cohort effects. In the cross-sectional analysis, the VSL peaks at age 39 and subsequently declines so that the VSL for workers in their early 60s has values of about \$2 million. In the cohort-adjusted analysis, the VSL peaks at age 46, and experiences a more modest decline to about \$5 million by age 62.[5] Based on these VSLs, we calculate age-specific VSLYs from our age-VSL profiles and find that VSLYs also take an inverted-U shape with a peak at an older age than the VSLs. In the cross-sectional analysis, the VSLY peaks at \$375,000 at age 45 and subsequently declines to about \$150,000 in workers' early 60s. In the cohort-adjusted analysis, the VSLY peaks at \$401,000 at age 54, and experiences a more modest decline to about \$350,000 by age 62.

The next section describes the construction of our novel age-industry mortality risk data and methods. Section III presents the VSLs estimated from the age-group-specific hedonic wage-mortality risk analyses. Section IV provides the age-VSL profiles in the cross-sectional and cohort-adjusted minimum distance estimator analyses. Section V illustrates the implications of these VSL estimates on how VSLY varies with age. Section VI concludes the paper.

II. Hedonic Wage Data and Methods

A. *Data*

To characterize the fatality risks faced by workers of different ages more precisely than is possible using average risk values by industry, we constructed a novel risk measure conditional upon age and the worker's industry rather than using an industry basis alone, which is the typical approach in the literature.[6] The source of the fatality measures is the BLS CFOI data for the 1992–2000 period. We structured the mortality risk cells by two-digit SIC industries and these six age groups specified in the CFOI data: 16–19, 20–24, 25–34, 35–44, 45–54, and 55–64. To construct the denominator for the mortality risk variable, we used the 1992–2000 Current Population Survey Merged Outgoing Rotation Group files to estimate worker populations for each cell in the mortality data. The annual mortality risk measures are averaged to minimize any potential distortions associated with catastrophic mortality incidents in any one year and to have a better measure of the underlying risks for industry-age groups with infrequent deaths. Our injury risk measure, the probability of a lost-workday injury, also varies by age, and we constructed it in an identical manner for each two-digit industry and for each of the age groups listed

[4] See Viscusi and Aldy (2003) for a meta-analysis of the VSL income elasticity value.

[5] All VSL estimates presented in this paper are in year 2000 dollars.

[6] We report the additional details regarding the age variation in mortality risk based on this measure in Viscusi and Aldy (2007).

above. While injury risk decreases with age across most industries, mortality risk increases monotonically with age in all industries, except for in mining.[7]

We have matched these constructed mortality risk and injury risk measures by age and industry with data on adult workers in the Current Population Survey Merged Outgoing Rotation Group data files for 1993–2000. We 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 ninth grade education, workers with an effective hourly labor income less than the minimum wage, less than full-time workers, which we defined as those working at least 35 hours per week, and those with top-coded income.

B. *Hedonic Wage Regression Framework*

The standard hedonic wage model estimates the locus of tangencies between the market offer curve and workers' highest constant expected utility loci. The age variation in the wage-mortality risk tradeoff simultaneously reflects age-related differences in preferences as well as age-related differences in the market offer curve. If older workers are more likely to be seriously injured than are younger workers because of age-related differences in safety-related productivity, then the market offer curve will reflect that, given that age is a readily monitorable attribute. Because workers' constant expected utility loci and firms' offer curves each may vary with age, there is no single hedonic market equilibrium. Rather, workers of different ages will settle into distinct market equilibria as workers of different ages select points along the market opportunities locus that is pertinent to their age group.[8]

The canonical hedonic wage analyses of job risks specifies the natural logarithm of the hourly wage or some comparable income measure as a function of worker and job characteristics, mortality risk, and, in more comprehensive specifications, injury risk and a measure of workers compensation. The semi-logarithmic wage specification is much closer to the formulation implied by Box-Cox specification tests than the linear variation of the model.[9] Moreover, use of the more flexible Box-Cox variable structure has a very minor effect on the point estimates of VSL. Our base specification takes the following form:

$$\ln(w_i) = \alpha + H_i'\beta + \gamma_1 p_i + \gamma_2 q_i + \gamma_3 q_i WC_i + \varepsilon_i, \qquad (1)$$

where

w_i is the worker i's hourly after-tax wage rate,
H is a vector of personal characteristic variables for worker i,
p_i is the fatality risk associated with worker i's job,
q_i is the nonfatal injury risk associated with worker i's job,
WC_i is worker i's workers compensation replacement rate for a job injury, 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.[10] The terms α, β, and the γ's represent parameters to be estimated.

All wage regression specifications used in this paper include the following controls: demographic indicator variables (race and ethnicity, gender of head of household, marital status, union membership, public-sector employment, and resident of urban area); educational attainment; indicator variables for one-digit occupation and region of residence; and job mortality risk, job nonfatal injury risk, and expected workers compensation replacement rate.[11]

The estimated regression then yields a measure of the average value of a statistical life for the sample:

$$VSL = \hat{\gamma}_1 \times \bar{w} \times 2{,}000 \times 100{,}000. \qquad (2)$$

This equation normalizes the VSL to an annual basis by the assumption of a 2,000-hour work-year and by accounting

[7] Viscusi and Aldy (2007) present evidence on the age variation in fatality risks by industry and occupation. Aldy and Viscusi (2004) provide more details about the construction of this age-specific job mortality risk measure.

[8] Refer to Viscusi and Aldy (2007) for a model illustrating these age-specific equilibria. This analysis generalizes the hedonic model analysis for heterogeneous worker groups using the model developed for an evaluation of smokers and nonsmokers by Viscusi and Hersch (2001). Their worker groups differ in their safety-related productivity and in their attitudes toward risk.

[9] For the standard Box-Cox specification, the dependent variable in equation (1) is $\frac{w_i^\lambda - 1}{\lambda}$, where $\lambda = 1$ corresponds to the linear specification and $\lambda = 0$ corresponds to the semi-logarithmic specification. For the eight years of the data, the value of λ ranges from 0.09 to 0.21 in seven of the eight years, and is -0.08 in one year. The estimated VSL levels differ by an average of only 4% using the Box-Cox parameter estimate λ rather than the semi-logarithmic model. The variation in VSL over the life cycle is also similar. We have also estimated wage equations rather than log wage equations, using the after-tax wage as the dependent variable. This approach yields very similar inverted-U shapes of VSL with respect to age. An appendix including those models is available from the authors.

[10] The procedures for calculating the workers compensation benefit variable are discussed in more detail in Viscusi (2004), which also provides supporting references.

[11] The workers compensation expected replacement rate 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, state benefit formulas, and estimated state and federal tax rates. Given the endogeneity of the wage, we have also estimated instrumental variables regressions. IV estimation does not qualitatively influence determinations of coefficient magnitudes or statistical significance for the mortality risk variable of interest in this study. Refer to Aldy and Viscusi (2004) for additional details.

for the units of the mortality risk variable. As a preliminary check on our age-industry risk variables, we estimated equation (1) with the 1997 CPS MORG and compared this with the results for industry risk variables merged with the 1997 CPS MORG data set presented in Viscusi (2004). We estimated a mean VSL of $4.5 million (1997 dollars), which is virtually indistinguishable from the Viscusi (2004) estimate of $4.7 million, and both studies fall within the range of VSLs from hedonic wage regression studies of the U.S. labor market reported in Viscusi and Aldy (2003).[12]

III. Estimated Age Group VSLs

As an initial assessment of how the value of life varies with age across the population, we modified equation (1) so that the estimated compensating differentials can vary by age. We interacted five age group indicator variables—for age groups 18–24, 25–34, 35–44, 45–54, and 55–62—with the various risk measures, and included the first four age group indicator variables in the specification:

$$\ln(w_i) = \alpha + H_i'\beta + \sum_{j=1}^{4} \delta_j age_j + \sum_{j=1}^{5} \gamma_{1j} age_j p_i + \sum_{j=1}^{5} \gamma_{2j} age_j q_i + \sum_{j=1}^{5} \gamma_{3j} age_j q_i WC_i + \varepsilon_i, \tag{3}$$

where age_j are the indicator variables for the five age groups and δ_j and γ_{mj} are parameters to be estimated.

We estimated this modified specification with eight annual CPS MORG samples from 1993–2000 and our industry by age job mortality risk and nonfatal injury risk data.[13] As distinct cross-section regressions, these specifications cannot discern age effects from cohort effects. They do, however, reveal how much an individual currently in one age group at a point in time is willing to pay for a given risk reduction vis-à-vis how much a different individual currently in another age group is willing to pay for such a risk reduction.

Table 1 presents the age-group-specific results for this specification. We report two sets of standard errors: White heteroskedasticity-adjusted standard errors, and robust and clustered standard errors that account for within-group correlations due to the assignment of the same job risk level to workers in an age-industry cell in each year.[14] The eight annual cross-section regressions reveal similar patterns of the VSL with respect to age: an inverted-U shape with the VSL peaking for either the 25–34 age group (three times) or the 35–44 age group (five times). As an illustration, consider the results for the year 2000 cross section. The coefficient estimate on the 18–24 age group mortality risk variable is 0.0028, and it increases substantially to 0.0043 for the 25–34 age group. The mortality risk coefficient then declines with age: 0.0036 for the 35–44 age group, 0.0029 for the 45–54 age group, and 0.0013 for the 55–62 age group. The five age-group-specific job mortality risk coefficient estimates are individually statistically significant at the 1% or 5% level. The estimated VSLs for each age group depend on these coefficient estimates as well as age-group-specific average wages, which follow an inverted-U shape over the life cycle. The 35–44 age group has the largest VSL of $9.66 million, nearly triple the 18–24 VSL of $3.74 million and the 55–62 VSL of $3.43 million.

To show how these differences in magnitudes are often statistically significant, we focus on the results for the year 2000 cross section, which we report again at the top of table 2. We conducted a series of pairwise modified Wald tests on the estimated VSLs, and the table presents the F-statistics associated with these tests.[15] The first row of these tests shows that the 18–24 VSL of $3.74 million is statistically different from the VSL estimates for the next three age groups, but does not differ significantly from the 55–62 VSL of $3.43 million. The last column, corresponding to the 55–62 age group, shows that the estimated 55–62 VSL differs significantly from the VSL estimates for the 25–34, 35–44, and 45–54 age groups. These results indicate that the VSL takes an inverted-U shape with respect to age across a population. The VSL pattern is relatively flat in the middle age groups as there is no statistically significant difference among the age 25–34, 35–44, and 45–54 categories for the 2000 cross section.

Our age group results differ from the existing empirical literature. First, we do not find negative VSLs for older workers as evident in those specifications that interact age and mortality risk (see Aldy & Viscusi, 2004; Viscusi & Aldy, 2003). Our results suggest a more complicated relationship than can be captured by a simple interaction. Second, we find that the value of statistical life declines after peaking for prime-aged workers in contrast to the age group VSL estimates in Smith et al. (2004). We believe that our results reflect the effect of using an age-specific industry mortality risk measure. In a related paper, we compare age

[12] In our analysis with the 1997 CPS MORG, the mortality risk coefficient estimate is 0.0019 with a robust standard error of 0.00021.

[13] Note that we used averages of the lagged risk measures in these analyses. For example, the 1995 regression included risk measures averaged over 1992–1994, while the 2000 regression included risk measures averaged over 1992–1999.

[14] Refer to Hersch (1998) and Viscusi and Hersch (2001) as examples of papers in this literature that account for this type of correlation.

[15] We have developed this modified Wald test to account for the construction of the VSL estimates from two random variables: wages and coefficient estimates on mortality risk. The test also accounts for the correlation among coefficient estimates by drawing on Goodman (1960) and Bohrnstedt and Goldberger (1969). The test takes the following form: $W_{ij} = (\hat{VSL}_i - \hat{VSL}_j)^2[\hat{\mathrm{var}}(\hat{VSL}_i) + \hat{\mathrm{var}}(\hat{VSL}_j) - 2\,\hat{\mathrm{cov}}(\hat{VSL}_i, \hat{VSL}_j)]^{-1}$. We use age-group-specific wage sample averages and standard deviations and coefficient estimates and their robust variance-covariance matrices to construct the means, variances, and covariances of VSLs in the test statistic.

TABLE 1.—AGE-GROUP-SPECIFIC VALUES OF A STATISTICAL LIFE, 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	Mortality risk	0.00068	0.0047	0.0033	0.00069	0.0012
		(0.00061)	(0.00042)***	(0.00043)***	(0.00042)	(0.00067)*
		[0.00062]	[0.00080]***	[0.00085]***	[0.00068]	[0.00090]
	Mean VSL	$0.95	$9.95	$8.29	$1.79	$2.91
1994	Mortality risk	0.0030	0.0033	0.0027	0.0012	0.0017
		(0.00051)***	(0.00040)***	(0.00040)***	(0.00044)***	(0.00066)**
		[0.00072]***	[0.00066]***	[0.00078]***	[0.00079]	[0.00086]*
	Mean VSL	$4.54	$7.42	$7.09	$3.40	$4.30
1995	Mortality risk	0.0030	0.0031	0.0022	0.0017	0.0014
		(0.00056)***	(0.00041)***	(0.00040)***	(0.00044)***	(0.00061)**
		[0.00066]***	[0.00066]***	[0.00082]***	[0.00078]**	[0.00084]*
	Mean VSL	$4.57	$6.98	$5.68	$4.69	$3.67
1996	Mortality risk	0.0030	0.0035	0.0031	0.0014	0.0011
		(0.00085)***	(0.00045)***	(0.00046)***	(0.00044)***	(0.00058)*
		[0.00098]***	[0.00072]***	[0.00090]***	[0.00074]**	[0.00074]
	Mean VSL	$4.53	$7.68	$8.04	$3.93	$2.77
1997	Mortality risk	0.0036	0.0034	0.0033	0.0020	0.0016
		(0.00064)***	(0.00045)***	(0.00044)***	(0.00045)***	(0.00063)***
		[0.00088]***	[0.00075]***	[0.00078]***	[0.00077]***	[0.00087]*
	Mean VSL	$5.48	$7.52	$8.62	$5.40	$4.23
1998	Mortality risk	0.0041	0.0029	0.0033	0.0019	0.0014
		(0.00068)***	(0.00045)***	(0.00044)***	(0.00046)***	(0.00058)**
		[0.00093]***	[0.00070]***	[0.00076]***	[0.00072]**	[0.00078]*
	Mean VSL	$6.45	$6.72	$8.99	$5.42	$3.81
1999	Mortality risk	0.0029	0.0041	0.0042	0.0038	0.0019
		(0.00058)***	(0.00052)***	(0.00053)***	(0.00050)***	(0.00065)***
		[0.00069]***	[0.00080]***	[0.00096]***	[0.00085]***	[0.00088]**
	Mean VSL	$3.43	$7.45	$9.13	$8.70	$3.20
2000	Mortality risk	0.0028	0.0043	0.0036	0.0029	0.0013
		(0.00067)***	(0.00051)***	(0.00049)***	(0.00047)***	(0.00058)**
		[0.00080]***	[0.00077]***	[0.00091]***	[0.00076]***	[0.00085]
	Mean VSL	$3.74	$9.43	$9.66	$8.07	$3.43

VSLs are expressed in millions of year 2000 dollars based on age-specific wages. Dependent variable: natural logarithm of hourly labor income. Each specification includes nine one-digit occupation indicator variables, eight regional indicator of variables, demographic variables, nonfatal injury risk, and expected workers compensation 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, two-tailed test.

group VSLs generated from age-industry risk measures with industry-only risk measures, and find that the latter results in higher VSLs for older workers (Viscusi & Aldy, 2007).

IV. Minimum Distance Estimator and Cohort Effects

We extend this age-specific regression analysis in section III through a two-stage minimum distance estimator using VSL estimates for each year rather than age bands. This approach allows us to infer information about the VSL with respect to age from a larger number of regressions based on more narrowly defined age bands for each year. While these individual regressions will provide less precise estimates of the compensating differential for risk than broader age groups, it will then be possible to estimate VSLs as a function of age if age-specific VSLs follow a systematic pattern over the life cycle.

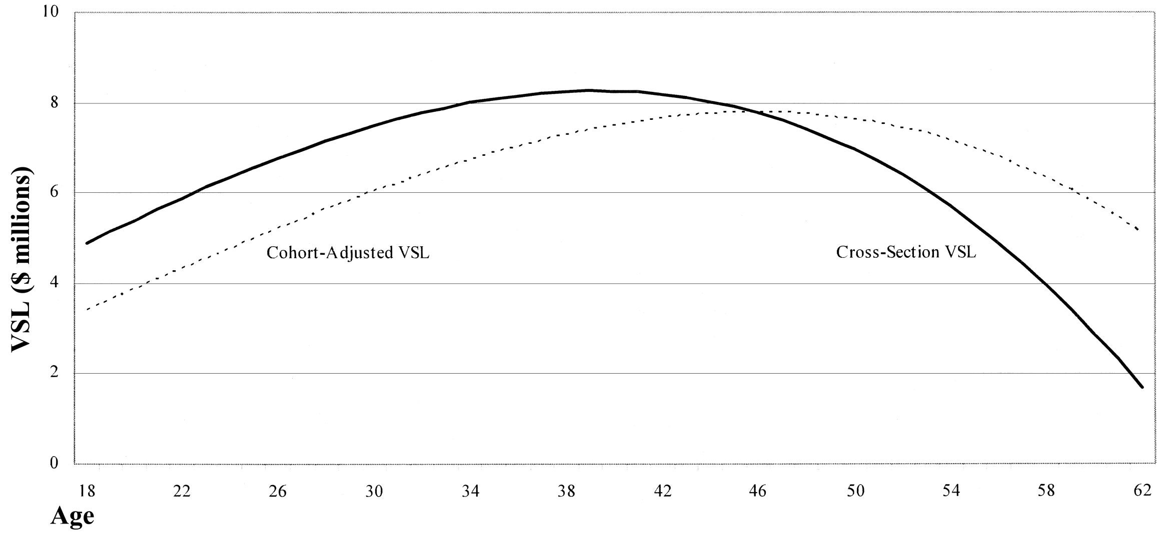
In the first stage, we estimate age-specific hedonic wage regressions of the form expressed in equation (1) and use the

TABLE 2.—AGE-GROUP-SPECIFIC VALUES OF A STATISTICAL LIFE, 2000

	18–24 Age Group	25–34 Age Group	35–44 Age Group	45–54 Age Group	55–62 Age Group
Mortality risk	0.0028	0.0043	0.0036	0.0029	0.0013
	(0.00067)***	(0.00051)***	(0.00049)***	(0.00047)***	(0.00058)**
	[0.00080]***	[0.00077]***	[0.00091]***	[0.00076]***	[0.00085]
Mean age group VSL (millions 2000 dollars)	$3.74	$9.43	$9.66	$8.07	$3.43
Age group	H_0: Pairwise Tests of Equality of VSL Estimates, F-Statistics				
18–24	—	15.87***	14.25***	7.56***	0.032
25–34	—	—	0.019	0.63	9.89***
35–44	—	—	—	0.75	9.57***
45–54	—	—	—	—	5.28**

N = 123,439. R^2 = 0.58. Dependent variable: natural logarithm of hourly labor income. Specification includes nine one-digit occupation indicator variables, eight regional indicator variables, demographic variables, nonfatal injury risk, 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%, and 5% levels, two-tailed test.

FIGURE 1.—COHORT-ADJUSTED AND CROSS-SECTION VALUE OF STATISTICAL LIFE, 1993–2000



Both series are based on equally weighted minimum distance estimator with a third-order polynomial in age. The cohort-adjusted VSL also includes indicator variables for year of birth.

mortality risk coefficient estimates to construct age-specific VSLs. We estimate age-specific compensating differentials for 45 age levels from age 18 to 62 and eight cross sections from 1993 to 2000, yielding 360 separate regressions. With the exception of the youngest and oldest birth-year cohorts, every cohort has eight observations in our constructed panel.[16] We estimate the VSL using the mean after-tax real wage for that respective age and year. Based on these first-stage regressions, we construct a panel of cohort-specific and age-specific VSL estimates. Each VSL estimate is assigned to a birth-year cohort. For example, the estimated VSL for a 40-year-old in 1993 is assigned to the 1953 birth-year cohort; the estimated VSL for a 41-year-old in 1994 is also assigned to the 1953 birth-year cohort, and so on. We followed this procedure for all 360 VSL estimates.

In the second stage, we specify these VSLs by age. To characterize how the VSL estimates from the first stage, $V\hat{S}L$, vary with age across a population, the second stage includes a polynomial in age, $a(\theta)$. To characterize how the VSL varies over the life cycle, we account for the differences across cohorts by including a vector of birth-year indicator variables, c, in addition to the age polynomial. We also employ $\hat{V}$, the inverse of a diagonal matrix of the variance estimates of these VSLs, as a weight matrix based on Chamberlain's (1984) analysis of the minimum distance estimator and the choice of the inverse of the variance-covariance matrix as the optimal weight matrix.[17,18]

For the cross-sectional analysis, the minimum distance estimator solves

$$\min_{\theta\in\Theta}[V\hat{S}L - a(\theta)]'[\hat{V}]^{-1}[V\hat{S}L - a(\theta)]. \tag{4}$$

For the life cycle (cohort-adjusted) analysis, the minimum distance estimator solves

$$\min_{\theta\in\Theta,\delta\in\Delta} [V\hat{S}L - a(\theta) - c'\delta]'[\hat{V}]^{-1}[V\hat{S}L - a(\theta) - c'\delta], \tag{5}$$

where θ and δ represent parameters to be estimated. We specified $a(\theta)$ in a variety of analyses as a polynomial in age of order one to order eight.

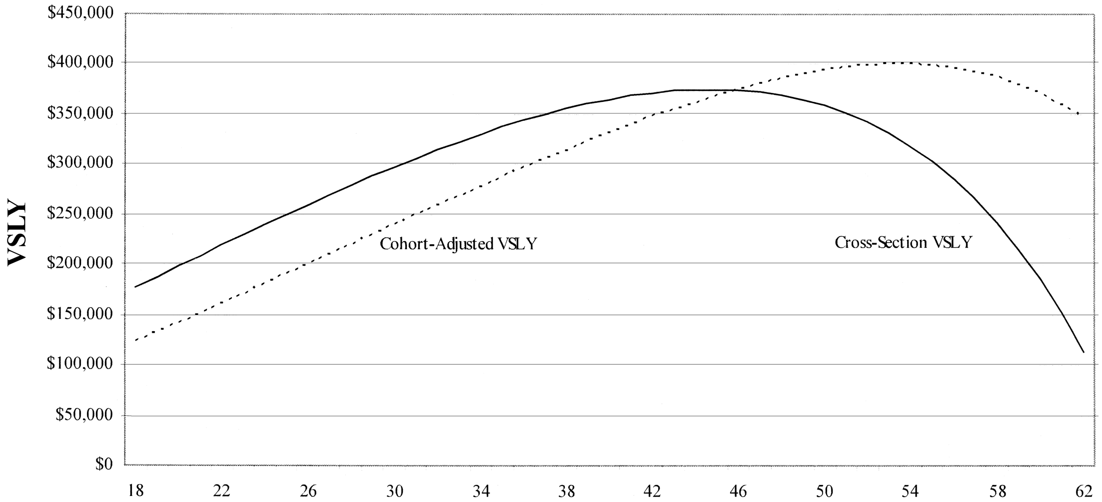
The solid curve in figure 1 presents the fitted age-VSL functions based on a third-order polynomial in age specification (cross-section VSL), while the dashed line presents the relationship based on a third-order polynomial in age with birth-year cohort indicator variables (cohort-adjusted VSL). Based on the specification test presented in footnote 15, we could not reject the hypothesis that a third-order age polynomial fit the data as well as higher-ordered polynomials. All order-two through order-eight polynomials resulted in similar inverted-U-shaped relationships between the value of a statistical life and age. We could, however, reject the hypothesis that lower-ordered polynomials fit the data as well as a third-order polynomial. These tests indicate that the estimated VSLs are neither consistent with an age-invariant VSL nor a VSL that allows decline with age.

[16] Refer to Deaton (1985) and Deaton and Paxson (1994) for the advantages of such a constructed panel based on birth-year cohorts.

[17] Because of the potential small-sample bias in the optimal minimum distance estimator, we also evaluated the equally weighted minimum distance estimator (Altonji & Segal, 1996). To address concerns about the small-sample bias, we have presented the results for the equally weighted minimum distance estimator in figures 1 and 2. The choice of weight matrix has no qualitative impact on our conclusions.

[18] We have employed a test of overidentifying restrictions to assess the appropriate order of the polynomial in age. If we assume that θ is a $K \times 1$ vector, then a restricted parameter vector, α, which is $R \times 1$ where $R < K$, can be estimated by some function, $b(\alpha)$. The following test statistic can then be used to evaluate the restrictions on the parameter vector: $N[V\hat{S}L - b(\hat{\alpha})]'\hat{V}^{-1}[V\hat{S}L - b(\hat{\alpha})] - N[V\hat{S}L - a(\hat{\theta})]'\hat{V}^{-1}[V\hat{S}L - a(\hat{\theta})] \sim \chi^2_{K-R}$. An analogous statistic was employed to evaluate the order of the age function in the cohort-based minimum distance estimator.

FIGURE 2.—VALUE OF A STATISTICAL LIFE-YEAR BASED ON COHORT-ADJUSTED AND CROSS-SECTION VALUE OF STATISTICAL LIFE, 1993–2000



Value of statistical life-years based on an assumed 3% discount rate and average age-specific life expectancy and derived from the age-specific VSLs presented in figure 1.

In the pooled cross sections, the value of statistical life increases with age from age 18 with a VSL of $4.87 million through age 39, at which the VSL peaks at $8.27 million. The value of a statistical life then declines with age to a minimum of $1.67 million at the highest age in the sample, which is 62. The cohort-adjusted function also yields a VSL that follows an inverted-U shape over the life cycle. It starts at $3.39 million at age 18, peaks at $7.79 million at age 46, and then declines to $5.09 million at age 62. Across the population and along the life cycle, VSL increases, peaks, and then decreases with age. While not presented, the birth-year indicator variables follow a general trend of increasing values with year of birth, consistent with the proposition that the value of life has increased with temporal increase in lifetime income and longevity.

The cohort adjustment affects the age-related pattern of VSLs in several ways. The peak of the age-VSL curve is seven years later when accounting for date of birth. The high VSLs for younger age groups are due in part to their higher lifetime wealth, as their cross-section VSLs lie above those in the cohort-adjusted values. For older age groups the pattern is reversed. While there is a steep drop in VSL levels with age in the cross-section results, this decline is due in part to cohort effects. Accounting for cohort differences attributable to changes in lifetime income more than doubles the estimated VSLs for the older age groups and flattens their VSL trajectory. Finally, the counterclockwise pivoting of the VSL function from the cross-sectional analysis to the cohort-adjusted analysis also illustrates the importance of accounting for lifetime income, implicitly through the birth-year indicator variables, in estimating the age-VSL relationship over the life cycle.[19]

[19] We also evaluated whether the higher VSLs for individuals in the 25–44 age range reflect major life cycle events such as getting married or having children, and not variations in age, but find no evidence to support this notion. Refer to Aldy and Viscusi (2004) for more details.

Our minimum distance estimator results differ from the existing literature in several respects. First, like our age group results, we find an inverted-U shape for VSL with respect to age. The innovation of an age-specific industry mortality risk measure is important in driving this result. Second, ours is the first paper to account for birth-year cohorts to discern age effects from cohort effects when estimating an age-specific VSL. Our cohort- and age-adjusted minimum distance estimator results are very similar to those found in Aldy and Smyth's (2007) numerical model calibrated to U.S. labor income, labor participation, consumption, and savings data with realistic representation of social security and uninsurable persistent and transitory labor income shocks.

V. Implications for the Value of a Statistical Life-Year

The preceding section illustrates the estimated age-VSL profile consistent with previous simulations published in the literature. The implicit assumptions underlying a constant VSLY approach, which requires the value of life to be decreasing with age at all ages, are rejected by our data. We have estimated age-specific VSLYs based on our age-specific VSLs.

To construct values of statistical life-years, we have annuitized age-specific VSLs based on age-specific years of life expectancy L and an assumed discount rate r of 3%:[20]

$$VSLY = \frac{rVSL}{1-(1+r)^{-L}}. \tag{6}$$

Figure 2 presents these calculations for the cross-section and cohort-adjusted VSLs derived from the minimum distance

[20] We have also calculated VSLYs based on a 7% discount rate, which is the current preferred rate by the U.S. Office of Management and Budget for evaluating government regulations. The higher discount rate yields larger VSLYs and a more pronounced inverted-U-shaped age-VSLY relationship.

estimator. The average VSLY is $296,000 for the cross-section estimates and $302,000 for the cohort-adjusted estimates. VSLYs follow a similar inverted-U-shaped relationship over the life cycle as depicted for VSL. The increase in VSLY is clearly expected for young workers because VSL is increasing and life expectancy is decreasing. The monotonic decrease in VSLY after its peak indicates that age-specific VSLs are decreasing at a faster rate than life expectancy. The peak in the VSLY occurs at a higher value and at a much higher age for the cohort-adjusted measure. It peaks at a value of $401,000 at age 54 for the cohort-adjusted measure, as compared with a peak of $375,000 at age 45 for the cross-section measure. The cohort-adjusted VSLY declines at a much slower rate than the VSLY after the peak for the cross-section measure. The influence of cohort adjustments has an even greater relative effect on the VSLY levels for the older workers in the sample than they did on VSL. Interestingly, the VSLY for those age 62 is higher than for all workers age 39 or younger.

These results for an age-varying VSLY clearly differ from the prior hedonic wage models developed to estimate VSLYs. In part, this reflects the fact that those models are constructed to generate age-invariant VSLYs. We believe that the use of an age-specific mortality risk measure also accounts for how the levels of VSLYs for older workers differ from the estimates in this earlier work. Recent numerical modeling by Murphy and Topel (2006) yields a very similar life cycle VSLY pattern as what we have found here, reflecting the decline in consumption and health with age in their model.

VI. Conclusion

The implications of wage-risk tradeoffs for the dependency of VSL on age is consistent based on both age-group-specific estimated VSLs and a minimum distance estimator derived from age-specific VSLs. We find that the VSL rises and then falls with age across the population and over the life cycle, displaying an inverted-U-shaped relationship. The minimum distance estimator results are perhaps most instructive, as they can more flexibly represent the age relationship while controlling for cohort effects. Failing to account for the secular increase in incomes with birth-year indicator variables yields much lower VSLs for older individuals and higher VSLs for younger individuals in cross-section analysis. Including cohort effects results in a much flatter age-VSL function over the life cycle, and older individuals have a higher value of a statistical life.

The result that the VSL rises and falls with age is of theoretical interest. Theoretical analysis of VSL over the life cycle suggests such a relationship may exist, particularly in situations in which there are insurance and capital market imperfections. The results are supportive of these models rather than those that generate steadily declining VSL with age, such as some models with perfect annuity and insurance markets. VSL is not steadily declining with age even though the amount of expected lifetime at stake steadily declines with age. As the life cycle models indicate, this result is not surprising because the age-VSL linkage depends on factors such as the life cycle consumption pattern, which also displays a similar age structure.

Recognition of cohort effects substantially influences the VSL trajectory for older age groups. The cross-section analysis implies that workers in their early 60s have a VSL of about $1.7–$2.0 million, which is between one-fifth and one-fourth the size of the VSLs for prime-aged workers. The cohort-adjusted VSL levels for older workers are much higher than in the cross-section analysis, with a VSL of about $5 million for workers in their early 60s. While this value is below the peak VSL over the life cycle, these older workers' VSLs are above the VSLs for very young workers.

Explicit construction of age-specific VSLY levels from our age-VSL profiles shows that the value of a statistical life-year varies with age. The conventional assumption of a constant VSLY is not borne out.[21] This result in turn stems from the failure of VSL to decline monotonically with age, which is a common assumption that lacks a firm empirical basis. Both VSL and VSLY vary with age, but the relationship is not a simple one.

[21] This result has implications for other models that assume a constant VSLY except for changes in health status, such as quality-adjusted life year approach.

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