Journal of Benefit-Cost Analysis

Volume 2, *Issue* 1 | 2011 | *Article* 1

The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations

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Recommended Citation:
Hammitt, James K. and Robinson, Lisa A. (2011) "The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations," *Journal of Benefit-Cost Analysis*: Vol. 2 : Iss. 1, Article 1.
Available at: http://www.bepress.com/jbca/vol2/iss1/1
DOI: 10.2202/2152-2812.1009

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The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations

James K. Hammitt and Lisa A. Robinson

Abstract

The income elasticity of the value per statistical life (VSL) is an important parameter for policy analysis. Mortality risk reductions often dominate the quantified benefits of environmental and other policies, and estimates of their value are frequently transferred across countries with significantly different income levels. U.S. regulatory agencies typically assume that a 1.0 percent change in real income over time will lead to a 0.4 to 0.6 percent change in the VSL. While elasticities within this range are supported by substantial research, they appear nonsensical if applied to populations with significantly smaller incomes. When transferring values between high and lower income countries, analysts often instead assume an elasticity of 1.0, but the resulting VSL estimates appear large in comparison to income. Elasticities greater than 1.0 are supported by research on the relationship between long-term economic growth and the VSL, by cross-country comparisons, and by new research that estimates the VSL by income quantile. Caution is needed when applying these higher elasticities, however, because the resulting VSLs appear smaller than expected future earnings or consumption in some cases, contrary to theory. In addition to indicating the need for more research, this comparison suggests that, in the interim, VSL estimates should be bounded below by estimates of future income or consumption.

KEYWORDS: value per statistical life, benefit-cost analysis, income elasticity, developing countries

1.0 INTRODUCTION

Mortality risk reductions often dominate the monetized benefits of environmental and other health or safety policies and regulations. As a result, changes in the value of these risks can significantly affect the extent to which alternative policies appear cost-beneficial. When assessing these policies, analysts often transfer estimates of the value per statistical life (VSL) from high income countries to countries with substantially lower incomes. The results are very sensitive to the income elasticity used; i.e., to the change in the VSL associated with a change in income. Research conducted largely in the United States suggests that this change is less than proportional, with estimated elasticities averaging between 0.4 and 0.6. Studies addressing lower income countries often instead assume that the change is proportional to income, applying an elasticity of 1.0. However, recent research suggests that higher elasticities may be appropriate. While these higher values result in VSL estimates that appear more reasonable in relationship to income, for very poor countries they may result in estimates that are smaller than future earnings and consumption, contrary to accepted theory.

This article explores these issues in more detail, assessing the income elasticity appropriate for transferring VSL estimates between high and low income populations. We review related research and recommend changes in the approach typically used for extrapolation. We focus on providing practical advice for policy analysts working within the traditional benefit-cost analysis framework, based on currently available research. This introductory section first describes the VSL concept and current practices. The following section explores the empirical research on its income elasticity. The final section discusses the relationship of income-adjusted VSL estimates to future earnings and consumption, as well as the conclusions and implications of this work.

1.1 The VSL Concept

Mortality risk reductions frequently represent a major share of the benefits of environmental policies, accounting for over 80 percent of the monetized benefits for many U.S. air pollution rules.[1] They also often represent a significant fraction of the benefits of other health-related policies and programs, such as those

[1] For example, retrospective analysis of the Clean Air Act indicates that mortality risks account for 95 percent of the present value of monetized benefits from 1970 to 1990 (EPA 1997), and prospective analysis indicates that they account for 88 percent of the benefits from 1990 to 2010 (EPA 1999). In its more recent analysis of the National Ambient Air Quality Standards for particle pollution, EPA again finds that premature mortality dominates the monetized benefits, but the extent varies due to uncertainty in the concentration-response function (EPA 2006).

addressing transportation or food safety.[2] These risks are relatively small at the individual level, but significant when aggregated into "statistical lives" over the larger population affected.[3]

The value of these risk reductions, expressed as the VSL, can be calculated by dividing individual willingness to pay (WTP) for a small risk change in a defined time period by the risk change. For example, an individual who is willing to pay $600 for a 1 in 10,000 reduction in his or her risk of dying in the current year has a VSL of $6 million ($600 ÷ 1/10,000 = $6 million). Alternatively, WTP can be described as a population measure. A $6 million VSL also results if each member of a population of 10,000 is willing to pay an average of $600 for a 1 in 10,000 annual risk reduction ($600 x 10,000 = $6 million).

The VSL concept is illustrated more formally in Figure 1 (based on Hammitt 2000), which plots wealth along the vertical axis and the probability ("*p*") of survival along the horizontal axis. The indifference curve traces the combinations of wealth and survival probabilities among which the individual is indifferent. For each change in survival probability ("Δ*p*"), WTP or willingness to accept (WTA) compensation is measured by the vertical distance between the two points on the indifference curve.[4] Because the VSL is the value of a "statistical" case (i.e., sums the values for small changes in risk), it can be calculated as the individual's average WTP or WTA divided by the change in survival probability. More precisely, the VSL represents the marginal rate of substitution between wealth and mortality risk in a defined time period.

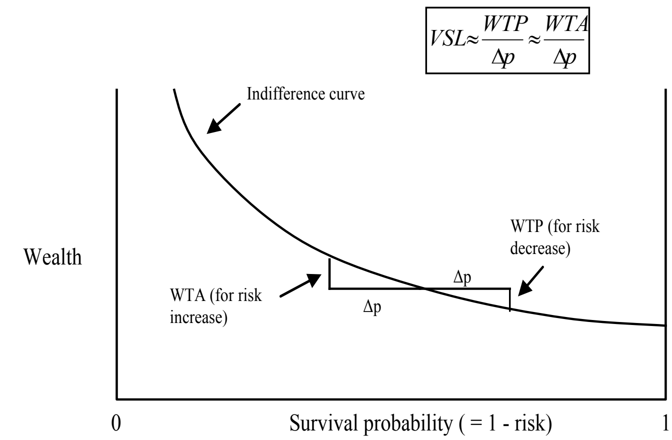
[2] For example, the U.S. Department of Transportation found that mortality risks accounted for 60 percent or more of the injury-related benefits of their electronic stability control rule (DOT 2007) , and the U.S. Food and Drug Administration found that mortality risks accounted for over 80 percent of the monetized benefits of their trans-fat rule (FDA 2003).

[3] For many policies, the individuals whose lives would be extended cannot be identified in advance. A policy that is expected to "save" a statistical life is one that is predicted to result in one less death in the affected population during a particular time period. "Saving" a statistical life is not the same as saving an identifiable individual from certain death. See Schelling (1968) for the seminal discussion.

[4] We refer to WTP throughout this paper for simplicity. WTA is also consistent with the benefit-cost analysis framework, but used less often in practice due to difficulties in its measurement.

DOI: 10.2202/2152-2812.1009

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



The VSL is most frequently estimated using wage-risk studies, which are also described as compensating wage differential or hedonic wage studies.[5] Researchers compare earnings across workers in different occupations or industries who face varying levels of on-the-job risks, using statistical methods to control for the effects of other factors on this relationship, including worker qualifications (such as education and experience) and job characteristics (such as nonfatal risks). In recent years, researchers have explored the use of other revealed preference methods and completed an increasing number of stated preference studies. Many of these studies focus on traffic safety or other types of accidents; some consider illnesses associated with air pollution or other contaminants.

1.2 Current Practices

Because the scenarios studied in empirical research often differ somewhat from the risks associated with many policies and regulations, analysts usually apply estimates derived from one scenario (generally job-related accidents) to a somewhat different scenario (such as air pollution risks). This "benefit transfer"

[5] See Viscusi and Aldy (2003) for a comprehensive review.

involves assessing the quality of the data and methods used in the available studies as well as the extent to which they consider populations and risks similar to those addressed by the policy. Analysts may be able to adjust the primary research results to reflect some differences between the study and the policy scenario, but often the implications of these differences can only be explored qualitatively.

Analysts have used the benefit transfer approach to value mortality risks in numerous studies, generally following a two-step process. First, they identify a best estimate (or range of estimates) of the base VSL from the available research. Second, they determine whether and how to adjust this base VSL quantitatively to better fit the policy scenario. Each step is described briefly below.

1.2.1 Base VSL

U.S. regulatory agencies have well-established approaches for estimating the base VSL; some international studies rely on the same research for their base estimates. The U.S. Office of Management and Budget's (OMB's) guidance for regulatory analysis (OMB 2003) suggests that the VSL is generally between roughly $1 million and $10 million (no dollar year reported). Most U.S. agencies use central values somewhat above the middle of this range, between about $5 million and $8 million when expressed in 2007 dollars.

These base estimates are derived largely from wage-risk studies conducted in the U.S. and other high income countries. The U.S. Environmental Protection Agency (EPA) relies on a review conducted by Viscusi (1992, 1993) for its base estimates (EPA 2000). The U.S. Department of Transportation's (DOT's) guidance (DOT 2009) relies on one wage-risk study (Viscusi 2004) and four meta-analyses (Miller 2000, Mrozek and Taylor 2002, Viscusi and Aldy 2003, and Kochi et al. 2006). A review conducted for the U.S. Department of Homeland Security (DHS) (Robinson 2008) and applied in recent DHS analyses (U.S. Coast Guard 2008a, 2008b) instead relies solely on the Viscusi (2004) wage-risk study, due largely to concerns raised by a recent expert panel (Cropper et al. 2007) about the data and methods used in the meta-analyses.[6]

Some analyses conducted for lower income countries rely on similar sets of studies for their base VSL estimates. For example, Lvovsky et al. (2000) use EPA's VSL estimates as the starting point for their analysis of six cities (Bangkok, Krakow, Manila, Mumbai, Santiago, and Shanghai); and World Bank (2006) cites U.S. and European studies as the source of the base estimates for Pakistan. This use of studies from high income countries results from the lack of research conducted in lower income countries. In a recent review, Robinson and

[6] Robinson (2008) has since been updated and published in abbreviated form as Robinson et al. (2010).

DOI: 10.2202/2152-2812.1009

Hammitt (2009) were unable to locate any VSL studies conducted in countries defined as low income by the World Bank.[7] They review 17 studies conducted in countries defined as middle income (some of which have now moved into the high income category), but find that these studies often suffer from shortcomings that limit their usefulness as the base VSL for extrapolation to lower income countries.

1.2.2 Income and Other Adjustments

In U.S. regulatory analyses, the base VSL discussed above is often adjusted to address changes in real income over time, any significant delays between changes in exposure and changes in mortality incidence (latency or cessation lag), and some external costs (e.g., insured medical costs) not likely to be included in estimates of individual WTP (see Robinson and Hammitt 2010). While U.S. regulatory agencies do not currently adjust their estimates for cross-sectional differences in population subgroups (using the same average VSL regardless of the age or income of the group affected), such adjustments have been made elsewhere. For example, some Canadian analyses adjust for the age of those affected (e.g., Jenkins et al. 2007), as do some analyses conducted for the World Bank (e.g., Lvovsky et al. 2000).

For the purpose of this article, we are primarily concerned with the approach used for income adjustments. U.S. regulatory agencies make these adjustments to reflect changes in real income between when the studies were conducted and when the regulation or policy would be implemented, although the approach differs across agencies. This adjustment involves estimating the proportional change in the VSL in response to a proportional change in real income; i.e., its income elasticity.

The EPA generally applies a distribution of values to characterize uncertainty about the relevant income elasticity, with a mode of 0.40 and endpoints at 0.08 and 1.00 based on its 1999 review of the literature (Industrial Economics 1999, EPA 1999). It measures the change in income using yearly estimates of real per capita gross domestic product (GDP) (see EPA 2006 for an example). DOT (2009) instead applies an income elasticity of 0.55 based on Viscusi and Aldy (2003), measuring changes in real income using the wages and salary component of the Employment Cost Index.

[7] The World Bank classifies countries based on their gross national income (GNI) per capita, using exchange rates to convert to U.S. dollars. As of 2007, the categories are: low income, $935 or less per capita; lower middle income, $936 to $3,705; upper middle income, $3,706 to $11,455; and high income, $11,456 or more. "World Bank List of Economies (July 2008), Country Classification Table" (http://go.worldbank.org/K2CKM78CC0, as viewed September 26, 2008).

Recent DHS regulatory analyses (e.g., U.S. Coast Guard 2008a, U.S. Coast Guard 2008b) use estimates developed in Robinson (2008). That report adjusts the VSL estimates from Viscusi (2004) from the year when the underlying data were collected (1997) to the year used in the analysis (2007). For income elasticity, estimates are derived from Viscusi and Aldy (2003), but taken from a different model than referenced in the DOT guidance. In this case, the estimates are from the model that both controls for the largest number of potentially confounding variables and uses robust regression with Huber weights to adjust for outliers that may distort the results. These elasticities include a mean of 0.47 and a 95 percent confidence interval ranging from 0.15 to 0.78. For income growth data, the DHS report relies on the Current Population Survey, which is the source of earnings data for the Viscusi (2004) study (as well as for several of the U.S. VSL studies used by Viscusi and Aldy in developing the income elasticity estimates). U.S. regulatory agencies do not use different VSL estimates for different income subgroups; they apply the same average VSL to all the members of the population affected by their regulations in a given year, adjusting only for changes in income over time.

Thus the central estimates of income elasticity used by U.S. regulatory agencies are similar. The elasticity used in recent DHS analyses (0.47) is slightly larger than the best estimate (0.40) currently used by EPA and below the estimate (0.55) used by DOT. However, the DHS confidence interval (0.15 to 0.78) includes the best estimates applied by these other agencies. The interval is somewhat narrower than the range used by EPA (0.08 to 1.00), which was based on the studies available when it conducted its 1999 literature review, rather than on the more recent Viscusi and Aldy meta-analysis.[8]

In contrast, studies that transfer VSL estimates from high income countries to lower income countries frequently use higher values. In some cases (e.g., World Bank 2002a, World Bank 2002b), the elasticities are not reported. However, many studies apply an elasticity of 1.0 as their central or best estimate (e.g., Lvovsky et al. 2000, Larson and Rosen 2002, World Bank 2002c, World Bank 2006), often with little or no discussion of related theory or empirical research. We have found only a few studies (e.g., Stevens et al. 2005) that use higher elasticities.[9] The following section explores the available research on income elasticity in more detail.

[8] DOT uses a single elasticity estimate rather than a range.

[9] Another example of the use of a higher elasticity is Blumberg et al.'s (2006) study of air pollution in China. While they apply a base VSL derived from Chinese research rather than from a higher income country, they use an elasticity of 1.42 (based on Wang and Mullahy 2006) to estimate the effect of future income growth on this VSL.

DOI: 10.2202/2152-2812.1009

2.0 EMPIRICAL RESEARCH

Both economic theory and numerous empirical studies indicate that the VSL increases as income increases, similar to a normal good. The key question is whether the increases are proportionate, and if not, whether mortality risk reductions can be viewed as a "luxury" (i.e., WTP for risk reductions grows faster than income, with an elasticity greater than 1.0).[10] This issue is of particular importance in estimating the VSL for low income populations. Because of the lack of studies conducted in these countries, analysts often extrapolate the VSL from values for higher income countries. Changing the elasticity can alter the resulting VSL by orders of magnitude.

Holding all else constant, elasticities should be the same regardless of whether they are measured longitudinally (following the same population over time) or cross-sectionally (across different groups at a single point in time). However, a mean elasticity calculated over a defined income interval may differ from the mean calculated over a narrower or wider interval, if elasticity is not constant across income levels. In addition, elasticity estimates are likely to reflect effects for which controls are lacking in the statistical analyses, such as cultural attitudes towards risk, structural differences in job markets and healthcare systems, and other factors. As a result, different studies can lead to significantly different estimates. This section begins with an example illustrating the importance of this concern, then reviews the evidence on VSL income elasticity.

2.1 An Illustration

Given that the VSL represents individuals' willingness to exchange income (or wealth) for small changes in mortality risks, it seems self-evident that the VSL would increase as income increases. However, this increase is not necessarily proportional: the income elasticity of the VSL may be greater or less than 1.0. Assuming that elasticity is constant over the income levels of concern, it can be used to estimate the VSL as follows:

$$\text{VSL}_B = \text{VSL}_A * (\text{Income}_B/\text{Income}_A)^{\text{elasticity}} \qquad (1)$$

[10] Luxury goods are usually defined as those that are purchased in larger quantities as income increases. As discussed by Flores and Carson (1997), the income elasticity of WTP for a particular quantity is influenced by many additional (and often unobservable) factors. This means that a good for which demand elasticity is greater than 1.0 will not necessarily have an elasticity of WTP that is greater than 1.0 and vice-versa. As they note: "the rich man may buy proportionately more loaves of bread than his poorer brother, but this does not imply he is willing to pay proportionately more for the same loaf." (p. 295).

In this formula, "VSL_B" is the result of extrapolating from "VSL_A" given the ratio of the income levels for groups *A* and *B* and the elasticity estimate.[11]

A simple example illustrates this relationship. In 2007, per capita gross national income (GNI) was about $46,000 in the U.S., compared to an average of about $1,900 in Sub-Saharan Africa.[12] Robinson (2008) suggests a central U.S. VSL of $6.3 million for the same year, based on the Viscusi (2004) wage-risk study and applying an income elasticity of 0.47 from Viscusi and Aldy (2003).

If the VSL were constant regardless of income (an income elasticity of zero), the average U.S. resident would be willing pay the same amount for mortality risk reduction as the average resident of Sub-Saharan Africa. Based on the relationships introduced in Section 1.1, a VSL of $6.3 million is equivalent to a payment of $630 for a 1 in 10,000 annual risk reduction, which is about 1.4 percent of a $46,000 income but about 33 percent of a $1,900 income. Assuming that the VSL does not vary with income in this case appears nonsensical, because the individual with the smaller income is much more constrained in the money he or she has available for essential expenditures on food, shelter, or basic health care—and seems unlikely to choose to allocate such a high fraction of income to such a small risk reduction.

Intuitively, an individual with a very low income devotes most of his or her consumption expenditures to survival: spending a comparatively large amount for a relatively small change in survival probability appears irrational. Such individuals face many opportunities to purchase goods or services that will potentially increase their longevity, many of which are more cost-effective than the $630 investment in a 1 in 10,000 risk reduction implied by a $6.3 million VSL. Purchasing these less expensive risk reductions is likely to quickly exhaust the budget of a low income individual.

The effects of alternative elasticities are illustrated in Table 1, which indicates that applying different values can change the extrapolated VSL (for an income of $1,900) by orders of magnitude.

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[11] This formulation uses a logarithmic approach to calculate arc elasticity, assuming that elasticity is constant over the income range. If we instead estimate elasticity by dividing the percent change in the VSL by the percent change in income, it will no longer be constant, varying depending on the starting point. The detailed derivation of this formula is provided in Appendix B of Robinson (2008).

[12] Unless otherwise noted, in this article all currencies are translated to international dollars based on purchasing power parity (PPP). An international dollar is designed to have the same purchasing power as a dollar of GNI spent in the U.S. economy. GNI data are from "Gross National Income Per Capita 2007, Atlas Method and PPP," World Development Indicators Database, revised October 17, 2008 (http://go.worldbank.org/7RQCV7Z0U0, as viewed April 10, 2009).

DOI: 10.2202/2152-2812.1009

Table 1. Illustration of the Effect of Income Elasticity[a] on the Estimated VSL

	Extrapolated VSL for income = $1,900[b]	Converted to WTP for 1 in 10,000 risk change	WTP as a percent of income = $1,900
Elasticity = 0	$6.3 million	$630	33 percent
Elasticity = 0.5	$1.3 million	$130	7 percent
Elasticity = 1.0	$260,000	$26	1.4 percent[c]
Elasticity = 1.5	$52,900	$5.29	0.3 percent
Elasticity = 2.0	$10,700	$1.07	0.06 percent

Notes:
a. Elasticity estimates are illustrative; see text for discussion of related research.
b. Extrapolated from a U.S. VSL of $6.3 million and U.S. per capita gross national income (GNI) of $46,000.
c. The U.S. VSL of $6.3 million is 1.4 percent of U.S. income if converted to WTP for a 1 in 10,000 risk change.

The final column indicates that an elasticity of 1.0 maintains the U.S. relationship of WTP (for a 1 in 10,000 risk change) as 1.4 percent of income. The smaller elasticities lead to WTP estimates that are an increasing fraction of income for poorer individuals, while larger elasticities lead to estimates that decline as a fraction of income. Because it seems reasonable to assume that WTP as a percentage of income might drop below the U.S. level at very low incomes (given the limited money available to fund more basic needs), this comparison suggests that elasticities larger than one might be appropriate when extrapolating to very low income countries.

2.2 Results of Empirical Studies

In the research literature, five approaches have been used to varying degrees to estimate the income elasticity of the VSL: (1) cross-sectional analysis of within-sample variation from contingent valuation surveys; (2) meta-analysis of (primarily) wage-risk studies; (3) longitudinal analysis of wage-risk estimates within a particular population; (4) comparisons of VSL estimates across countries with differing income levels; and (5) quantile analysis of wage-risk data.[13] We briefly summarize each approach and the resulting findings below.

[13] The work discussed in this section is closely related to work that addresses the relationship between the income elasticity of the VSL and the coefficient of relative risk aversion found in financial studies. As Kaplow (2005) discusses, the latter coefficient is generally greater than 1.0, suggesting that the VSL income elasticity should also be greater than one. The rationale for discrepancies between VSL income elasticity and financial risk aversion, as well as the reconciliation of these differences, are discussed in Eeckhoudt and Hammitt (2001), Kniesner et al. (2010), Evans and Smith (2010), and Hammitt and Haninger (2010).

2.2.1 Estimates from Contingent Valuation Surveys

When the EPA first developed its approach for adjusting the VSL for real income growth over time (EPA 1999), the research available on income elasticity was primarily derived from contingent valuation surveys (Industrial Economics 1999). These studies allow researchers to look at cross-sectional differences within the population surveyed at that particular point in time, and assess the extent to which WTP varies depending on the income levels of the respondents.

EPA based its estimates on seven then-available contingent valuation studies as well as two previous literature reviews, resulting in the range of income elasticities discussed earlier (a mode of 0.40 and endpoints at 0.08 and 1.00). More recent contingent valuation surveys and other stated-preference studies appear to provide estimates towards the low end of this range. For example, Corso et al. (2001) find an elasticity of 0.4 in a general population while Alberini et al. (2004) find elasticities ranging from 0.2 to 0.3 in a study focused on individuals over age 40. Hammitt and Haninger (2010) find elasticities of 0.1 to 0.3 in their study of pesticide and motor vehicle risks to adults and children. All of these studies were conducted in the U.S. or other high income countries.

Contingent valuation studies conducted in lower income countries result in varying estimates. For example, Hammitt and Zhou (2006) find elasticities ranging from about 0.06 to 0.2 in their Chinese study, while a study from another area in China (Wang and Mullahy 2006) finds a much larger elasticity of about 1.4. The reasons for these differing estimates are unclear; they may result from differences in the populations and types of risks studied as well as from differences in survey design and implementation.

2.2.2 Estimates from Meta-Analyses

As EPA was developing its income-adjustment approach based on the then-available stated-preference research, a number of meta-analyses were underway that combined estimates from various VSL studies—primarily wage-risk studies. In these studies, individual's wages (or the log of wages) are the dependent variable in the regression analysis, so one cannot enter the interaction between wage and risk as an independent variable. While it might be possible to instead enter the interaction of risk with total personal or household income as an independent variable, the strong correlation of wages with total income makes estimation difficult.

Meta-analyses address this challenge by combining results across studies. As noted above, DOT and DHS rely on income elasticities from the meta-analyses reported in Viscusi and Aldy (2003), who review the results of previous research and develop additional estimates. Viscusi and Aldy first use their dataset

DOI: 10.2202/2152-2812.1009

of wage-risk studies to re-estimate selected models developed in four previous meta-analyses: Liu, Hammitt and Liu (1997), Miller (2000), Bowland and Beghin (2001), and Mrozek and Taylor (2002). In the four original meta-analyses, these models result in mean income elasticities ranging from 0.46 to 1.66. When the models are applied instead to the wage-risk studies reviewed by Viscusi and Aldy, the mean elasticity ranges from 0.51 to 0.61; i.e., the use of a consistent set of studies substantially narrows the range of mean estimates despite differences in the modeling.

Viscusi and Aldy (2003) then evaluate numerous other model specifications. They present the results for six additional models, using two different regression techniques (ordinary least squares and robust estimation with Huber weights) with three, four, or eighteen control variables. The mean income elasticities from Viscusi and Aldy's six models range from 0.46 to 0.60, with five of the six estimates between 0.46 and 0.51.

More recently, Bellavance et al. (2009) completed a meta-analysis using a different modeling approach (mixed effects regression). They found elasticities ranging from 0.72 to 1.08 based on wage-risk studies from nine (primarily high income) countries. Thus the meta-analyses find elasticities generally towards the high end of the range suggested by the contingent valuation studies, in most cases greater than 0.4 but less than 1.0.

2.2.3 Estimates from Longitudinal Studies

An alternative to conducting meta-analyses of the wage-risk studies is to estimate income elasticity longitudinally from wage-risk data, focusing on how the VSL changes over time in a particular population. The two available longitudinal studies lead to different conclusions than most of the stated preference studies and meta-analyses described above. Hammitt, Liu, and Liu (2000) estimate the relationship between wages and job-related risks for each year from 1982 to 1997 in Taiwan, when real per capita gross national product (GNP) grew by a factor of about 2.5 and the workplace fatality rate dropped by half. They find income elasticities ranging from 2.0 to 3.0 based on per capita GNP. Costa and Kahn (2004) consider changes in the wage-risk relationship between 1940 and 1980 in the U.S., as earnings increased and job-related risks declined over time. Their preferred elasticity estimates are 1.5 to 1.7 based on per capita GNP.

These two studies suggest that, as economies develop, income increases and job-related risks decrease. As a result, workers have a greater ability to exchange wages for improved safety and the compensating wage differential for riskier jobs rises. It is unclear, however, whether the larger elasticities primarily reflect the effects of income growth or also reflect changes in attitudes towards risk that occur over these time periods.

2.2.4 Estimates from Cross-Country Comparisons

The research discussed above relies primarily on studies from high income countries. In a recent review, Robinson and Hammitt (2009) were unable to locate any studies conducted in countries now classified as low income by the World Bank, but evaluated 17 studies from middle income countries. The authors of some of these studies note that their results are smaller than would be expected if an elasticity of 1.0 were applied to VSL estimates from the U.S. or other high income countries, but most do not quantify the implied elasticity. One exception is Hammitt and Ibarrarán (2006), who indicate that, if the entire difference between their Mexican VSL estimates and U.S. estimates is attributed to income, then the elasticity is between 1.4 and 2.0. Thus the limited evidence from cross-country comparisons appears consistent with the longitudinal studies in suggesting elasticities greater than 1.0.

2.2.5 Estimates from Quantile Regressions

The research described above presents something of a quandary, with contingent valuation studies and wage-risk meta-analyses generally providing elasticities below 1.0 and longitudinal studies and cross-country comparisons showing elasticities well in excess of 1.0. Recent studies provide important insights into these issues, exploiting the development of new data and statistical tools.

Evans and Schaur (2010) explore the inter-relationship between age and income within the context of a wage-risk study.[14] Data on wages and other personal characteristics are taken from the Health and Retirement Survey, which began in 1991 and tracks individuals over time starting between the ages of 51 and 61. Fatality risk data are taken from the Census of Fatal Occupational Injuries (CFOI), which was initiated in 1992 to address problems with older fatality risk data sources. For example, as a census, it avoids possible biases associated with previous sampling strategies; it also involves substantially increased confirmation of the data.

In their statistical analysis, Evans and Schaur use a quantile approach, which allows them to examine the wage-risk trade-offs at different points in the wage distribution as well as at different ages. This is a significant enhancement to the approach used in older wage-risk studies, which generally estimate the average VSL. Evans and Schaur find that variation in wages contributes more to variation in the VSL than does age variation. While the VSL declines with age, its absolute value as well as the rate of decline varies depending on the point in the wage distribution where it is estimated.

[14] In a related article, Evans and Smith (2010) explore how leaving the labor force, healthcare costs, and mortgage commitments affect the relationship between income and the VSL.

DOI: 10.2202/2152-2812.1009

Kniesner et al. (2010) also use quantile regressions to explore the income elasticity of the VSL. They rely on the Panel Study of Income Dynamics for data on wages and other worker characteristics and on the CFOI for data on fatality risks. They find that elasticity generally declines as income rises. In the lowest quantile (0.10), the elasticity is 2.24, declining to 1.23 in the highest quantile (0.90), with a mean of 1.44 across quantiles. Because the analysis is based on U.S. data, even those individuals in the lowest quantile have incomes well above the mean in low income countries. Assuming a 2,000 hour work year and inflating to 2007 dollars, the average hourly wage at the 10^{th} percentile is equivalent to annual U.S. earnings of about \$20,300; as noted earlier, the dividing line between high and middle income countries was \$11,455 per capita GNI in 2007 according to the World Bank.

In combination, these newer studies indicate that the income elasticity of the VSL varies depending on the income level, providing an explanation for the divergent results of the studies discussed earlier. At higher incomes, the lower elasticities found in the contingent valuation studies and wage-risk meta-analyses appear sensible. At lower incomes, the elasticities found in the longitudinal studies and cross-country comparisons may be more reasonable.

2.3 Conclusions and Implications

As noted earlier, this article is primarily concerned with the approach used to estimate the VSL in lower income countries where the value of small mortality risk reductions has not been well studied. When assessing the benefits of risk-reducing policies in these areas, analysts generally use the benefit transfer method to extrapolate values from studies conducted in higher income countries. As illustrated in Section 2.1, the income elasticity applied in this extrapolation can substantially influence the results.

While several contingent valuation studies and meta-analyses suggest VSL income elasticities below 1.0, these studies were conducted largely in high income countries and their results may not be applicable to countries in significantly different stages of development. The illustrative analysis in Section 2.1 suggests that using these elasticities to extrapolate to countries with very low incomes leads to VSL estimates that appear implausibly large. It seems unreasonable to assume that the average individual in these countries would be willing to devote a large fraction of his or her own income to such small risk reductions, given both the need to fund basic necessities and the opportunity to invest in less costly risk-reducing activities. Comparison of VSL estimates from high and middle income countries reinforces the conclusion that elasticities greater than 1.0 may be reasonable in these extrapolations.

The longitudinal and income quantile studies provide insights into why the results of the contingent valuation studies and meta-analyses appear to conflict with these comparisons. The longitudinal studies suggest that economic development provides more opportunities to exchange wages for reduced risks, increasing the rate at which the VSL grows in proportion to income. In addition, societal attitudes towards risks may change as countries become wealthier and safer. Recent studies using quantile regressions also suggest that differences in elasticities across income groups are masked in the older studies by the focus on sample means.

Elasticities greater than 1.0 mean that individuals' WTP for small mortality risk reductions becomes a smaller percentage of income as income decreases, which appears consistent with the constraints faced by very poor populations—who are likely to find it challenging to fund day-to-day needs for basic subsistence. These higher elasticities are also consistent with the intuition that, as material wants are better satisfied, the relative value of health and longevity increases.

However, while elasticities above 1.0 appear sensible, the actual value is uncertain given the diverse results of the available studies. Extrapolating to very low income countries also involves going outside of the range of incomes considered in the empirical studies. This uncertainty suggests that the effects of a range of elasticities should be explored when extrapolating VSL estimates from high income countries to low income countries with significantly different economies. In addition, analysts may find it useful to calculate the "breakeven" VSL; i.e., the VSL at which the benefits of a policy no longer exceed its costs or at which the ranking of the different policy options changes. This breakeven VSL can be compared to the values that result when different income elasticities are applied to determine whether the policy appears cost-beneficial.

3.0 RELATIONSHIP TO FUTURE EARNINGS AND CONSUMPTION

Given the uncertainty in the income elasticity estimates, one question that arises is whether it is possible to compare the VSL that results from their application to other measures to determine its reasonableness. Theory suggests that the VSL will exceed the present value of future earnings (i.e., of human capital) and of future consumption (discounted to reflect time preferences), because it reflects the values that individuals place on the joy and satisfaction of living in addition to their productivity or consumption. Given that consumption is largely funded by earnings (as well as wealth), the two measures are closely associated but can follow different patterns over an individual's lifecycle. Earnings and consumption may not occur in the same time period because of the ability to transfer income over time by borrowing, saving, and investing or purchasing insurance. Below,

DOI: 10.2202/2152-2812.1009

we discuss the lifecycle model and then use it to explore the reasonableness of VSL estimates calculated with alternative income elasticities.

3.1 The Lifecycle Model

Intuitively, it seems reasonable to assume that an individual's VSL would be at least as great as his or her expected future income, because life is about more than producing income. Similarly, the VSL is likely to exceed the value of future consumption, because early death deprives an individual of other sources of utility. In the U.S., where the VSL has been well-studied and where considerable data are available on the economic status of different age groups, these assumptions are supported by substantial evidence. For example, if discounted at 3 percent, at age 40 (as of the year 2000) the present value of future earnings and household production was about \$1.1 million (Grosse 2003), whereas Viscusi (2004) estimates the VSL as \$5 million for the same year.[15] Excluding nonwage (household) production from the comparison increases the difference between the VSL and earnings: the present value of the later drops to \$0.8 million if only labor market earnings are included.[16]

This relationship is also evident in studies conducted in middle income countries, where in most cases the VSL is roughly 60 to 200 times greater than mean annual earnings, although some studies result in substantially higher or lower ratios (see Robinson and Hammitt [2009], Exhibit 3.5, p. 39). Given that the (discounted) remaining life expectancy (and the number of working years) for the average adult studied is likely to be much less than 60 years, these ratios further support the assumption that the VSL will exceed future earnings and the consumption it supports.

These relationships have been formalized as a lifecycle model by a number of economists, who have explored how earnings relate to consumption and the implications for the VSL. This model takes into account the probability of dying during each year of age, conditional on surviving until that age. Because everyone ultimately dies, these probabilities sum to 1.0 over an individual's remaining lifetime. The model also considers the utility associated with each year of life. It assumes that this utility increases with consumption; i.e., with increases

[15] While the average age of the sample is not reported in Viscusi (2004), the study relies on wage data from the 1997 Current Population Survey (CPS) for fulltime workers ages 18 to 65. Based on the underlying CPS data, our calculations show that the average fulltime worker in this age range was 39 years old. (Derived from unpublished 1997 CPS data, "Table 13: Full- and part-time status of the civilian labor force by age and sex, annual average 1997," provided via email by James Borbely, U.S. Bureau of Labor Statistics, April 16, 2009.)

[16] Although some U.S. studies (particularly those using stated-preference methods) result in lower VSLs, a recent review (Robinson 2008) suggests that the estimates are still usually greater than these future earnings.

in the total value of goods, services, or other desired outcomes for which income is exchanged. Expected lifetime utility is thus at least equal to the sum of the utility gained from the consumption associated with living in each future year, multiplied by the probability of surviving through that year.

In simpler versions of this model, total consumption is constrained by total earnings; more complex models consider the role of wealth as well as how loans, savings, and insurance may be used to re-allocate spending over time. Regardless, reducing mortality risks increases expected income by the product of the gain in survival probability and future income. When expressed as the VSL, the value of these risk reductions is expected to at least equal the discounted present value of future income as well as the resulting consumption.

This relationship can be illustrated using a simple one-period model (Drèze 1962, Jones-Lee 1974, Bergstrom 1982, Hammitt 2000), building on the discussion of Figure 1 above. Let p be the probability of surviving the current period, $u(c)$ be the utility from surviving the current period with future consumption c, and $u'(c)$ be the marginal utility of consumption conditional on survival. The utility of dying during the period is zero.[17] Then the individual's VSL or marginal rate of substitution between c and p is:

$$VSL = -\frac{dc}{dp} = \frac{u(c)}{pu'(c)}. \tag{2}$$

Under the standard assumption that the individual is averse to risks in the consumption level (i.e., $u(c)$ is concave and its second derivative is negative), $u(c) > c \cdot u'(c)$, and so the VSL > c.[18]

Much of the work on the lifecycle model has focused on the relationship between the VSL and age. For example, Shephard and Zeckhauser (1982, 1984) note that earnings will generally increase with age then drop at retirement, but that consumption will not necessarily follow the same pattern given the ability to save and to purchase annuities. More recent work introduces additional factors that influence the relationship between the VSL and age (e.g., Hammitt 2007, Aldy and Viscusi 2007, and Krupnick 2007).

The life-cycle model also has been extended to investigate other aspects of the VSL. For example, Cropper and Sussman (1990) and Hammitt and Liu (2004) consider the value of future (latent) risk reductions, Johansson (2002) assesses the

[17] The standard one-period model includes a bequest motive, in which case the utility conditional on dying depends on the consumption level (Drèze 1962, Jones-Lee 1974, Hammitt 2000). In multi-period models, the utility conditional on dying is typically set to zero.

[18] See Bergstrom (1982) for a more complete analysis that includes the possibility that living with sufficiently low consumption is worse than death and the effects of increased survival probability on lifetime income and life insurance.

DOI: 10.2202/2152-2812.1009

duration of the risk reduction and the effects of annuities, and Ehrlich and Yin (2005) explore investments in health protection and differences in life expectancy.

Because the lifecycle model focuses solely on monetary flows, it leaves out the value of survival for its own sake as well as other intangibles. For example, it excludes the value of increasing the time spent with loved ones. Thus future earnings and the associated consumption are likely to provide a lower bound for the VSL. In the analysis that follows, we apply a core assumption of the lifecycle model—that the VSL is expected to equal or exceed the discounted present value of remaining lifetime earnings and consumption—to develop a simple check on the VSL that results from applying income elasticities greater than 1.0 when extrapolating from high to low income populations.

3.2 Comparison of VSL to Future Income and Consumption

Below, we assess the relationship between the VSL in low income countries estimated by extrapolating from U.S. values, using alternative income elasticities and estimates of future earnings and consumption. The objective is to determine whether the extrapolated VSL appears small in relationship to these measures. Because the data available for low income countries are limited, these comparisons involve several simplifying assumptions. We discuss the implications of the uncertainty that results at the end of the section.

Our first step involves estimating the VSL for each country by extrapolation. We start with a U.S. estimate of $6.3 million, based on the Viscusi (2004) wage-risk study introduced earlier. We extrapolate using alternative estimates of the income elasticity (1.0, 1.5, 2.0) based on the review in Section 2.2, using GNI per capita (based on purchasing power parity) as our income measure.[19]

Our second step involves comparing the results to estimates of the present value of future income and consumption. We use simplifying assumptions where needed to address limitations in the available data.

The average age in the data that underlie the Viscusi (2004) VSL estimate is about half of U.S. life expectancy at birth (39 years vs. 78 years). Because life expectancy varies significantly across high and low income countries, we also use half of the life expectancy at birth ("mid-point age") for each country as the assumed current age for the calculations in that country.[20] (This assumption is

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[19] "Gross National Income Per Capital 2007, Atlas Method and PPP," World Development Indicators Database, revised October 17, 2008 (http://go.worldbank.org/7RQCV7Z0U0, as viewed April 10, 2009). GNI includes the value of the country's GDP plus net monetary flows from abroad.

[20] All life expectancy data are for 2008 and taken from the World Health Organization Global Health Observatory (http://apps.who.int/ghodata/, as viewed June 22, 2010).

consistent with the approach used in many analyses, which applies an invariant average VSL to the full population affected.) We then determine remaining life expectancy for an individual of that age in each country. We simplify the calculations by assuming that individuals will live for this time period with certainty, rather than calculating survival rates conditional on reaching each year of age.

For both income and consumption, we select values that use purchasing power parity rather than exchange rates to translate between different currencies. Purchasing power parity is particularly important for analyses addressing lower income countries because it takes into account differences in the relative prices of goods and services, including those that may not be traded in markets in some areas. For developing countries, GNI based on purchasing power generally exceeds GNI based on exchange rates.

For income, we rely on the same estimates of 2007 per capita GNI as used in our VSL calculations. For consumption, we rely on 2005 estimates developed as part of the World Bank's International Comparison program (World Bank 2008), updated to 2007 using U.S. inflation rates for simplicity.[21] As expected, the consumption estimates are less than GNI (to varying degrees) due to the effects of taxes, saving decisions, and other factors. We assume that income and consumption are constant at each year of age, discounting to the mid-point age using a 3 percent rate.[22]

Below, we provide the results of these steps for selected countries, listed in order of per capita GNI. We are primarily interested in the results for lower income countries, where the VSL has not been well studied, and thus focus on examples of these countries.[23] We exclude those countries with incomes similar to

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[21] In the U.S., 2007 prices were 1.06 times greater than in 2005, based on the Consumer Price Index (http://www.bls.gov/data/inflation_calculator.htm, as viewed June 22, 2010).

[22] Cropper and Sussman (1990) note that the discount rate used in these types of calculations should reflect the consumption rate of interest; i.e., how individuals are willing to trade consumption in the current time period against consumption in future time periods. If capital markets were perfect, the consumption rate and the rate of return to capital would be equal; in reality, these rates differ. For example, in U.S. regulatory analyses, 3 percent is generally used as the consumption rate, while 7 percent is generally used as the rate of return to capital (OMB 2003). These rates reflect, respectively, U.S. estimates of the social rate of time preference and the average rate of return (before-tax) to private capital.

[23] The World Bank's categorization scheme is based on exchange rates rather than purchasing power parity. Because the latter increases the estimates for poorer countries, countries in the World Bank's low income category ($935 GNI per capita and below based on exchange rates) tend to have GNI per capita of about $1,700 and below when calculated using the purchasing power parity measures reflected in Table 2. The difference is less stark at higher income levels; the top of the Bank's middle income category ($11,455) is roughly equivalent to $14,400 when calculated using purchasing power parity. However, the ranking of individual countries varies depending on the measure used.

DOI: 10.2202/2152-2812.1009

or higher than the U.S. because our review (in Section 2.2) suggests that smaller income elasticities may be appropriate in these areas.

Table 2 illustrates the changing relationship between the extrapolated VSL and the estimates of future income and consumption. We shade cells that include VSL estimates that are less than the present value of future income, and shade and bold cells where the estimates are also less than the present value of future consumption. In these cases (given the implications of the lifecycle model discussed earlier), we recommend that analysts test the sensitivity of their results to replacing the extrapolated VSL with the larger income- or consumption-based estimates. The unshaded cells represent cases where the extrapolated VSL exceeds the present values of both future income and consumption.

Table 2. Extrapolated VSL Compared to Future Income and Consumption (2007 dollars, 3 percent discount rate, purchasing power parity)

Country	Annual Per Capita GNI	Annual Per Capita Consumption	Midpoint LE[a]	Future Income[b]	Future Consumption[b]	Extrapolated VSL[c]		
						Elasticity =1.0	Elasticity =1.5	Elasticity =2.0
United States	$45,850	$33,915	45	$1,124,183	$831,545	$6,300,000	$6,300,000	$6,300,000
South Korea	$24,750	$12,928	41	$579,457	$302,670	$3,400,800	$2,498,600	$1,835,700
Mexico	$12,580	$9,393	43	$302,731	$226,029	$1,728,500	$905,400	$474,300
South Africa	$9,560	$6,239	34	$203,050	$132,517	$1,313,600	$599,800	$273,900
Thailand	$7,880	$4,760	38	$177,995	$107,530	$1,082,700	$448,900	$186,100
China	$5,370	$1,857	42	$126,506	$43,750	$737,900	$252,500	$86,400
India	$2,740	$1,542	41	$64,310	$36,199	$376,500	$92,000	**$22,500**
Kenya	$1,540	$1,279	40	$35,410	$29,418	$211,600	$38,800	**$7,100**
Tanzania	$1,200	$866	36	$26,361	$19,024	$164,900	$26,700	**$4,300**
Uganda	$920	$866	37	$20,515	$19,311	$126,400	**$17,900**	**$2,500**
Ethiopia	$780	$506	42	$18,509	$11,998	$107,200	$14,000	**$1,800**
Mozam-bique	$690	$643	36	$15,041	$14,025	$94,800	**$11,600**	**$1,400**
Liberia	$290	$280	41	$6,773	$6,535	$39,800	**$3,200**	**$300**

Notes:
See text for information on data sources and calculations.
a. Life expectancy (LE) at mid-point age.
b. Present value of future income or consumption, discounted at 3 percent.
c. Shading indicates that future income exceeds VSL estimate; **shading and bold** indicates that future consumption also exceeds VSL estimate.

In many countries, the extrapolated VSL varies by orders of magnitude depending on the income elasticity. With an elasticity of 1.0, the VSL exceeds the present value of future income and consumption in all cases. As the elasticity rises, the number of countries for which the extrapolated VSL exceeds future income or consumption decreases, with the VSL estimates for the poorer countries falling below the future income and (in most cases) consumption estimates. Because our estimates are derived from a U.S. VSL, the VSL for the U.S. is the same regardless of the elasticity. As illustrated in Table 1, an elasticity of 1.0 maintains the relationship between the VSL and income, while higher elasticities lead to estimates that decrease in proportion to income as income declines.

Given that uncertainty about the income elasticity significantly affects the extrapolated VSL, Table 2 emphasizes the need to test the impact of different elasticities as discussed in Section 2.3. While uncertainty about future income and consumption are unlikely to be as consequential, data limitations and related simplifying assumptions mean that the sensitivity of the analytic results to these estimates should also be tested.

Uncertainty about future income and consumption arises from a number of factors. We use per capita GNI to represent income in our calculations because the World Bank calculates it on a reasonably consistent basis across countries and it is easily accessible and frequently updated. However, GNI often exceeds the earnings measures used in many VSL studies, because it is a broader measure of production and reflects the effects of taxes and other factors.[24] For both income and consumption, we use constant annual estimates because we were unable to locate data by year of age for most of the lower income countries. This means that our analysis does not reflect how income and consumption change over the lifecycle.[25] Earnings are zero at very young and very old ages, whereas our approach spreads income as well as consumption evenly across all years of age.

The extent to which assuming constant income and consumption might bias our estimates is unclear, especially given that the pattern of earnings and consumption over the lifecycle may differ significantly between low and higher

[24] For example, while the World Bank estimates U.S. per capita GNI as $45,850 in 2007, the U.S. Census reports personal income as $38,654 in the same year (U.S. Census [2010], "Table 663: Selected Per Capita Income and Product Measures in Current and Chained (2000) Dollars: 1960 to 2008"). In addition, because income and wealth are highly skewed in many countries, mean values may differ significantly from the actual income of the majority of the population.

[25] Constant consumption is consistent with versions of the lifecycle model that assume perfect capital markets, but provides only a rough approximation of actual behavior given market imperfections and other factors. The relationship between expected future earnings and future consumption will vary across individuals depending on their financial decisions as well as their survival probabilities. Borrowing against future income means that some consumption may occur in advance of earnings, but investments from previous periods can also be used to fund future consumption. Income from transfers (such as private bequests or public programs such as Social Security) further complicates this relationship.

DOI: 10.2202/2152-2812.1009

income countries. The impact of other factors on our estimates is more straightforward: increasing the remaining life span or decreasing the discount rate will increase the present value estimates for future income and consumption and vice-versa.

In sum, our comparisons suggest that while income elasticities greater than one are consistent with some of the empirical research, they may lead us to underestimate the VSL in very low income countries. Replacing the VSL with estimates of the present value of future income or consumption will limit the potential for understatement in these cases. Given uncertainty in both the extrapolated VSLs and the estimates of future income and consumption, analysts will need to test the sensitivity of their analytic results to variation in the values. More importantly, our analysis suggests the need for more research on the values held by low income populations, which may vary due to a number of other factors such as cultural attitudes towards risks and characteristics of the labor market, healthcare systems, and so forth.

3.3 Implications and Conclusions

The research summarized in Section 2.0 suggests that there is increasing evidence that the income elasticity of the VSL exceeds 1.0 in lower income populations; i.e., that the small reductions in mortality risks that underlie the VSL are a luxury good. However, the comparisons in Section 3.2 suggest that there is substantial uncertainty in the resulting VSL estimates. Extrapolating from higher income countries, using the range of elasticities that result from the available research, leads to large differences in the resulting VSLs. These VSL estimates may fall below estimates of the present value of future consumption and income, contrary to theory.

Given that valuing mortality risks provides potentially useful information on the relative costs and benefits of alternative policies in countries where the VSL has not been well studied, we expect that policy analysts are likely to continue to value these risks by extrapolating from studies conducted in higher income countries. However, our research suggests that analysts should avoid relying on a single VSL estimate, and instead examine how the application of a range of estimates affects their results.

As noted earlier, the VSL represents individuals' willingness to exchange their own income for small reductions in their own risks, and is likely to vary across individuals and communities as well as across countries with different income levels. This variation is particularly evident when comparing U.S. values to estimated values for areas where very low incomes constrain individuals' ability to purchase even basic necessities.

While this article explores only the effects of income, there are a number of other differences between the job-related risks that are the basis of many VSL estimates and the environmental and other risks that are the subject of many policy analyses. The VSL will be affected by other population characteristics (such as age, life expectancy, health status, and total mortality risk) and characteristics of the risks themselves (such as whether they result from injuries or illness, or are viewed as voluntary or controllable). More research in low income countries is needed to refine the VSL estimates to reflect these potential sources of variation, and to better understand preferences for risk reductions among these populations. These values do not reflect many other public policy concerns, such as interest in redistributing income or reducing health disparities across population groups, which will also need to be considered in related decisions.

One issue that is not explored in detail above, but where more research also may be desirable, involves determining how to best measure income and consumption when performing these types of extrapolations, given data constraints. The VSL studies generally rely on earnings when estimating both the VSL and its elasticity, whereas policy analyses vary in the income measures used when determining changes in the VSL. Estimates of annual per capita GDP or GNI, while plentiful, do not reflect income variation over the lifecycle, and are likely to exceed personal earnings and consumption due to the effects of taxes and other factors.

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