Methodology for Valuing the Health Impacts of Air Pollution

Discussion of Challenges and Proposed Solutions

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1. Introduction

This discussion note is meant to inform a joint publication by the World Bank and Institute for Health Metrics and Evaluation (IHME) on the economic costs of air pollution. Air pollution is a global challenge and one that is acutely felt in developing countries. Illnesses caused by ambient and household air pollution claim the lives of nearly 6 million people each year, with a disproportionate majority of deaths occurring in low- and middle-income countries. The goal of the joint World Bank–IHME report is to raise awareness about the severity of this challenge and to strengthen the business case for countries to take action on reducing air pollution. To that end, the report will present new evidence on the health impacts of air pollution from the Global Burden of Disease 2013 study (GBD 2013), provide estimates of the economic costs that societies bear as a result of these impacts, and highlight the potential for economic benefits resulting from air quality management and emissions reductions.

A secondary goal of the joint World Bank–IHME report is to further the development of a consistent framework for valuing the costs of air pollution in World Bank operations. Whether in assessing potential investments or in advising client governments on policy, the World Bank undertakes a variety of activities that require it to estimate the economic costs of pollution. In recent decades, tremendous progress has been made in understanding both the epidemiology and the economics of health risks from pollution. The joint World Bank–IHME report provides an opportunity to assess what has been done and to bring more uniformity and consistency to the way pollution costs are valued across World Bank operations. The need for greater consistency was noted, for example, in a 2014 review by Cropper and Khanna of the World Bank's methodology for estimating damages from particulate emissions for the adjusted net savings (ANS) indicator (Cropper and Khanna 2014).

The joint report with the IHME will explore several alternative approaches to valuing health risks from air pollution and will provide guidance on key issues in implementing these approaches, including when certain approaches may be more appropriate than others. This discussion note serves as a background paper for the joint report and provides a detailed discussion of the key methodological choices that must be made in valuing the health impacts of pollution. This note also makes recommendations on how these challenges can be addressed. Although past efforts to value the health impacts of pollution have greatly contributed to the discussion of challenges and potential solutions, analysts have tended to make some methodological choices on an ad hoc basis. The hope in developing this note is to bring greater clarity to what the issues are and to provide guidance on how the issues can be addressed consistently. The note provides clear recommendations where possible and a framing of issues where the literature or the context does not yet provide clarity on potential solutions. Lastly, although the primary purpose of this note is to serve as a background paper for the joint report and therefore to make recommendations for the methodological

choices that are relevant in that context, this note also, to the extent possible, discusses how these choices may differ in different contexts (project analysis, for example). The note should nevertheless be treated as a living document—one that will need to be updated regularly as applications and consultations highlight other challenges and provide greater clarity on potential solutions.

2. Decisions on What Is to Be Valued: Metrics of Health Impacts

The choice of what metric to use to quantify health outcomes attributable to pollution has important implications for how the economic costs of these outcomes are valued and for their magnitude. This section discusses two key questions in the choice of metrics:

1. Should both mortality and morbidity impacts be valued together in terms of disability-adjusted life years (DALYs) lost?
2. Should mortality impacts be measured as the number of deaths or number of years of life lost?

Metrics of Health Impacts

Metrics of the health burden of pollution estimated for GBD 2013 include deaths, years of life lost (YLLs), years lived with disability (YLDs), and DALYs. Deaths and YLLs are mortality metrics, YLDs measure morbidity, and DALYs are a measure of total mortality and morbidity. DALYs are commonly used in the epidemiology literature as a summary measure of health loss, taking into account both fatal and nonfatal conditions. Under certain assumptions, DALYs are equivalent to the inverse measure of quality-adjusted life years (QALYs)—a concept that was developed a couple of decades before the concept of DALYs and that is widely used in cost-effectiveness studies of alternative disease prevention and control strategies. These metrics (or a subset of them) are found in most studies that estimate the health impacts of pollution.

In GBD 2013, for each country and cause of death, YLLs are calculated against a standard life table, which was updated by GBD researchers to account for recent demographic changes and population projections (GBD 2013 Collaborators 2015a). In calculating YLLs for GBD 2013, the GBD researchers do not discount for years of life lost at later ages, a procedure that contrasts with that used by the World Health Organization (WHO). (WHO originally calculated only discounted YLLs but now reports both discounted and undiscounted versions.) Also, the life expectancy for men and women is assumed to be the same (Murray et al. 2012).[1] YLDs per health outcome are calculated as the number of prevalent cases multiplied by a disability weight, which is "the general public's assessment of the severity of health loss" associated with that condition (GBD 2013 Collaborators 2015b: 743). Disability weights are a relative measure of different health states, ranging from 0 (no health loss) to 1 (equivalent to death). Weights for the GBD 2013 were assigned on the basis of face-to-face surveys in Bangladesh, Hungary, Indonesia, Italy, the Netherlands, Peru, Sweden, Tanzania, and the United States as well as an open Internet survey (GBD 2013 Collaborators 2015b, 743; Salomon et al. 2012). Finally, DALYs are calculated as the sum of YLLs and YLDs.

Valuing Mortality and Morbidity Together

Although DALYs are a useful summary measure of health impacts, they may be problematic for the purposes of economic valuation. The disability weights used to calculate YLDs (and thus DALYs) are meant to be a universal, value-neutral, and context-independent measure of health loss. Although the GBD survey results indicate consistency in the rankings of disability weights across countries and levels of development, disability weights are not intended to be a measure of welfare (that is, lost utility or value) or a reflection of the social consequences of various health states. This makes DALYs problematic for use in economic valuation,[2] particularly when aggregated across different health outcomes. As an example,[3] consider two patients suffering from vision loss. One is in a society in which corrective lenses are readily available and people with impaired vision have good job prospects. The other is in a society in which corrective lenses are not available or are prohibitively expensive and job opportunities are limited. When measured in terms of YLDs and DALYs, both people are considered to have suffered an equal reduction in health; however, the consequences of impaired vision are vastly different and would likely be valued differently by individuals in the two societies.[4] From this perspective, Hammitt (2002) argues that DALYs are inconsistent with the Willingness-to-Pay (WTP) approach (discussed in the next section) under which characteristics such as wealth and age may influence how individuals value health risks. By the same logic, DALYs are also inconsistent with the forgone output approach (also discussed in the next section) because the effect of health loss on an individual's capacity to perform work may depend on her profession, the industry in which she works, and other context-specific factors, including how households adjust labor inputs in response to death or illness.

Using DALYs as a metric of health impacts for economic valuation requires some additional restrictive assumptions about individual preferences (Pliskin et al. 1980, cited in Hubbell 2002; Hammitt 2002, 2013). First, longevity and the quality of life must be independent in the individual's utility function, meaning that someone's preference to live longer does not depend on how healthy she is and that preferences for health are not influenced by age or remaining lifespan. Second, there must be constant proportionality in tradeoffs between the quantity and quality of life, such that an individual would trade living 20 years in "fair" health over 10 years in "good" health the same way she would trade 10 years in "fair" health over 5 years in "good" health. Third, the individual must be risk neutral with respect to years of life such that she will prefer living longer given equal odds and that she will not take a gamble to extend her life expectancy if the odds are not as good. Fourth, there must be independence in utility functions over time, meaning that an individual's health state in previous periods will not influence her preferences in subsequent periods. Yet, empirical WTP studies have shown that (a) people disproportionately prefer reduced fatality risks over improvements in quality of health, (b) WTP for reducing mortality risks is disproportionately affected by the duration and severity of illness, and (c) WTP for reducing mortality risks varies little with age or may decline only later in life (Hammitt and Haninger 2011; Krupnick 2007).

Similar assumptions apply in monetizing the cost of YLLs as with DALYs. Assigning a single monetary value per YLL implies that individual preferences to extend life are independent of age (for example, a 30-year-old would value a year of life the same way a

75-year-old would) and that WTP is proportional to the gain in life expectancy (in other words, that WTP for 10 years of additional life should be 10 times that for 1 year of life gained). As noted, economic studies of how people value changes in the probability of death suggest that WTP is not proportional to age. However, as will be discussed more later, relatively few studies have explicitly looked at how people value changes in life expectancy. Also, although changes in mortality risks and life expectancy are mathematically related, people may not think about them in the same way and may not attach the same monetary value to one versus the other.

Despite criticisms on theoretical grounds, it is nonetheless common international practice to measure both fatal and nonfatal health outcomes in terms of DALYs in assessing their economic cost (Cropper and Khanna 2014). Recent cost of environmental degradation (COED) studies by the World Bank that evaluate health outcomes in terms of DALYs include those done in Colombia (Golub et al. 2014), India (World Bank 2013), Jordan (Croitoru et al. 2010), Kosovo (World Bank 2013c), Macedonia (Meisner et al. 2015), and Nicaragua (Klytchnikova et al. 2013). Table 2.1, drawn from the India study, shows how DALYs are used to quantify premature mortality risks as well as other health endpoints. In the India study, each premature death from air pollution is assumed to result in a loss of 7.5 DALYs for adults and 70.0 DALYs for children, while each nonfatal case of chronic bronchitis leads to a loss of 4.0 DALYs (0.2 x 20 = 4). Note in table 2.1 that other nonfatal health endpoints such as hospital admissions or outpatient visits to the emergency room are also translated into terms of DALYs (but these are very small, with the time lost measured in days).

TABLE 2.1   Disability-Adjusted Life Years for Fatal and Nonfatal Health Endpoints, Example from World Bank Study of India (2013)

Fatal health outcomes	Average YLLs	DALYs per 1,000 cases
Mortality (adults)	7.5 years	7,500.0
Mortality (children)	70.0 years	70,000.0

Nonfatal health outcomes	Disability weight	Average duration	DALYs per 1,000 cases
Lower respiratory illness (children)	0.28	10.0 days	7.7
Respiratory symptoms (adults)	0.05	0.5 days	0.1
Restricted activity days (adults)	0.10	1.0 day	0.3
Emergency room outpatient visits	0.30	5.0 days	4.1
Hospital admissions	0.40	14.0 days	15.3
Chronic bronchitis	0.20	20.0 years	4,000.0

Source: World Bank 2013a.

Note: DALYs represent the sum of YLLs for fatal outcomes plus years lived with disability (YLDs) for nonfatal outcomes. In the tables above, the calculation of DALYs follows the method originally used for the 1990 Global Burden of Disease (GBD) study by the World Health Organization and subsequent updates for 2000 and 2004. Under this method, YLDs = incident cases x disability weight x average duration. GBD 2010 and GBD 2013, on the other hand, calculate YLDs as the number of prevalent cases x disability weight. *Disability weights for lower respiratory illness and chronic bronchitis* are those used by the National Institutes of Health in the United States. Weights for other endpoints are drawn from Larsen (2004). *Average years of life lost per death from air pollution* are calculated by applying age weights and have been discounted at 3 percent per year. DALY = disability-adjusted life-year; YLL = years of life lost.

TABLE 2.2   Global Health Effects of Exposure to Ambient and Household Pollution (millions), 2013

Risk category	DALYs	YLDs	YLLs
Ambient PM$_{2.5}$	69.6	1.8	67.8
Household PM$_{2.5}$	81.0	5.4	75.6

Source: GDB 2013 Collaborators 2015c.

Note: Household PM$_{2.5}$ is from cooking with solid fuels. PM$_{2.5}$ = particulate matter less than 2.5 micrometers in Aerodynamic diameter; DALYs = disability-adjusted life years; YLDs = years lived with disability; YLLs = years of life lost.

BOX 2.1   Question: Should Mortality and Morbidity Impacts Be Valued Together in Terms of Disability-Adjusted Life Years?

Proposal: Given the problems associated with disability-adjusted life years (DALYs) when used in economic valuation, the fact that mortality is easier to explain, and the fact that deaths (or years of life lost—YLLs) represent the bulk of the overall health burden of pollution in the Global Burden of Disease study, it is recommended that only mortality impacts be valued while measuring the economic costs of air pollution for the joint report.

Outside the context of this report, both the morbidity and mortality outcomes will be relevant for the economic analysis in other situations. For example, and as recommended by the World Health Organization, both fatal and nonfatal health outcomes should be used in assessments of cost-effectiveness of particular projects or policies. Or when morbidity impacts are a nontrivial proportion of the total health impacts of air pollution, researchers may want to value DALYs and not just YLLs, problems associated with DALYs when used in economic valuation notwithstanding.

It is also important to note that morbidity represents a very small share of the total health impacts of air pollution in the context of the GBD analysis. The shares of YLLs and YLDs in total DALYs from exposure to ambient and household PM$_{2.5}$ (particulate matter less than 2.5 micrometers in aerodynamic diameter) are shown in table 2.2, as estimated for GBD 2013. Because YLLs contribute 97 percent of DALYs from ambient PM$_{2.5}$ exposure and 93 percent of DALYs from household air pollution exposure, valuing health losses in the form of DALYs yields practically the same results as valuing premature mortality risks in the form of reduced life expectancy (YLLs).[5] (See box 2.1.)

Measuring Premature Mortality

Theoretical issues aside, whether premature mortality is measured in terms of excess deaths or lost life expectancy raises important ethical questions about how health impacts suffered by the very old and very young should be weighted. According to the GBD 2013 estimates, 62 percent of deaths attributed to ambient PM$_{2.5}$ and 59 percent of deaths from household air pollution in 2013 were suffered by the over age 65 population. Children under the age

of 15, meanwhile, accounted for only 4 percent of deaths from ambient $PM_{2.5}$ and 8 percent of deaths from household air pollution in 2013. When expressed in terms of YLLs, the profile of health impacts looks much different. YLLs among the over age 65 population represented 34 percent of total YLLs due to ambient $PM_{2.5}$ and 30 percent of YLLs due to household air pollution. About 16 percent of YLLs from ambient $PM_{2.5}$ and 26 percent of YLLs from household air pollution were among children under the age of 15. The differences in the age profile of premature deaths and YLLs due to household air pollution are illustrated in figures 2.1 and 2.2.

Although YLLs per death are greater for young people, they are not the same as life expectancy, and their usefulness may be limited for the purposes of economic valuation. Because YLLs are calculated against a standard life table, YLLs per death are assumed to be the same for similar-age people around the world, regardless of actual life expectancy. For example, life expectancy in Swaziland was 21 years at age 50. The calculated number of YLLs per death for a person of that age is 35 years for all countries. Thus, valuing the economic benefit of an avoided death from air pollution due to ischemic heart disease for a 50-year-old in Swaziland using YLLs may lead to overestimates because YLLs ignore competing risks and use a lower overall risk profile for all causes of death in that country. (See box. 2.2.)

FIGURE 2.1 Worldwide Deaths Due to Household Air Pollution from Cooking with Solid Fuels, 2013
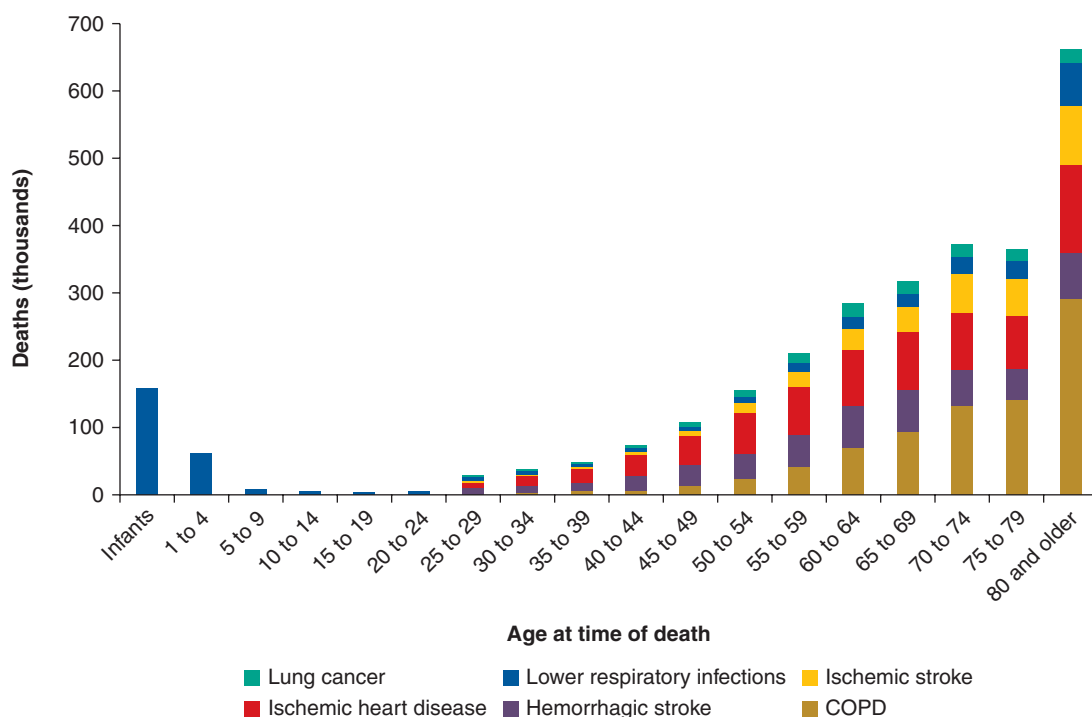
Source: GBD 2013 Collaborators 2015c.
Note: COPD = chronic obstructive pulmonary disease.

FIGURE 2.2   Worldwide Years of Life Lost Due to Household Air Pollution from Cooking with Solid Fuels, 2013
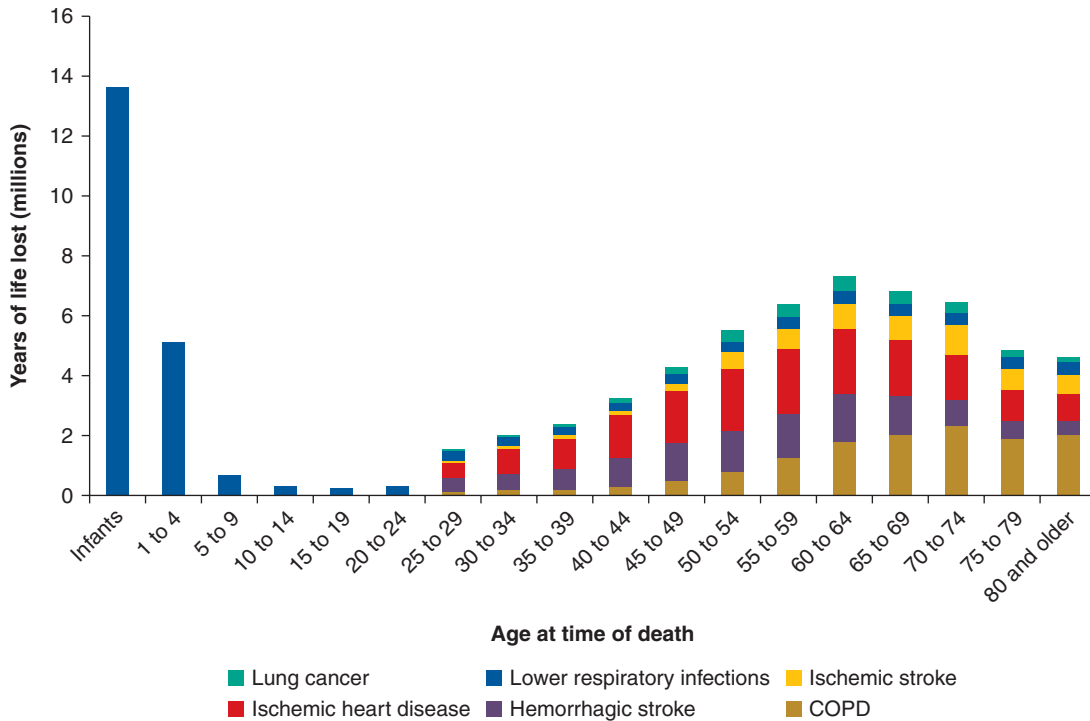
Source: GBD 2013 Collaborators 2015c.
Note: COPD = chronic obstructive pulmonary disease.

BOX 2.2   Question: Should Mortality Impacts Be Measured as Number of Deaths or Number of Life Years Lost?

Proposal: The literature offers almost no guidance as to whether it is better to measure number of deaths or reduced life expectancy when evaluating the economic costs of premature mortality from air pollution. Both deaths and years of life lost (YLLs) are common in the medical literature, though the usefulness of YLLs versus actual life expectancy increases may be limited for the purposes of economic valuation. The choice between valuing deaths or reduced life expectancy in assessing the burden of disease from air pollution hinges on whether impacts among children or older people should be weighted more heavily in the calculation. This is as much an ethical question as it is an economic one. For the purposes of assessing the global burden of disease, separate calculations will be made in valuing both deaths and reduced life expectancy. In other contexts, the choice of metric may be guided by the context of the project or policy at hand.

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Notes

1. The choice not to apply age weighting or to differentiate life expectancy for men and women in calculating YLLs represents a departure from common practice before the GBD 2010. See Haagsma et al. 2014.
2. The exception is with cost-effectiveness analysis. For example, WHO has recommended the use of DALYs as a standard parameter for comparing the cost-effectiveness of health interventions and policies (such as by comparing implementation costs per avoided DALY) (Tan-Torres Edejer et al. 2008; WHO 2008). U.S. government agencies have also used DALYs in assessing the cost-effectiveness of policies that reduce health risks (see Robinson 2007).
3. The following hypothetical is posed by Voigt and King (2014).
4. The example by Voigt and King (2014) points to additional concerns about equity. For a relevant discussion of equity and the choice of health metrics in economic analysis, see Whitehead and Ali (2010).
5. This point is raised by Cropper and Khanna (2014).

3. Approaches to Valuing the Economic Costs of Premature Mortality

This section considers the different approaches to valuing the economic costs of premature mortality and the methodological challenges in implementing them. In particular, it tries to provide answers to the following questions:

1. When should the willingness-to-pay (WTP) approach be used versus the forgone-output approach?
2. Should value of statistical life (VSL) be adjusted for age differences, health status, income, or risk characteristics?
3. How should deaths among children be valued?
4. Should VSL or value per statistical life year (VSLY) be used? How should VSLY be estimated?
5. What base VSL should be used, and how should the VSL be transferred between countries?
6. How should working age, future growth rates, and discount rates be defined when implementing the forgone-output approach?

Willingness-to-Pay Approach

By causing illness, pollution is a detriment to the things that individuals fundamentally value, including consumption, leisure, good health, and life itself. Individuals make tradeoffs between things of value every day. For example, they sacrifice leisure by going to work so that they can increase consumption. In valuing the increased risk of death due to pollution, the task of the economist then is to weigh the tradeoffs that individuals would be willing to make to reduce their chances of dying. What the economist seeks to measure is the individual's willingness to pay (WTP) in exchange for a reduced chance of dying—or willingness to accept (WTA) compensation in exchange for an increased fatality risk—to maintain the same level of utility.[1] Graphically, the marginal rate of substitution between wealth and the probability of survival (or risk of death) is depicted in figure 3.1 as the slope of an individual's indifference curve (see Cropper et al 2011, 315–316). Supposing that pollution reduces the probability of survival from P_1 to P_2, the cost to the individual would be equal to the vertical distance from W_1 to W_2. The economist would monetize the loss of value suffered by the individual due to pollution by assigning a dollar amount to ΔW, which is what the individual would be willing to pay to avoid such an increase in mortality risk and thereby sustain the same level of utility.

The value of statistical life (VSL) represents an aggregate of individuals' willingness to pay (WTP) for marginal reductions in their mortality risks (R). It is *not* the value of any single person's life or death, nor does it represent a society's judgment as to what that value should be. In figure 3.1, for small changes in survival probability, the VSL can be approximated as VSL = $\Delta W/\Delta P$. As a stylized example of how the VSL is derived and how it relates to the cost of pollution, suppose that pollution increases the odds that any given individual would die in a year on average from 2 in 10,000 to 3 in 10,000.[2] This is ΔP. Probability implies that among 10,000 people, 1 person dies each year due to the increased risk from pollution. Suppose further that individuals in this society are willing to pay US\$30 on average to reduce their risk of

FIGURE 3.1 The Tradeoff between Wealth and the Probability of Survival (or Risk of Death)
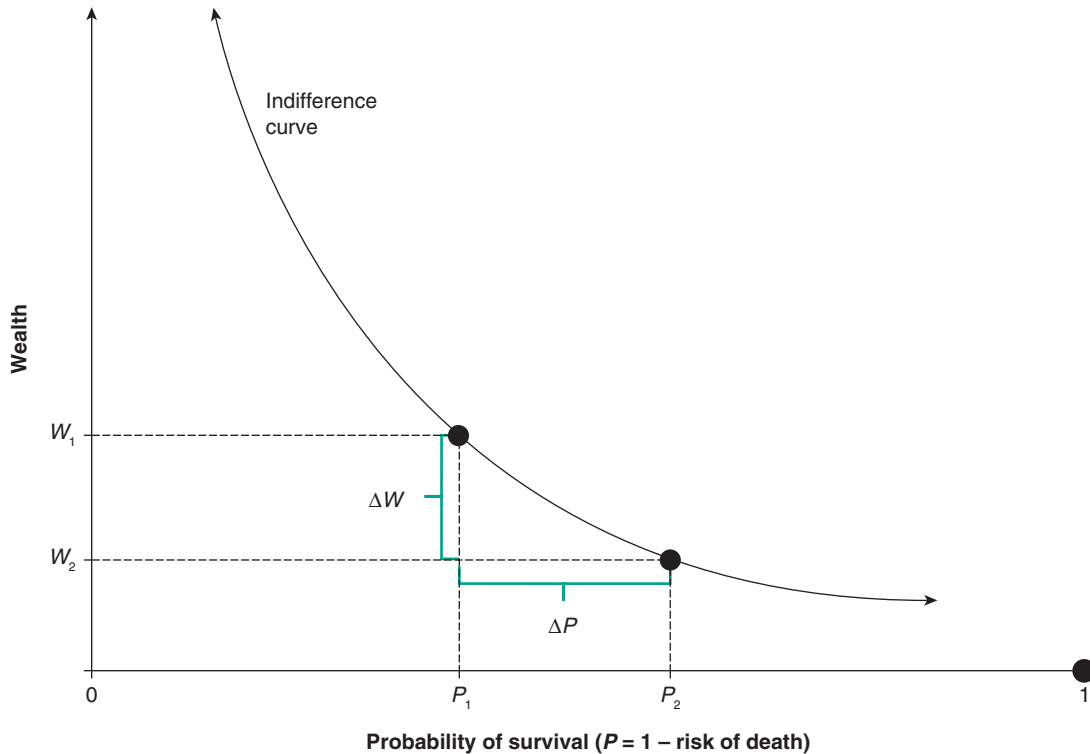
Source: *World Bank, adapted from* Cropper et al. 2011.
Note: Δ = change.

death by a margin of 1 in 10,000. This is ΔW. Summing this average WTP value over 10,000 individuals, the value of one statistical life would be equal to US$300,000.

Empirically, the VSL is derived from studies of people's stated preferences or revealed preferences (actual behavior). In stated-preference studies, individuals are presented with hypothetical scenarios and asked to make choices. For example, they might be asked about how much they would be willing to pay for a new medical treatment that would reduce their risk of dying from cancer, or they might be asked to choose between paying for different programs to reduce the risk of traffic fatalities in their city. In any case, researchers must: (a) present respondents with information about their baseline risk of death and the nature of the risk; (b) describe the context; (c) define how much their risk will be reduced (or increased) and who exactly will benefit from the risk reduction (for example, adult individuals or their children); (d) clarify the time period over which risks will be reduced (for example, now or 10 years later); (e) explain who will be expected to pay (for example, the individual or general public); and (f) provide other relevant information (Kling et al. 2012).

For the purposes of evaluating the costs of pollution, the appeal of stated-preference studies is that they enable researchers to investigate the preferences of a broad array of individuals, including those most affected by pollution, and to ask about health risks similar to those actually experienced by people exposed to pollution. The main disadvantage of such studies is that

they are based on hypothetical situations in which respondents may disregard their actual budget constraints or make spurious choices without real consequences (Cropper et al. 2011; OECD 2012). Also, respondents may be asked about small changes in survival probability that are difficult to comprehend, and their choices may be influenced by how those choices are embedded (for example, whether a hypothetical program is presented by itself, in comparison with another program, or bundled in a package) or the order in which choices of different magnitude are posed. Whether such differences lead to systematic bias or unreliability in VSL estimates derived from stated-preference studies is open to debate (see Carson 2012; Hausman 2012; Kling et al. 2012). For some goods, individuals tend to overstate their WTP when asked in surveys; for reducing illness-related risks, however, previous reviews have found that individuals often understate their WTP when survey results are compared with revealed market behavior (Cropper et al. 2011; Kochi et al. 2006).[3]

In revealed-preference studies, researchers investigate individuals' WTP by observing their behavior in actual markets. The most common approach in estimating the VSL has been to examine differences in wages for more or less risky occupations (see Viscusi 2004). This is the approach that the U.S. Environmental Protection Agency (EPA) has primarily taken in valuing mortality risk reductions (Robinson 2007). Other approaches may value pollution costs by looking at differences in real estate prices between more and less polluted areas (see Zheng et al. 2014), or gauge individuals' willingness to spend on protective measures such as face masks that limit their exposure to air pollution (see Zheng et al. 2015).

Although revealed-preference studies of wage-risk differentials are often seen as more credible, they face drawbacks that may limit their usefulness for valuing pollution-related health risks. Wage-risk studies used to estimate the VSL assume that workers are well informed about their actual risk of on-the-job injury and that they are in a competitive labor market in which they are perfectly mobile and can negotiate higher wages with employers for taking riskier jobs. These conditions do not hold for workers in many developing countries. Furthermore, because wage-risk studies focus on working adults, they do not capture the preferences of people outside the labor force "whether because of illness, retirement, child raising, or other reasons" (Cropper et al. 2011, 317). Studies of wage differentials for morality risks also face a host of econometric issues, such as determining how to account for unobserved characteristics of workers that incline some to take more or less risky jobs for reasons other than pay (Cropper et al. 2011, 317; Kniesner and Viscusi 2005).

Other Approaches to Valuing Health Impacts

Alternative approaches to valuing health impacts include the cost of illness (COI) approach. The COI approach seeks to account for the direct and indirect financial costs of death and illness. Direct financial costs include ambulance costs, medical expenses, wages lost by sick workers, and time spent caring for ill family members, among others. Indirect financial costs include such costs as productivity losses to firms from declining customer service quality and missed business opportunities because of sick employees. The COI approach could be used to value the financial costs of health impacts arising from either acute or chronic exposure. As an example of the COI approach in practice, the U.K. Department for Transport includes direct and indirect financial costs in valuing the costs of road traffic fatalities. It counts these financial costs apart

from what the agency calls "human costs," which "are based on willingness to pay to avoid pain, grief and suffering to the casualty, relatives and friends, as well as intrinsic loss of enjoyment of life" (U.K. DFT 2012, 2). The COI approach is also frequently used in measuring the costs of morbidity (nonfatal health outcomes), as will be discussed in greater detail in a later section.

The forgone output (FO) approach, sometimes referred to as the human capital approach, is related to the COI approach. It is an income-based approach and equates the financial cost of premature mortality with the present value of forgone lifetime earnings. The Ministry of Social Development (MDS) in Chile, for example, has adopted the FO approach in its guidelines for valuing premature mortality. MDS estimates the average cost of an early death at UF 12,868 (Chile MDS 2014). A common criticism of this approach is that it excludes losses suffered by individuals outside the labor force, including retirees. The income-based approach also raises questions about how unpaid work that contributes to the economy, such as subsistence farming and domestic activities, should be valued. An adjusted approach seen in countries such as China is to value mortality among all individuals regardless of participation in the labor force using gross domestic product (GDP) per capita discounted over remaining life expectancy (see World Bank–SEPA 2007).

Although the FO approach accounts specifically for reduced labor output due to the loss of individuals' time endowment, computable general equilibrium (CGE) modeling may be applied to measure the wider productivity losses to the economy. These models simulate how the effects of premature deaths and nonfatal health outcomes are propagated across sectors and over time, leading to changes in overall economic activity and consumption. For example, Matus and coauthors (2012) use an expanded version of the Emissions Prediction and Policy Analysis (EPPA) model developed by the Massachusetts Institute of Technology to simulate the broader economic impacts caused by air pollution exposure in China as a result of diverting labor from productive activities and reducing the time for leisure. Tracking the effects of exposure to PM_{10} and ozone in major cities from 1970 to 2005, they estimate that air pollution reduced annual consumption in China in 2005 by 7 percent, or US$69.0 billion (1997 prices). Including welfare losses—estimated in terms of lost leisure time and valued at the wage rate, not the WTP to avoid mortality risk—they figure total economic losses due to air pollution in 2005 to be US$184.5 billion. Similar analyses using the health-adjusted EPPA model have been done for the United States (Matus et al. 2008) and Europe (Nam et al. 2009). Analysis by the World Bank in India has used CGE modeling to estimate the GDP impacts of reducing air pollution emissions through the use of a tax on coal or emissions (World Bank 2013b).

Use of the Willing-to-Pay–Based Approach versus the Forgone Output Approach

The WTP-based approach is best suited for analyses of economic welfare and has become the standard approach in high-income countries for valuing mortality risks associated with pollution (see Cropper 2000; OECD 2012; Viscusi 1993). The forgone output approach continues to be used for policy analysis by public agencies in some countries such as Chile and China. Both the WTP-based approach and forgone output approach may be applicable for cross-country comparisons of health impacts and costs or other applications depending

on the scope of the application. In theory, the present value of lifetime earnings should be less than the VSL, which captures the utility derived from intangibles such as being alive and spending time with loved ones in addition to consumption (Hammitt and Robinson 2011).

The forgone output provides an income-based measure of health impacts and may be more appropriate for financial analysis and accounting, for example, in calculating pollution costs as a component of adjusted net savings (ANS) within the System of National Accounts framework. ANS, or "genuine savings," is a measure of the change in the value of a nation's assets, including manufactured capital as well as natural and human capital (see Hamilton and Clemens 1999; World Bank 2005, 2011). Positive savings represent an investment in future well-being as a nation accumulates the assets needed to drive economic growth and at least sustain current levels of consumption. Within the ANS framework, premature mortality due to pollution represents a disinvestment in a nation's human capital stock. As with the degradation of other forms of capital, the value of this disinvestment would be valued according to an expected loss of income over the lifetime of the asset.[4]

Losses valued under a FO approach are typically much smaller than those valued under a WTP approach. Because of this, in COED studies by the World Bank, the FO approach is still frequently used to estimate the lower bound of losses in economic welfare due to pollution.[5] FO may represent to the lower bounds of WTP so long as average utility of consumption is greater than marginal utility of consumption, which is true for strictly concave utility functions (Cropper 2000). However, although welfare-based and income-based measures typically provide a range of health costs, they should not be averaged and presented as a single measure. Also, in COED studies, welfare-based estimates of damages should not be added to other productivity-based measures of environmental degradation that are presented as a percentage loss of GDP, as GDP is an income-based measure. If presenting the welfare-based estimate as a percentage of GDP, appropriate language should be added to explain to readers how they should interpret this measure.

Finally, both types of approaches can be used in project analysis: income-based measures in project financial analysis, and welfare-based measures in project economic analysis. (See box 3.1)

BOX 3.1   Question: When Should the Willingness-to-Pay Approach Be Used Instead of the Forgone Output Approach?

Proposal: Both the willingness to pay (WTP) approach and forgone output (FO) approach may be applicable for cross-country comparisons of health impacts or other applications, depending on the scope of the applications. Estimates based on both approaches will be provided for the joint study. FO is more appropriate for financial analysis and accounting, as in calculating pollution costs as a component of adjusted net savings or in project financial analysis. The WTP approach, on the other hand, should be used in project economic analysis. Both approaches can be used in cost of environmental degradation studies. Although welfare-based and income-based measures typically provide a range of health costs, they should not be averaged and presented as a single measure. Welfare-based estimates of health damages should also not be presented as a percentage of gross domestic product without appropriate language to clarify that the comparison is only being made for convenience as a benchmark of magnitude.

Factors Influencing the Value of Statistical Life

A variety of factors influence the VSL, including the income, wealth, age, life expectancy, cultural beliefs, and health status of the affected individuals who make up a society. Moreover, as Cropper and coauthors write, an individual has no single VSL: "Different people have different preferences, and for an individual, the value of a 1-in-10,000 risk reduction may depend on whether death results immediately from injury or from a lingering illness, whether it is caused by a hazard viewed as particularly fearsome, whether one is rich or poor or old or young, and other factors" (Cropper et al. 2011, 316).

The following section describes salient population and risk characteristics that affect the VSL. Population characteristics discussed include age, health status, and income.

Age

The relationship between age and the value of mortality risk reductions is a complex and contentious issue. As noted above, the age question is important because of how the health impacts of air pollution are distributed.

Experts and public agencies around the world are split as to whether the VSL should be adjusted in assessing health benefits and costs for people of different ages. The US EPA, OMB, and DOT have discontinued the practice of discounting the VSL for the elderly or making other adjustments for age in valuing mortality risks, with the expert panels advising these agencies citing a lack of consistent empirical support (Morgan et al. 2007; NRC 2008; U.S. EPA 2014; U.S. OMB 2003). The Organisation for Co-operation and Development (OECD) also disfavors making age adjustments to the VSL (OECD 2012). Meanwhile, the Canadian government has regularly applied a 25 percent discount to monetize reduced mortality risks for the over age 65 population (Chestnut and Civita 2009). The European Commission Directorate-General for Environment (EC DG Environment) has recommended that the VSL be discounted by 30 percent for the elderly (Hurley et al. 2005). Previous studies by the World Bank of the health costs of pollution have also applied age discounting to value premature mortality, either directly or implicitly through the use of a constant VSLY to monetize DALYs (Hammitt and Robinson 2011). If the VSLY is used to monetize health impacts rather than the VSL, the U.S. Office of Management and Budget (OMB) has recommended a higher VSLY be used for older adults (U.S. OMB 2003).

The effect of age on the VSL is theoretically indeterminate (Morgan et al. 2007; Hammitt 2007; Hammitt and Robinson 2014). As people age, their life expectancy shortens, but they may also be wealthier. As their preferences evolve, they may place a greater value on longevity or preserving their health. Stated-preference studies have found some evidence of a lower VSL only among the very old.[6] For example, in a survey by Alberini and coauthors (2004), respondents in Canada who were over the age of 70 were willing to pay about 33 percent less than younger respondents to reduce their risk of dying over the next 10 years. Respondents in the United States over the age of 70 were willing to pay about 20 percent less than younger respondents, although the difference in WTP for the U.S. sample was statistically insignificant. Similarly, in another stated-preference study, Krupnick and coauthors (2010) observed that WTP among respondents over the age of 70 in the Chinese cities of Shanghai, Nanning, and Jiujiang declined

by 20 percent for contemporaneous risk reductions, after controlling for differences in health and other factors. Reviewing the results from more than 20 other stated-preference studies, Krupnick concludes that "the evidence for a senior discount is too thin to be relied on for policy purposes" (Krupnick 2007, 262).

Blomquist and coauthors (2011) posit that the relationship between age and the VSL may be nonmonotonic. The authors conducted two separate surveys in the United States in which adults weighed the tradeoffs between drugs that better control asthma symptoms but also increase fatality risks. In the first survey, parents with asthmatic children between the ages of 4 to 17 were asked to make choices to treat their children. In the second survey, adults in the general population ages 23 and older were asked about their own preferences. The survey results show that the VSL for children is about 1.7 times higher than the average adult VSL. The VSL gradually declines for young people between the ages of 4 and 30, rises for adults over 30, and then declines again for people in retirement age. Another study by Hammitt and Haninger (2010) estimated that the WTP of parents to reduce risks to their children is 1.5 to 2.0 times larger than the WTP to reduce their own mortality risks or the risks faced by other adults. Not only does the higher VSL for young children reflect the altruistic concerns of parents, but also it is influenced by the fact that parents tend to be more affluent than young people in their teens and twenties with lower VSLs (Viscusi 2010).

The practice of assigning higher values to mortality risk reductions among children has tended to be less controversial than discounting the VSL for older adults (Hammitt and Robinson 2014; Viscusi 2010). Normally, the VSL should reflect the aggregate of affected individuals' *own* WTP for reducing their risk of death, but children represent a special case. Children have little concept of risk and are usually not held responsible for making decisions affecting their well-being or chance of death. The U.S. EPA has endorsed the use of parent surveys to value costs and benefits to children's health, finding that "the parental perspective provides value estimates from individuals likely to have the child's best interest at heart, incorporates the household context into the estimation approaches, and can be implemented using a variety of valuation techniques" (U.S. EPA 2003, 2–11). Although the EPA does not find sufficient evidence to derive age-specific VSLs for children (U.S. EPA 2014), it does suggest that these values are systematically higher (U.S. EPA 2003). The U.S. OMB recommends the use of monetary values that are at least as large as those used for adults (U.S. OMB 2003). The OECD has recommended that the VSL for children should be 1.5 to 2.0 times higher than the mean adult VSL when assessing public health risks that mainly affect children or evaluating programs that specifically target children (OECD 2012).

Virtually all of the COED studies by the World Bank in recent years have forgone the use of a VSL in monetizing impacts on children's health from pollution and instead have taken a forgone output approach.[7] The commonly cited reason for this approach is that no VSL studies have been done for children, and children have poorly defined risk preferences. An exception is the 2007 study of pollution damages in China by the World Bank and the Chinese environmental protection authority, which applies the adult VSL to value child mortality following U.S. EPA guidance (World Bank—SEPA 2007). Under a forgone output approach, children's deaths are monetized as the discounted value of their expected lifetime earnings (see box 3.3 and box 3.11.)

BOX 3.2   Question: When Using the Value of Statistical Life, Should the Value of Statistical Life Be Adjusted for Age Differences in the Adult Population Affected by Air Pollution?

Proposal: Given that the effect of age on VSL is theoretically indeterminate and that the empirical evidence is mixed, experts and public agencies around the world are split as to whether the VSL should be adjusted in assessing health benefits and costs for people of different ages. Consequently, conditional on using VSL, an age-independent VSL will be used for adults, though sensitivity analysis may be done to compare the effect of discounting the VSL by 20–30 percent for persons aged 70 and older, corresponding roughly to the differences in WTP observed by Alberini and coauthors (2004), Krupnick and coauthors (2010), and the rate used by the European Commission Directorate-General for the Environment. Note that use of a VSLY, as opposed to the VSL, implicitly discounts health impacts among older people with shorter remaining lifetimes. The choice to use an age-invariant VSL in other contexts will depend on the nature of the health risk being evaluated and whether a particular policy or project targets people in a specific age group.

BOX 3.3   Question: How Should Deaths among Children Be Monetized?

Proposal: The VSL for children should be set according to what adults are willing to pay to reduce risks to children in the country where the health impacts are taking place. If such an estimate is not available, then it is recommended that the default be to use the adult VSL as the existing empirical evidence on what parents are willing to pay is mixed. Furthermore, use of the forgone income approach to value deaths among children while using a WTP-based approach to value deaths among adults is also not recommended as this implicitly discounts the value of children's deaths, and also mixes welfare-based measures and income-based measures in a single indicator.

Health Status

As noted by the U.S. EPA, individual health status "is an especially relevant factor for valuation of environmental risks because individuals with impaired health are often the most vulnerable to mortality risks from environmental causes. For example, particulate air pollution appears to disproportionately affect individuals in an already impaired state of health" (U.S. EPA 2014, B-5). However, the empirical evidence for how individual health status influences the VSL is mixed at best. A study by Tsevat and coauthors (1998) of elderly hospitalized patients found that patients placed a higher premium on extending life than did medical care providers and family members. Stated-preference studies in the United States and Canada by Krupnick and coauthors (2002) and Alberini and coauthors (2004) showed that individuals in poor health did not have a significantly different WTP for mortality risk reductions than others. A more recent survey of people's WTP to avoid air pollution in Beijing and Shanghai similarly did not reveal any difference in WTP among respondents suffering from respiratory disease versus those who reported good health (Tan and Zhao 2014).

As with the influence of age on the VSL, the EPA finds insufficient theoretical and empirical support to warrant the use of a health-adjusted VSL for policy purposes (U.S. EPA 2014).

This advice mirrors that of earlier expert panels (Morgan et al. 2007; NRC 2008). The OECD also has avoided making adjustments for varying health status between countries in its estimates of the costs of air pollution (OECD 2014; WHO-OECD 2015). None of the COED studies by the World Bank have adjusted the VSL for an affected population's general state of health. (See box 3.4.)

Income

Both theory and the available body of empirical evidence support the notion that the value attached to mortality risk reductions increases for individuals with higher incomes. For equity concerns, governments have typically not adjusted VSLs to reflect cross-sectional differences between poorer and richer citizens. In country-level policy analysis, a single VSL is typically used for the entire country despite pronounced differences in income between people living in different regions (see World Bank-SEPA 2007). The reasoning behind this choice is that the costs of pollution should be aggregated at the societal level at which the collective economic burden is typically shared and the policies to control pollution are typically made: the nation state (WHO-OECD 2015).

Although the notion that the VSL should rise with income is commonly accepted, the extent to which the VSL varies with income is the subject of debate. Lindhjem and coauthors (2011) conducted a meta-regression analysis for the OECD of VSL estimates from more than 80 stated-preference studies done in 38 countries between 1970 and 2008. They estimate an income elasticity of between 1.17 and 1.31 for the entire sample set.[8] This finding suggests that WTP for mortality risk reductions would increase more quickly than would income and that the ratio of the VSL to per capita income would be greater in high-income countries than in low-income or middle-income countries.[9] After screening for studies that meet certain quality standards,[10] however, the elasticity estimated by Lindhjem and coauthors falls to between 0.77 and 0.88, implying that the VSL is income inelastic. Imposing further restrictions to include only studies that satisfy validity tests reduces the elasticity to between 0.33 and 0.75.[11] Although this restricted sample is composed mainly of VSL estimates from studies in high-income OECD countries, it does include estimates from a number of middle-income countries. Attempting to eliminate the effect of methodological differences, Lindhjem and coauthors proceed to use an even more restricted sample of estimates drawn from studies that employ the best-practice survey instrument developed by Krupnick and coauthors (2002). This set yields income elasticities in the range of 0.30 to 0.44. Using the same questionnaire, a more recent WTP study by Hoffmann and coauthors (2012) in Ulaanbaatar, Mongolia, estimates an average within-sample income elasticity of 0.38 to 0.60 for WTP for

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BOX 3.4   Question: Should Mortality Risks Be Valued Differently for People in Different Health States?

Proposal: Although individuals in poor health may be more susceptible to the health effects of pollution, theoretical and empirical evidence are insufficient to suggest that their WTP for reduced mortality risk is any different. The VSL, therefore, need not be adjusted to reflect differences in health status.

contemporaneous risk reductions and 0.38 to 0.52 for longer-term risk reductions. Also using the same survey instrument, Krupnick and coauthors (2010) estimate an even lower average income elasticity in the range of 0.15 to 0.25 for respondents in the Chinese cities of Shanghai, Jiujiang, and Nanning.

Others argue that income elasticity of the VSL should be greater than 1, as suggested by the literature on risk aversion (see Kaplow 2005). Kniesner and coauthors (2010), for example, use data on wages, occupational risks, and demographics in the United States. Rather than looking at the average effect of wage difference, they employ a quantile regression model to capture how people at different income levels value mortality risk reductions. They find that income elasticity ranges from 1.23 for people in the top 10th percentile of wages to 2.24 for people in the bottom 10th percentile. In a meta-analysis of VSL estimates from stated-preference studies, Biausque (2012) takes a similar methodological approach to explore differences in income elasticities estimated from studies in poorer versus richer countries. He estimates income elasticities above 1 for countries in the bottom 40th percentile of income and below 1 for countries at higher income levels. Viscusi (2010) argues that it is reasonable to assume an elasticity of at least 1 in assessing costs and benefits to the general public—well above the values of 0.5–0.6 estimated from wage-risk studies of people of working age and in decent health (Aldy and Viscusi 2007).

The paucity of contingent valuation studies in low-income countries makes it difficult to say whether the observed relationship between the VSL and income in middle-income and high-income countries also holds for poorer countries. Robinson and Hammitt (2009), Hammitt and Robinson (2011), and Cropper and Sahin (2009) argue that basic economic reasons explain why the income elasticity of WTP for risk reductions is likely higher in low-income countries than in richer countries and may be greater than one. In low-income countries, survival probabilities are lower, private discount rates are higher, and a larger share of consumption expenditure is devoted to satisfying basic needs. In such an environment where baseline health risks are often higher and basic social services and safety nets lacking, individuals' attitudes toward risk are also likely different. Given that, it seems reasonable that WTP for relatively small reductions in mortality risk, such as those commonly posed in stated-preference studies, would represent a smaller percentage of income for people in lower-income countries than in more affluent countries such as the United States. Comparing the ratio of the VSL to per capita income as estimated from previous meta-analyses of empirical WTP studies in developing countries, Cropper and Sahin (2009) find this to indeed be the case.

Further support for the claim that income elasticity of the VSL is higher in developing countries is provided by longitudinal studies. These studies gauge how WTP for mortality risk reductions has varied at different stages of economic development. For example, using wage-risk data from 1982 to 1997 in Taiwan, Hammitt, Liu, and Liu (2000) estimate the income elasticity of the VSL to be in the range of 2.0–3.0. Using wage-risk data from 1940 to 1980, Costa and Kahn (2004) estimate the elasticity for the United States at 1.5–1.7. There are no longitudinal estimates of the VSL from stated-preference studies.

Moreover, little consensus exists on how the VSL should be adjusted to account for the effect of income growth over time. The U.S. EPA has recommended making an adjustment for

BOX 3.5   Question: Should the Value of Statistical Life Be Adjusted for Differences in Income?

Proposal: For the purposes of the global assessment, for which most assessments are at the national level, a single country-level VSL will be used. For country-level assessments, subnational VSL may be applied. This decision should be made in consultation with local stakeholders.

The VSL should, however, be adjusted for cross-sectional differences in income between countries as well as for income growth over time. Although the empirical evidence from many stated-preference studies suggests an income elasticity value of less than one, a low elasticity produces estimates of VSL for low-income countries that are often not credible. Other empirical studies have provided support for elasticity values above one. Consequently, it is suggested that a range of elasticity values be considered, especially for situations in which large differences in income exist among the affected population and in which mortality risks are being valued over a long time period. Especially when the VSL is transferred to a different context from the one in which it was originally estimated, the choice of elasticity value could have a material influence on the resulting cost estimates. This choice should be communicated clearly and discussed with local stakeholders involved in the analysis.

For the World Bank–IHME report, differentiated elasticity values will be assumed for countries of different income levels. The value of 0.8 recommended by the OECD (2012, 2014) will be assumed for high-income countries, with a range of 0.6–1.0 for sensitivity analysis. For low-income and middle-income countries, a higher central value of 1.2 will be assumed, with a range of 1.0–1.4 for sensitivity analysis. The choice of elasticity values for the global assessment is tied closely to the choice of the base VSL and will be discussed in greater detail in a later section of this report on benefit-transfer methods (see "Transferring base estimates of the VSL to value health impacts in other countries").

income growth when assessing the potential benefits of reducing mortality risks in future years (U.S. EPA 2014). A prospective study done by the EPA in 2000, for example, examined the benefits of the Clean Air Act from 1990 to 2010. In the study, the agency assumed a wide range of income elasticities (0.08, 0.40, and 1.00). The U.S. Department of Transportation, meanwhile, assumes an income elasticity of 1 to project the VSL in assessing costs and benefits in future years (U.S. DOT 2015) (see box 3.5).

Risk Characteristics

Whether different estimates of the VSL should be applied for different risks or causes of death is another contentious issue. Dimensions of risk that affect the VSL include whether a risk is voluntary or involuntary, ordinary or catastrophic, immediate or delayed, natural or constructed, old or new, controllable or uncontrollable, necessary or unnecessary, and occasional or continuous (U.S. EPA 2010, B-3). For example, in the European Union and United Kingdom, economic assessments by public agencies may use higher values to monetize cancer risks because of the dread that people feel toward cancer (cited in Cropper et al. 2011, 330). Empirical evidence of a "cancer premium" is mixed. Hammitt and Haninger (2011) find little difference in WTP for reduced risk of death from cancers, other diseases, and traffic accidents. Alberini and Ščaný (2013), on the other hand, observe that the VSL

increases with dread, exposure to risk, and respondents' perceptions of their baseline level of risk. They estimate that the WTP for avoided cancer deaths and respiratory illnesses is significantly higher than that for motor crashes. In a nationally representative stated-preference study in the United States, Viscusi, Huber, and Bell (2014) found evidence of a 21 percent premium in WTP for avoiding the latent risk of cancer compared with acute fatality risks. As standard practice, the United Kingdom typically doubles the VSL in estimating the economic benefits of asbestos removal compared with traffic safety (U.K. Treasury 2011, 62).

WTP should increase with the magnitude of risk, and Cropper and coauthors (2011) recommend that this assumption be used as a minimum criterion for acceptability of VSL studies. In theory, WTP should increase proportionally to the size of the risk reduction, but this has not been borne out by many empirical studies. For example, Alberini and coauthors (2004) find that the mean WTP among U.S. respondents of reducing the annual risk of mortality by a factor of 10-in-10,000 is about 1.6 times that for a 5-in-10,000 risk reduction. Hoffmann and coauthors (2012) estimate that the mean VSL in Ulaanbaatar, Mongolia, for reducing annual mortality risks by 10 in 10,000 is only 1.15 times the WTP for a risk reduction of 5 in 10,000.

Individuals living in riskier environments, with lower baseline survival rates and other kinds of competing risks, may value health risks differently from those in less risky environments, all else being equal. Eeckhoudt and Hammitt (2001) have shown that the higher level of background mortality or competing financial risks faced by an individual, the lower the WTP to reduce any one risk. If the competing risk is much larger than the target risk, the result may be a "why bother?" effect (Eeckhoudt and Hammitt 2001, 274). Because the individual is unlikely to survive the competing risk anyway, WTP to reduce a target risk may be much lower. However, for smaller changes in baseline mortality rates, such as those commonly posed by competing environmental risk factors, the overall effect is usually negligible. (See box 3.6.)

The Value per Statistical Life Year

In the United States and other OECD countries, the WTP-based approach using the VSL is the standard method for monetizing the economic costs of premature mortality (WHO-OECD 2015). An alternative approach, which is found in international practice, is to monetize premature mortality in the form of reduced life expectancy using a value per statistical life year

(VSLY) (Cropper and Khanna 2014).[12] The VSLY is commonly used to value the cost of DALYs or YLLs, while the VSL is used to monetize the number of statistical deaths. But the issue of how the VSLY should be appropriately estimated is contentious.

In practice, the VSLY is usually derived by dividing the VSL by the discounted number of years remaining in the average person's expected lifespan (Cropper and Khanna 2014). In the World Bank's 2013 study of pollution costs in India, for example, the discounted remaining life expectancy for the average adult is assumed to be 7.5 years. Previously, in the World Bank's calculation of air pollution damages as part of adjusted net savings, it was assumed to be 22 years. This method for deriving a constant VSLY implies that that individuals' WTP for mortality risk reductions, and hence the VSL, should decline proportionally with age. As previously discussed in the section on age and the VSL, however, this assumption is not borne out by empirical evidence, and there is little support for using a single VSLY to value life years for people of all age groups (Aldy and Viscusi 2007; Cropper and Khanna 2014; Hammitt 2013; Krupnick 2007; Morgan et al. 2007; NRC 2008; Ryen and Svensson 2015; U.S. EPA 2014; Viscusi 2014). Valuing health impacts in the form of DALYs or YLL using a constant VSLY further implies that that the VSL should decline proportionally with the state of an individual's health. However, in comparing the VSLY for smokers and nonsmokers, Viscusi and Hersch (2008) have found this not to be the case. Smokers have similar VSLY values as nonsmokers despite generally being in poorer health.

Relatively few studies have attempted to determine the VSLY empirically (OECD 2012).[13] Desaigues and coauthors (2007, 2011) have produced two recent examples. The authors conducted a contingent valuation study in nine European countries to estimate a policy-relevant VSLY for the European Union as part of an European Commission–funded effort. In the survey, adult respondents were asked about hypothetical air pollution control measures that would lead to small gains in life expectancy of three to six months but would also increase the cost of living. As explained to respondents, this gain in life expectancy does not mean "additional months of misery at the end of one's life" (Desaigues et al. 2011, 905); rather it is more like decelerated aging. The authors argue that these marginal changes in life expectancy are easier to understand and provide better results than asking respondents about small reductions in the probability of dying (see also Morris and Hammitt 2001). The results indicate an appropriate VSLY for cost-benefit analysis of air pollution policies in the EU-25 of around €40,000, with a confidence interval of €25,000 to €100,000 (PPP-adjusted, year 2005 prices).[14] The authors find that respondents' WTP for marginal gains in life expectancy did not vary significantly by age.

The VSLY estimated by the Desaigues et al. study is below the range of values that has been used by the EC DG Environment elsewhere for cost-benefit analysis of environmental policies. Analyses of the Clean Air for Europe Programme (CAFE) and the EU Clean Air Package have employed a base VSLY of €59,000 to €133,000 (PPP-adjusted, year 2005 prices) (Hurley et al. 2005; Holland 2014).[15] The lower and upper values of this range correspond to the median and mean VSLY from a three-country study in France, Italy, and the United Kingdom by Alberini, Hunt, and Markandya (2004, 2006), adjusted for price inflation. This study employed a survey instrument similar to that originally developed by Alberini, Krupnick, and others in the United States and Canada (see Alberini et al. 2004 and Krupnick et al. 2002).

In the survey, respondents were asked about their WTP for marginal reductions in fatality risks over the next 10 years. Alberini, Hunt, and Markandya then computed the VSLY by dividing respondents' WTP by the gain in life expectancy implied by an annual risk reduction of 5 in 10,000. In other words, respondents were not asked directly about how they valued life expectancy. Gains in life expectancy were calculated using the life tables for the three countries. To gauge whether there was a difference between the life tables and subjective perceptions of remaining life expectancy, the authors also asked respondents to self-assess their remaining life expectancy. Using this subjective measure of life expectancy, the median and mean values for the VSLY are just slightly higher at €62,000 and €151,000 (PPP-adjusted, year 2005 prices).[16] The authors also find the VSLY increases with age, peaking among 60- to 69-year-olds before declining thereafter. The median and mean VSL calculated from the sample for an annual risk reduction of 5 in 10,000 are €1.122 million and €2.414 million (PPP-adjusted, year 2005 prices).[17]

Use of the VSLY to monetize YLLs introduces additional uncertainties into the analysis.[18] One issue is whether individuals who are more susceptible to pollution-related illnesses have the same life expectancy as the general population. The presence of co-morbid conditions and multiple hazards may further complicate matters. An individual's life expectancy could be influenced by any number of shocks to the individual's survival curve, both now and into the future (Hammitt 2007; Jones-Lee et al 2015).

Another issue with applying the VSLY to monetize YLLs is the implicit rate of discount with respect to remaining life expectancy. Moore and Viscusi (1990) estimate discount rates for deferred health losses and health benefits in the range of 1–14 percent using labor market data, and Dreyfus and Viscusi (1995) estimate a higher range of 11–17 percent by looking at prices paid for cars with higher fuel efficiency and better safety features. The rate of time preference may vary with individual characteristics, such as education level and state of health (Scharff and Viscusi 2011). Jones-Lee and coauthors (2015) point out the importance of ensuring consistency between the discount rate used to calculate health impacts (YLLs or DALYs) and the rate used to discount life expectancy in deriving the VSLY from the VSL.

Finally, there is the question of when the undiscounted VSLY should be allowed to vary for YLLs suffered by people of different ages and at different periods of time. Whereas the study by Desaigues and coauthors (2011) did not find significant variation of WTP for extended life expectancy among adults of different ages, the study by Alberini, Hunt, and Markandya (2004, 2006) estimated an age-varying VSLY for adults over age 40. As noted, the literature on the relationship between WTP for mortality risk reductions is inconclusive, though there is some evidence that WTP may decline only late in life. This situation would also suggest that the adult VSLY should increase with age. To that effect, the U.S. EPA had previously used a two-tiered VSLY of US$163,000 and US$258,000 (year 1999 prices) for people ages 65 and below and for people over age 65, respectively, to evaluate the benefits of the Clear Skies Initiative (U.S. EPA 2002, 36). The U.S. OMB has also recommended that the VSLY be allowed to increase with age (U.S. OMB 2003), though it has not said how this should be done. The European Commission's cost-benefit analyses of Europe's air pollution control strategies assume an age-invariant VSLY and VSL (Hurley et al. 2005; Holland 2014). They also make no adjustment to the undiscounted base VSLY for YLLs lost in future periods. (See box 3.7.)

BOX 3.7 Question: Should the Value of Statistical Life or Value per Statistical Life Year Be Applied in Monetizing Premature Mortality Costs? How Should the Value Per Statistical Life Be Estimated?

Proposal: The choice between using VSL versus VSLY depends in part on the metric of health impacts being used. The VSL is used for valuing the number of deaths and the VSLY is used for valuing YLLs or reduced life expectancy. As noted, this study will value both deaths and effects on life expectancy, so both the VSL and VSLY will be used.

The empirical basis for estimating the VSLY from WTP for gains in life expectancy is less developed, and there are fewer studies from which to derive a base value for the VSLY than there are for the VSL. Although it is common practice to derive the VSLY from the VSL by dividing the VSL by average remaining life expectancy, this practice is not really consistent with the empirical literature on mortality risks and on the levels at which adults of different ages value risk reductions.

Because no basis of evidence is robust enough to determine how WTP for gains in life expectancy varies with age, for the purposes of this study a constant VSLY will be used. This is common practice in the literature and in policy analysis using the VSLY. Also, given the limited guidance from the literature, a range of VSLY values will be used (1) from the Desaigues et al. study, (2) from the Alberini et al. study, and (3) by deriving the VSLY indirectly from the VSL (see the next section for choice of VSL and box 3.8 for details). For country-level analysis, if the VSLY is used, choices about such issues as a relevant base value, discounting, and adjusting the VSLY for age should be made in consultation with local stakeholders.

Base Value of Statistical Life Estimates for Policy Analysis

Table 3.1 illustrates guideline values for the VSL that have been used by public agencies in different countries and regions for policy analysis. In the table, all amounts have been converted into PPP-adjusted U.S. dollars at year 2011 prices. The VSL estimates in the table are first adjusted for inflation to 2011 prices in local currency units according to the consumer price index (CPI) in the respective country or region and then converted to U.S. dollars at purchasing power parity (PPP) using exchange rates for 2011 based on actual individual consumption (AIC) (Lindhjem et al. 2011; OECD 2012). Most of the agencies in the developing countries listed in table 3.1 have derived VSL estimates for policy analysis by transferring values from studies performed in other countries, mainly the United States.

Table 3.2 shows estimates of the VSL from stated-preference studies in middle-income countries, drawing primarily from the database assembled by the OECD (see Lindhjem et al. 2011). Table 3.3 shows highlighted VSL estimates from meta-analyses of stated-preference studies. The review by Kochi and coauthors (2006) only included studies from high-income countries, whereas the analyses by Dekker and coauthors (2011) and Lindhjem and coauthors (2011) include studies from a number of middle-income countries such as China, Malaysia, and Thailand. The WTP studies in the meta-analyses are for environmental, traffic-related, and general health risks. Table 3.4 provides a more detailed breakdown of descriptive statistics for

TABLE 3.1   Examples of Value of Statistical Life Estimates Used by Public Agencies in Policy Analysis

Agency	Application	VSL (Million U.S. dollars, PPP)	VSL/GDP per capita	Source
United States				
Office of Management and Budget (OMB)	Guideline value	1.3–12.7	28–276	U.S. OMB (2003)
Department of Transportation (DOT)	Guideline value	8.9 (5.1–12.6)	176 (99–246)	U.S. DOT (2015)
Department of Homeland Security	Report by US Customs and Border Protection	6.6	131	U.S. OMB (2015)
Environmental Protection Agency	NAAQS final rule review for PM standards	8.2	179	U.S. OMB (2015)
Department of Labor	OSHA hazard communication final rule	9.0	182	U.S. OMB (2015)
Food and Drug Administration	Examples of values used in rule-making	6.3, 7.0	135, 151	U.S. OMB (2015)
United Kingdom				
Department for Transport (DFT)	Accident and casualty costs table	2.3	62	U.K. DFT (2015)
Department for Environment and Rural Affairs (Defra)	Guidelines for valuing risk to life from flooding	2.0	62	U.K. Defra (2008)
Canada				
Policy Horizons Canada	Guideline value	5.5 (3.0–8.0)	133 (71–194)	Chestnut and De Civita (2009)
Australia				
Office of Best Practice Regulation	Guideline value	2.6	60	Australia OBPR (2014)
Mexico				
Ministry of Environment and Natural Resources (SEMARNAT)	Evaluation of fuel quality standards, from BT	0.9	19	Rojas-Bracho et al (2013)
Colombia				
Commission for Regulating Potable Water and Basic Sanitation	Assessing benefits of improved water and sanitation, from BT	1.0	108	Colombia CRA (2008)
Bogota, Local Secretary of Environment	Value in city air pollution control strategy, from BT	0.9	88	Golub et al (2014)
Peru				
Supervisory Organization for Energy Investment (OSINERG)	Value for assessing accidental deaths in energy industry, from BT	1.5	199	Vásquez Cordano (2006)
Malaysia				
Road Transport Department	Guidelines for calculating losses in road accidents	1.0	60	Cited in Mohd Faudzi et al (2013)

Note: VSL converted from base year and currency to 2011 U.S. dollars at PPP; the ratio of the VSL to GNI per capita in the year for which the VSL is estimated (in 2011 U.S. dollars, PPP); *from BT* is the value derived from studies performed in other countries using benefit-transfer function. VSL = value of statistical life; PPP = purchasing power parity; NAAQS = National Ambient Air Quality Standards; PM = particulate matter.

the VSL estimates contained in the OECD database and additional studies that have been published in recent years. All dollar amounts in Tables 3.2, 3.3, and 3.4 are expressed in PPP-adjusted U.S. dollars at 2011 prices.

Only a few governments have set guidelines for baseline estimates of the VSLY (Table 3.5). As noted, the EC DG Environment uses a range of €59,000 to €133,000 (PPP-adjusted, year 2005 prices) (Hurley et al. 2005; Holland 2014). The United Kingdom recommends a VSLY of £35,000 for chronic mortality and £18,000 for acute mortality in evaluating the costs and benefits of air pollution regulations (2012 prices) (U.K. Defra 2007, 2013). The U.K. values are drawn from a domestic survey by Chilton and coauthors (2004),[19] which asked respondents about their WTP for gains in life expectancy of one, three, and six months in "poor" versus "good" health. The Norwegian Ministry of Finance recommends a VSLY of NKr 425,000 (year 2005 prices) (cited in OECD 2012, 29). Best-practice guidelines by the Australian government

TABLE 3.2 Examples of Value of Statistical Life Estimates from Stated Preference Studies in Developing Countries

Country	Year of survey	Type of risk	VSL (2011 U.S. dollars, PPP)	VSL/Y	Source
Thailand	2003	Traffic	159,000	16	Vassanadumrongdee and Matsuoka (2005)
India	2005	Traffic	74,000	23	Bhattacharya, Alberini, and Cropper (2006)
Bangladesh	2003	Health	9,000	5	Mahmud (2009)
Malaysia	2004	Traffic	1,794,000	103	ADB-ASEAN (2005)
Malaysia	1999	Traffic	1,883,000	128	Nor Ghani and Mohd Faudzi (2003)
Turkey	2012	Health	641,000	36	TekeSin and Ara (2014)
Mongolia	2010	Health	638,000	83	Hoffman et al (2012)
Iran	2013	Traffic	2,636,000	169	Ainy et al (2014)
Sudan	2013	Traffic	243,000	63	Mofadal, Kanitpong, and Jiwattanakulpaisarn (2015)
China	2006	Health	398,000	63	Krupnick, Hoffmann, and Qin (2010)

Note: VSL is the mean VSL estimate for contemporaneous reductions in noncancer risks. VSL estimates in local currency units have been adjusted to year 2011 prices using the national consumer price index and converted to U.S. dollars at PPP rates; *VSL/Y* is ratio of the VSL to GDP per capita in the year of the survey. VSL = value of statistical life; PPP = purchasing power parity.

TABLE 3.3 Examples of Value of Statistical Life Estimates from Meta-Analyses of Stated-Preference Studies

Meta-analysis	Publication dates of underlying studies (number of studies)	Highlighted VSL estimates (Million 2011 US dollars, PPP)
Kochi, Hubbell, and Kramer (2006)	1988–2002 (14)	3.5
Dekker et al. (2011)	1983–2008 (26)	2.8–9.1
Lindhjem et al. (2011); OECD (2012)	1982–2007 (26)	3.5 (OECD countries) 4.3 (EU27 countries)

Source: Adapted from Cropper and Krupnick (2015).

Note: VSL estimates have been adjusted to year 2011 prices using the national consumer price index and at PPP rates.
VSL = value of statistical life; PPP = purchasing power parity; OECD = Organisation for Economic Co-operation and Development; EU27 = Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, the Slovak Republic, Slovenia, Spain, Sweden, and the United Kingdom.

TABLE 3.4 Average Values of Statistical Life from Database of Stated-Preference Studies

Sample	Surveys	Obs	Years	VSL (2011 U.S. dollars, PPP)	GDP per capita (2011 U.S. dollars, PPP)	VSL/ GDP per capita
All countries						
Mean	40	449	1990–2013	1,767,397	19,510	91
Median	40	449	1990–2013	2,422,302	30,671	79
Mean, passes scope test	26	257	1994–2013	1,482,549	20,459	72
Median, passes scope test	26	257	1994–2013	2,082,871	32,248	65
Middle income countries						
Mean	15	201	1999–2013	382,440	7,007	55
Median	15	201	1999–2013	481,347	6,360	76
Mean, passes scope test	9	86	2003–2013	176,801	5,730	31
Median, passes scope test	9	86	2003–2013	302,092	6,360	47
OECD countries						
Mean	24	240	1990–2010	4,055,891	34,960	116
Median	24	240	1990–2010	3,624,531	35,548	102
Mean, passes scope test	16	167	1994–2010	3,832,843	36,839	104
Median, passes scope test	16	167	1994–2010	3,182,057	35,810	89

Sources: OECD, "Meta-Analysis of Value of Statistical Life Estimates" database, http://www.oecd.org/env/tools-evaluation/env-value -statistical-life.htm; additional observations from Ainy et al. 2014; Alolayan, Evans, and Hammitt 2013; Hoffmann et al. 2012; Krupnick, Hoffmann, and Qin 2010; Mofadal, Kanitpong, and Jiwattanakulpaisarn 2015; Tekeşin and Ara 2014; and Veisten et al. 2013.

Note: Surveys indicates the number of willingness to pay studies in the sample. *Obs* are the total number of value of statistical life estimates from these studies. *GDP per capita* is for the year and country in which the survey was conducted, expressed in constant year 2011 prices. *VSL/GDP per capita* is the ratio of the average VSL to gross domestic product per capita. Only surveys satisfying the following quality-screening criteria have been included: (1) value for risk change reported, (2) main sample larger than 200 observations or subsample larger than 100 observations, and (3) sample representative of the general population. *Passes scope test* indicates that the subsample has been further restricted to studies that pass a test for internal or external consistency. Multiple observations are allowed per survey. Sample averages are weighted by the inverse number of observations from each survey. Underlying VSL estimates in national currency have been adjusted to year 2011 prices using the national consumer price index and at PPP rates. Mean VSL estimates are estimated from the log-transformed distribution. VSL = value of statistical life; PPP = purchasing power parity; OECD = Organisation for Economic Co-operation and Development; GDP = gross domestic product.

TABLE 3.5 Examples of Guideline Value per Statistical Life Year Estimates Used by Public Agencies

Agency	VSLY (2011 U.S. dollars, PPP)
United Kingdom Defra	24,000 (acute) 46,000 (chronic)
NORWAY Ministry of Finance	49,000
AUSTRALIA OBPR	113,000
EC DG Environment	82,000–184,000

Sources: Australia OBPR (2014); Holland (2014); OECD (2012); and U.K. Defra (2007).

Note: VSL estimates in local currency units have been adjusted to year 2011 prices using the national or regional (Euro area) consumer price index and converted to U.S. dollars at PPP rates. VSLY = value per statistical life year; PPP = purchasing power parity; Defra = Department for Environment and Rural Affairs; OBR = Office of Best Practice Regulation; EC DG Environment = European Commission Directorate-General for the Environment.

BOX 3.8   Question: What Base Value of Statistical Life and Value per Statistical Life Year Values Should Be Used?

Proposal: The choice of base value of statistical life (VSL) depends on the risk and context being evaluated. Ideally, a global assessment of premature mortality costs in different countries would use empirically estimated VSLs from those countries. However, studies on willingness to pay for mortality risk reductions are still lacking in many countries, so this approach is not feasible. Instead, for the World Bank–IHME report, the mean VSL estimate from the quality-screened sample of studies in Organisation for Economic Co-operation and Development (OECD) countries that pass some form of a scope test for internal or external consistency will be used as a base value: US$3.83 million (2011 U.S. dollars, purchasing power parity) (see table 3.4). For sensitivity analysis, a range of base VSL estimates from the distribution of stated-preference study estimates in different countries will be tested.

For deriving the base value per statistical life year from the base VSL in the World Bank–IHME report, the VSL estimates in the database of stated-preference studies are divided by remaining life expectancy for the study population. Table 3.10 provides descriptive statistics for the subsample of stated-preference studies from OECD countries for which the average age of respondents is reported. The mean VSL for the subsample is US$3.5 million (2011 U.S. dollars, purchasing power parity), which is slightly lower than the mean VSL for the larger sample. Associated gross domestic product per capita for the surveys and countries included in the subsample of OECD country studies is US$37,350. Respondents in this subsample are 50 years old on average, with a remaining life expectancy of 33 years. Discounting remaining life expectancy by an annual rate of 4 percent would imply that the VSLY is US$189,706. As noted, empirical studies provide little support for deriving the VSLY in this way, but it is nevertheless common practice and so is repeated in the World Bank–IHME report solely for the purposes of sensitivity analysis.

highlight the usefulness of the VSLY in evaluating policies that are designed to prevent injuries and disease that are not immediately fatal and suggest adjusting the VSLY to monetize nonfatal conditions using disability weights (Australia OBPR 2014; Australia ASCC 2008). Australia's guideline value for the VSLY for use in policy analysis is $A 182,000 (2014 prices). The U.S. OMB has also advised government agencies to present both VSL and VSLY-based estimates when valuing mortality risks (U.S. OMB 2003); however, no U.S. agency currently stipulates a guideline value for the VSLY. (See box 3.8.)

Transferring Base Estimates Of The Value Of Statistical Life To Value Health Impacts In Other Countries

VSL values are often transferred from the context in which they were originally estimated to a new context for policy analysis where it may be either impractical or cost-prohibitive to conduct a WTP study. This approach is called *benefit transfer*. This section discusses two approaches to benefit transfer: unit value transfer and function-based transfer.

Unit Value Transfer

A common method for benefit transfer (BT) is unit value transfer, which involves taking an estimate from one study or an average value from several studies and applying it directly

to the policy context. The OECD recommends this method "as the simplest and most transparent way of transfer between countries" (OECD 2012, 118). Unit value transfer assumes that individuals in the study context and policy setting have similar tastes and characteristics and that the type of risk being valued is the same, yielding a similar utility for marginal risk reductions (OECD 2012; U.S. EPA 2014). To capture population differences between the study and policy setting, the transferred VSL may be adjusted for salient characteristics such as per capita income. Use of the method thus requires discretion on the part of the analyst in screening high-quality studies for transfer and making appropriate adjustments for the policy case. Under these conditions, unit value transfer can be as accurate as more complex meta-regression analyses and other methods (Lindhjem and Navrud 2015).

Recent analyses by the OECD have relied on unit value transfer in estimating country-specific VSLs to assess the public health costs of air pollution in Europe, China, and India (OECD 2014; WHO-OECD 2015). The authors begin by selecting a base VSL of about US$3 million (year 2005, PPP), the median VSL from a quality-screened sample of VSL estimates from studies in OECD countries analyzed by Lindhjem and coauthors (2011).[20] They then make the following adjustment for cross-sectional differences in income between countries and post-2005 growth:

$$VSL_{c,2010} = VSL_{OECD,2005} \times \left(\frac{Y_{c,2005}}{Y_{OECD,2005}} \right)^b \times (1 + \%\Delta P + \%\Delta Y)^b$$

where $VSL_{c,2010}$ is the VSL for country C in 2010; $VSL_{OECD,2005}$ is the base value (VSL for OECD countries in 2005); Y is GDP per capita (in PPP terms); b is the income elasticity of the VSL, assumed by the authors to be 0.8, the midpoint of the best estimate of 0.7–0.9 (OECD 2012); $\%\Delta P$ represents price inflation, as estimated by the consumer price index; and $\%\Delta Y$ is post-2005 income growth. Several studies by the World Bank have also used VSL estimates derived from such a method, including analyses of Ecuador (Sander, Mira-Salama, and Feuerbacher 2015), Georgia (World Bank 2015b), and Nicaragua (Klytchnikova et al. 2013). In the Ecuador and Georgia examples, the base VSL estimated for OECD countries is transferred to the policy context assuming the same income elasticity of 0.8. The Nicaragua example uses a lower and upper base VSL from two other meta-analyses, which is transferred assuming an income elasticity of unity (1.0).

Function-Based Transfer

Another method commonly used for BT is function-based transfer, which proposes that the WTP may be described as a function of quantifiable characteristics in the study case and transferred to the policy case using the estimated function. This method is demonstrated in a recent COED study of Kosovo by the World Bank (2013c), which applies a BT function derived from the meta-regression analysis of the OECD's VSL database by Biausque (2012).[21] The VSL is formulated as

$$VSL = 1.044 \cdot Y^{1.022} \cdot r^{-0.445}$$

where *Y* is per capita GDP (in PPP terms, as above), and *r* is the change in risk mortality. For the Kosovo example, an annual change in risk mortality of 1 in 10,000 is assumed. A similar analysis by the World Bank of the costs of air pollution in Argentina uses the same functional form to specify the VSL but presents a range of VSLs assuming different rates of annual change in mortality risks, from 1 in 10,000 to 5 in 10,000. Note that the BT function used by the World Bank in its assessments of Kosovo and Argentina assumes that the VSL is income-elastic, unlike studies done by the World Bank in other middle-income countries that have used a lower elasticity. This difference implies that the WTP for mortality risk reductions when compared as a percentage of income is lower for people in Kosovo and Argentina than it is for those in Georgia, for example, where an elasticity coefficient of 0.8 is assumed. The BT function proposed in the Biausque (2012) meta-analysis is illustrated graphically in figure 3.2.

In their meta-analysis, Milligan and coauthors (2014) tailor a BT function specifically for low-income and middle-income countries. The function's parameters are estimated using the OECD database of quality-screened VSL estimates from stated-preference studies,[22] with some additional observations from middle-income and high-income countries (India, Republic of Korea, Mongolia, Sweden, and the United States). Including observations from all income levels (n = 410), they estimate an income elasticity of 0.6. Restricting the sample

FIGURE 3.2   Benefit-Transfer Function from Biausque (2012) Used in World Bank Cost of Environmental Degradation Studies

$$VSL = 1.044 \cdot Y^{1.022} \cdot r^{-0.445}$$
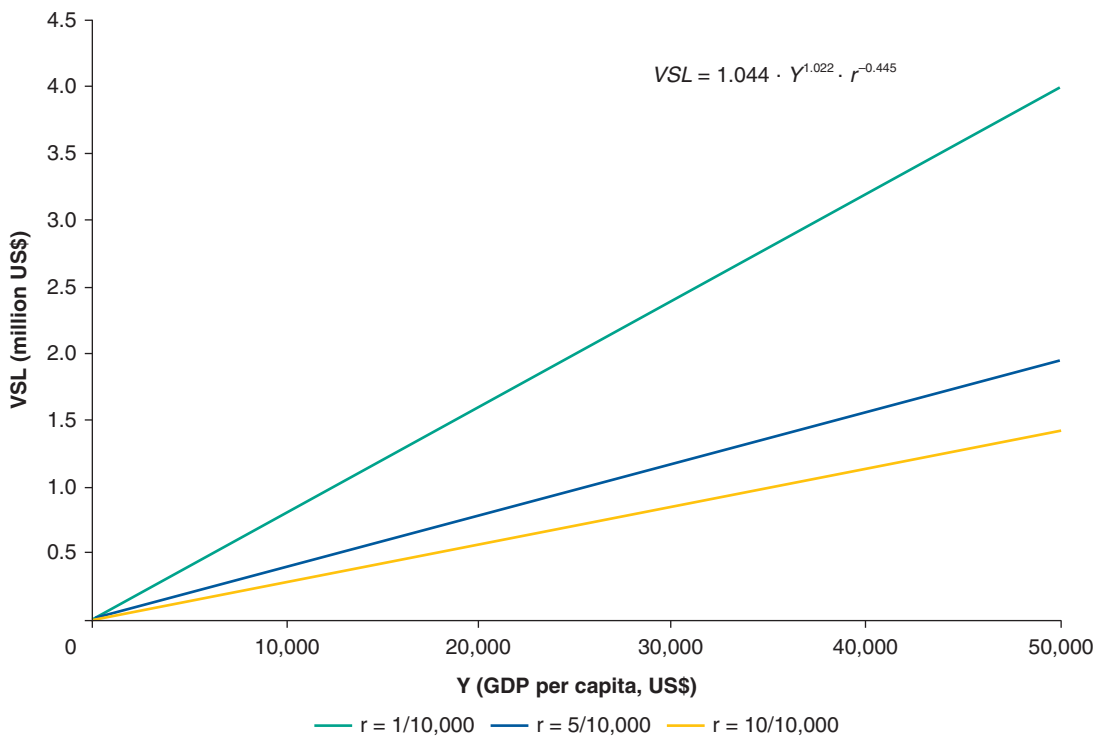
Source: World Bank.

Note: in the transfer function, Y is GDP per capita, r is the annual reduction in mortality risk. VSL = value of statistical life; GDP = gross domestic product.

to only lower-middle and middle income countries (n = 152), they calculate a much higher elasticity of 2.5. Although Milligan and coauthors (2014) specify the BT function in the context of evaluating road safety, the VSL estimates they use from the OECD database are also taken from environmental and health-related studies. The BT functions they estimate for road safety are:

$$VSL_{T,HIC} = 67.088 \cdot Y^{0.693} \cdot r^{-0.481}$$

$$VSL_{T,LMC} = 2.226 \cdot 10^{-7} \cdot Y^{2.478} \cdot r^{-0.698}$$

Where $VSL_{T,HIC}$ is the transferred VSL for traffic safety in high-income countries, $VSL_{T,LMC}$ is the transferred VSL for low-income and middle-income countries, Y is GDP per capita (at PPP exchange rates), and r is the change in risk mortality. Milligan and coauthors assume a threshold of US$14,000 (PPP-adjusted, 2005 prices) for GDP per capita in high-income countries. In tailoring the BT function for road safety, they set r equal to one-half the crude death rate for traffic accidents in high-income countries and developing countries. Using data for 2011 from the WHO, they estimate the rate of traffic fatalities at 9.0 and 19.9 per 100,000 people in high-income countries and developing countries, respectively (cited in Milligan et al. 2014, 245). Inserting the assumed r values, the authors simplify the BT functions as

$$VSL_{T,HIC} = 8.2474 \cdot 10^3 \cdot Y^{0.693}$$

$$VSL_{T,LMC} = 1.3732 \cdot 10^{-4} \cdot Y^{2.478}$$

Milligan and coauthors suggest that the BT function can be adjusted to value environmental and health-related risks in the same way (Milligan et al. 2014, 246). Re-estimating the BT functions for contemporaneous reductions in noncancer fatality risks related to general health using the VSL estimates from the OECD database and additional studies summarized in table 3.4 yields

$$VSL_{HIC} = 933.555 \cdot Y^{0.729} \cdot r^{-0.088}$$

$$VSL_{LMC} = 0.058 \cdot Y^{1.792} \cdot r^{-0.022}$$

According to the GBD 2013 data, fatality rates in 2013 attributed to ambient $PM_{2.5}$ exposure were 47 and 56 deaths per 100,000 people in high-income countries and developing countries, respectively. Assuming a baseline risk reduction equal to half the crude mortality rate, as done by Milligan and coauthors, simplifies the BT functions this way:

$$VSL_{HIC} = 1,947.645 \cdot Y^{0.729}$$

$$VSL_{LMC} = 0.069 \cdot Y^{1.792}$$

Figure 3.3 illustrates the estimated VSLs transferred using the piece-wise BT functions for countries of different income levels, along with the BT function estimated by Biausque. For the Biausque function, annual risk changes of 1.0 in 10,000, 2.5 in 10,000, and 5.0 in 10,000 are assumed.

FIGURE 3.3 **Benefit-Transfer Functions and Benchmark Value of Statistical Life Estimates**
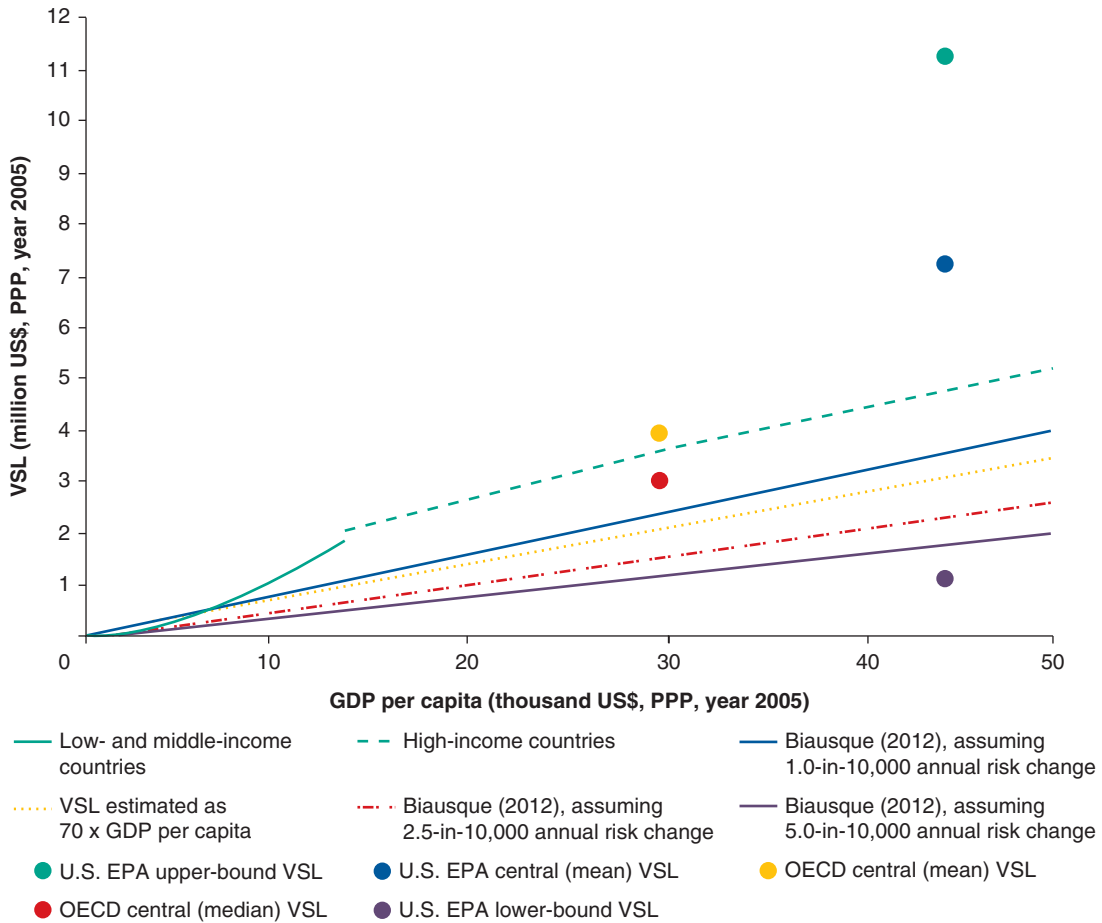
Source: World Bank.
Note: VSL = value of statistical life; GDP = gross domestic product; PPP = purchasing power parity; EPA = Environmental Protection Agency; OECD = Organisation for Economic Co-operation and Development.

Credibility Testing

The fact that fewer empirical studies of the VSL have been done in low-income and middle-income countries raises questions about the credibility of the VSL when it is transferred between countries with large differences in average income and vastly disparate social contexts. Although there is little empirical basis for judging the reasonableness of the transferred VSL where in-country studies are lacking, several rule-of-thumb methods have been proposed.

One method is to benchmark the VSL against GDP per capita. The International Road Assessment Programme (IRAP) and World Bank have recommended this method to estimate a rough VSL for the purpose of assessing traffic safety benefits. The logic behind comparing the VSL to GDP per capita stems from the relationship commonly assumed in BT functions such that differences in the VSL are proportional to income differences:

$$VSL_{transfer} = VSL_{study} * (Y_{transfer} / Y_{study})$$

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where *transfer* denotes the country for which the VSL is being transferred, *study* refers to the study context from which the original base value is estimated, and *Y* is GDP per capita. The function implies

$$VSL_{study}/Y_{study} = VSL_{transfer}/Y_{transfer.}$$

Cropper and Sahin (2009) suggest that a reasonable VSL/Y ratio for middle-income countries is 80:1. IRAP and the World Bank employ a value of 70 times GDP per capita (Dahdah and McMahon 2008). Larsen (2015) suggests a lower ratio of 50:1 for low-income and middle-income countries. By comparison, Miller (2000) has reported a ratio of 120:1 from a meta-analysis of WTP studies in 13 high-income countries. The VSL/Y ratio reported by Miller is more or less in line with the average ratio for the stated-preference studies from OECD countries shown in table 3.4, which is between 102:1 and 116:1. The average ratio for VSL estimates from stated preference countries in middle-income countries in table 3.4 is between 55:1 and 76:1.[23] The difference in means between the VSL/Y ratios of middle- and high-income countries is statistically significant,[24] further suggesting that the income elasticity of the VSL is higher in the poorer countries than in the richer countries included in the database of studies.

Figure 3.4 illustrates the spread of VSL/Y ratios for countries in different income groups for different assumed values of *e* using the chosen base VSL for the World Bank–IHME report: US$3.8 million (2011 US$, PPP). Average GDP per capita associated with this base value is about US$37,000 (2011 US$, PPP). Each observation in figure 3.4 represents a country and year for which the VSL is transferred. The distribution for *e* = 1 is not shown in the figure because when this elasticity is assumed, the ratio of VSL to Y is the same for all countries regardless of income (104:1). As figure 3.4 shows, values of *e* below 1 imply that the ratio of the VSL to Y is larger for poorer countries than for richer ones. The opposite is true for elasticities that are higher than 1. The ratio of the VSL to Y is lower for poorer countries, as seen with the VSL/Y ratios in the stated preference studies in table 3.4. The resulting VSL/Y ratios for different values of *e* are summarized in table 3.6.

As an alternative to benchmarking the VSL against GDP per capita, Hammitt and Robinson (2011) have suggested comparing the VSL to expected lifetime income and consumption. The authors take this approach to test the assumption that the income elasticity is above 1 in transferring VSL estimates from studies in high-income countries to low-income countries in Africa. Their approach is guided by the economic theory behind the VSL, which tells us that the amount individuals are willing to pay to reduce their risk of dying should reflect the utility they will experience over their remaining lifetimes. The level of utility, in turn, depends on such factors as age, life expectancy, survival probability, and their level of consumption.[25] From a simple point of view, how much individuals can consume is typically limited by their earnings.[26] This implies that the VSL should be at least the discounted present value of future income and consumption.

In table 3.7, transferred VSL estimates using a range of values for *e* are compared to the value of future income. The present value of labor income is discounted over the remaining working life for the average adult between the ages of 15 and 69. Remaining working life takes into account survival probabilities and labor participation rates for adults of different ages. As with

FIGURE 3.4   Ratio of Value of Statistical Life to Gross Domestic Product per Capita, Assuming Different Income Elasticities (*e*), All Years
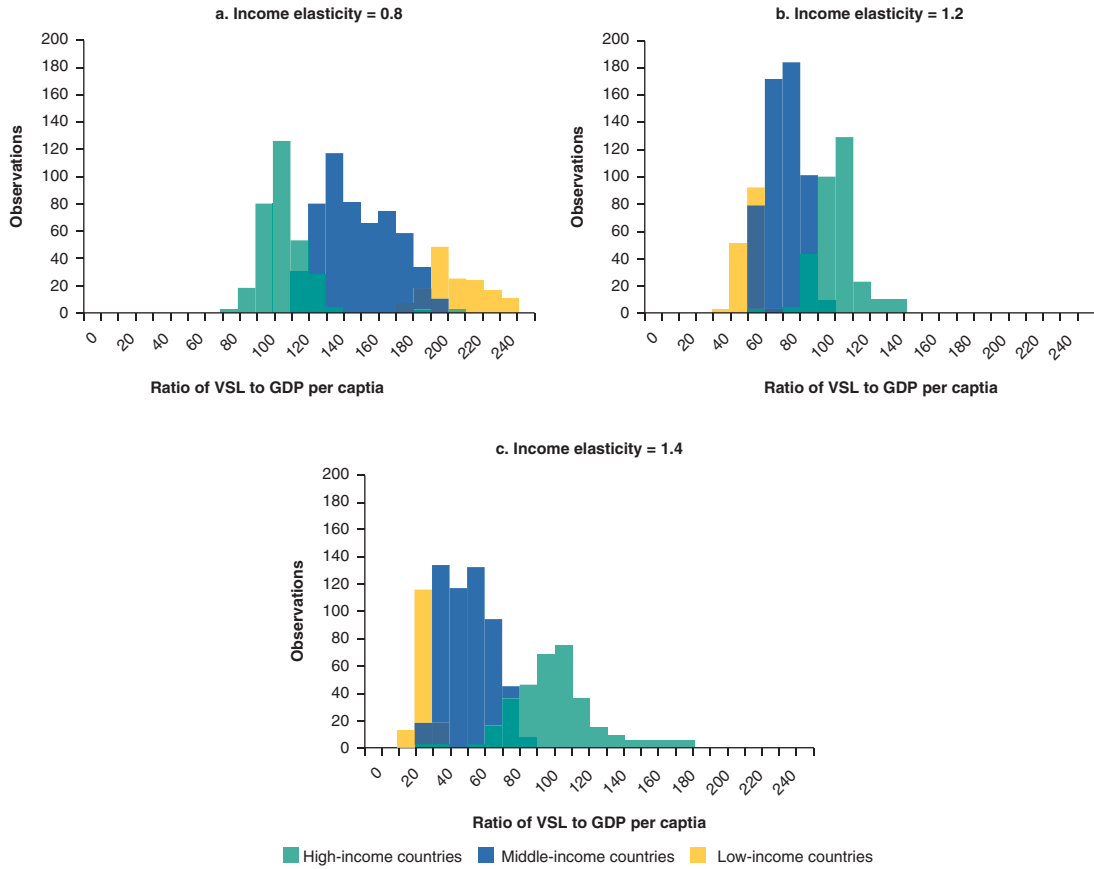
Source: World Bank.

Note: Base VSL of US$3.8 million and GDP per capita of US$37,000 are assumed (2011 US$, PPP); VSL estimates are transferred at PPP rates. VSL = value of statistical life; GDP = gross domestic product.

TABLE 3.6   Median Ratio of Transferred Value of Statistical Life Estimates to Gross Domestic Product per Capita, by Income Group, All Years (1990–2013)

Income group	Median VSL to GDP per capita ratio, assuming different income elasticities														
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Low income	409	291	206	147	104	74	52	37	26	19	13	9	7	5	3
Lower middle income	272	214	168	132	104	82	64	51	40	31	25	19	15	12	9
Upper middle income	178	156	136	119	104	91	80	70	61	53	46	41	36	31	27
High income	109	108	106	105	104	103	102	100	99	98	97	96	95	94	93

Source: World Bank.

Note: Base VSL of US$3.8 million and GDP per capita of US$37,000 are assumed (2011 US$, PPP); VSL estimates are transferred at PPP rates; table made of balanced sample of countries for which data are available for 1990, 1995, 2000, 2005, 2010, and 2013; each observation is a country and year. VSL = value of statistical life; GDP = gross domestic product.

TABLE 3.7   Median Ratio of Estimated Value of Statistical Life to Expected Future Earnings for the Average Worker, All Years (1990–2013)

Income group	Ratio of VSL to expected future labor income, assuming different income elasticities of VSL														
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Low income	17.9	12.4	8.8	6.3	4.5	3.2	2.2	1.6	1.1	0.8	0.6	0.4	0.3	0.2	0.2
Lower middle income	12.4	10.0	8.1	6.5	5.2	4.1	3.2	2.5	1.9	1.5	1.2	1.0	0.8	0.6	0.5
Upper middle income	9.8	8.6	7.6	6.7	5.9	5.1	4.5	4.0	3.5	3.1	2.7	2.4	2.1	1.8	1.6
High income	5.4	5.4	5.4	5.5	5.4	5.3	5.2	5.1	5.0	5.0	5.0	4.9	4.8	4.7	4.7

Source: World Bank.

Note: Base VSL of US$3.8 million and GDP per capita of US$37,000 are assumed (2011 US$, PPP); *Expected future labor income* is estimated assuming a constant average annual wage per employee and the expected remaining working life for the average worker in the labor force (ages 15 to 69), discounted at a rate of 4 percent per year for high-income countries and 6 percent per year for low-income and middle-income countries; table made of balanced sample of countries for which data are available for 1990, 1995, 2000, 2005, 2010, and 2013; each observation is a country and year. VSL = value of statistical life.

TABLE 3.8   Median Ratio of Estimated Value of Statistical Life to Expected Lifetime Consumption for Average Adult Ages 40–44, All Years (1990–2013)

Income group	Life expectancy	Ratio of VSL to remaining lifetime consumption, assuming different income elasticities of VSL														
		0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Low income	32	32.5	22.9	16.3	11.5	7.9	5.5	3.9	2.8	2.0	1.4	1.0	0.7	0.5	0.4	0.3
Lower middle income	34	23.2	18.0	14.3	11.1	8.7	6.8	5.4	4.4	3.5	2.8	2.2	1.8	1.4	1.2	0.9
Upper middle income	37	15.4	13.5	11.8	10.3	9.0	8.0	7.1	6.3	5.5	4.8	4.2	3.7	3.3	2.9	2.6
High income	40	7.7	7.7	7.5	7.3	7.1	7.1	7.0	6.9	6.9	7.0	6.8	6.7	6.6	6.6	6.5

Source: World Bank.

Note: Base VSL of US$3.8 million and GDP per capita of US$37,000 are assumed (2011 US$, PPP); *Remaining lifetime consumption* is estimated assuming constant per capita consumption in real terms, discounted into the future at a rate of 4 percent per year for high-income countries and 6 percent per year for low-income and middle-income countries; table made of balanced sample of countries for which data are available for 1990, 1995, 2000, 2005, 2010, and 2013; each observation is a country and year. VSL = value of statistical life.

consumption, real wages are held constant and future income is discounted at an annual rate of 4 percent for high-income countries and 6 percent for low-income and middle-income countries.

Tables 3.8 and 3.9 illustrate how the estimates of VSLs for different countries and years compare with the present value of future consumption for the average adult between the ages of 40 and 44 and 45 and 49. These age groups correspond with the median ages of survey respondents in middle-income and high-income countries, respectively, in the OECD database of VSL studies (see table 3.10). Life expectancy for respondents in the year of survey is estimated using data from the GBD 2013. On average, survey respondents had a remaining life expectancy of 33–36 years.

TABLE 3.9 Median Ratio of Estimated Value of Statistical Life to Expected Lifetime Consumption for Average Adult Ages 45–49, All Years (1990–2013)

Income group	Life expectancy	Ratio of VSL to remaining lifetime consumption, assuming different income elasticities of VSL														
		0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Low income	28	34.2	24.0	16.9	11.9	8.3	5.8	4.1	2.9	2.1	1.5	1.1	0.8	0.5	0.4	0.3
Lower middle income	29	24.3	18.9	14.9	11.6	9.1	7.2	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0
Upper middle income	33	15.9	14.0	12.2	10.6	9.3	8.3	7.3	6.5	5.7	4.9	4.4	3.9	3.4	3.0	2.7
High income	35	8.2	8.0	7.9	7.7	7.5	7.4	7.4	7.2	7.3	7.3	7.1	7.1	6.9	6.9	6.8

Source: World Bank.

Note: Base VSL of US$3.8 million and GDP per capita of US$37,000 are assumed (2011 US$, PPP); *Remaining lifetime consumption* is estimated assuming constant per capita consumption in real terms, discounted into the future at a rate of 4 percent per year for high-income countries and 6 percent per year for low-income and middle-income countries; table made of a balanced sample of countries for which data are available for 1990, 1995, 2000, 2005, 2010, and 2013; each observation is a country and year. VSL = value of statistical life.

By comparison, life expectancy for the average adult ages 40–44 in the low-income countries was 32 years in 2013. Conservatively, in comparing the ratio of the VSL with future consumption in the tables, real consumption per capita is assumed to be constant and is discounted into the future at a rate of 4 percent for high-income countries and 6 percent for low-income and middle-income countries.

For the World Bank–IHME report, in which a base VSL of US$3.8 million and GDP per capita of around US$37,000 (2011 US$, PPP) is assumed, the tables demonstrate that applying income elasticity values of 1 or lower may lead to VSL/Y ratios in low-income and middle-income countries beyond those observed in stated preference studies to date. At the same time, elasticity values of 1.4 or greater would result in VSL estimates that are lower than the expected future earnings for the average working adult in the majority of low-income countries and years. For elasticity values of 1.6 or greater, the present value of future consumption for adults between the ages of 40 and 49 would exceed the VSL in about one-third of low-income countries in 2013. Elasticity values of 1.6 or greater would also cause expected future earnings to be greater than the estimated VSL for the majority of lower-middle income countries.[27]

In figure 3.5, transferred VSLs using the base VSL for the World Bank–IHME report and the range of elasticity values for middle-income countries are compared with the empirical estimates of the VSL in the database of stated preference studies (see table 3.4). As figure 3.5 shows, the empirically estimated VSL is within the range of transferred VSLs for half of the studies in the database. GDP per capita in these countries ranges from US$3,419 (China in 1999) to US$17,864 (Malaysia in 2004). However, the range of transferred VSLs is still above the empirical estimates for the two poorest countries, Bangladesh in 2003 and India in 2005, with GDP per capita of US$1,781 and US$3,213, respectively. The average transfer error is smallest when the central elasticity value of 1.2 is assumed.

TABLE 3.10 Value of Statistical Life Estimates and Remaining Life Expectancy from Stated-Preference Studies in Organisation for Economic Co-operation and Development Database for which Age Is Reported

Sample	Surveys	Obs	Earliest	Latest	Age	Remaining life expectancy	VSL (2011 USD, PPP)	Per capita consumption (2011 USD, PPP)	Lifetime consumption (2011 USD, PPP)	VSL / lifetime consumption	GDP per capita (2011 USD, PPP)	VSL / GDP per capita
Middle-income country studies												
Mean	11	154	1999	2012	45	34	249,143	6,430	94,674	2.6	5,882	42
Median	11	154	1999	2012	43	36	337,163	6,168	85,701	3.9	5,675	59
Mean, passes scope test	7	78	2003	2012	46	32	171,947	6,284	92,161	1.9	6,077	28
Median, passes scope test	7	78	2003	2012	44	35	296,942	5,176	64,159	4.6	6,360	47
OECD country studies												
Mean	19	198	1995	2010	51	33	3,470,963	27,196	495,252	7.0	35,841	97
Median	19	198	1995	2010	50	33	3,257,430	27,153	480,561	6.8	35,810	91
Mean, passes scope test	14	142	1995	2010	51	33	3,504,928	27,905	509,853	6.9	37,350	94
Median, passes scope test	14	142	1995	2010	50	33	3,182,057	27,197	501,965	6.3	36,962	86

Source: World Bank using data from Ainy et al. 2014; Alolayan, Evans, and Hammitt 2013; Hoffmann et al. 2012; Institute for Health Metrics and Evaluation Global Burden of Disease study 2013 database; Krupnick, Hoffmann, and Qin 2010; Mofadal, Kanitpong, and Jiwattanakulpaisarn 2015; Organisation for Economic Co-operation and Development, "Meta-Analysis of Value of Statistical Life Estimates" database; Tekeşin and Ara 2014; and Veisten et al. 2013.

FIGURE 3.5 Transferred Values of Statistical Life Compared with Stated-Preference Study Results in Middle-Income Countries

Legend:
- ■ Mean empirical estimate of VSL in study
- ● VSL transferred from OECD base value, income elasticity 1.4
- ● VSL transferred from OECD base value, income elasticity of 1.2
- ● VSL transferred from OECD base value, income elasticity of 1.0
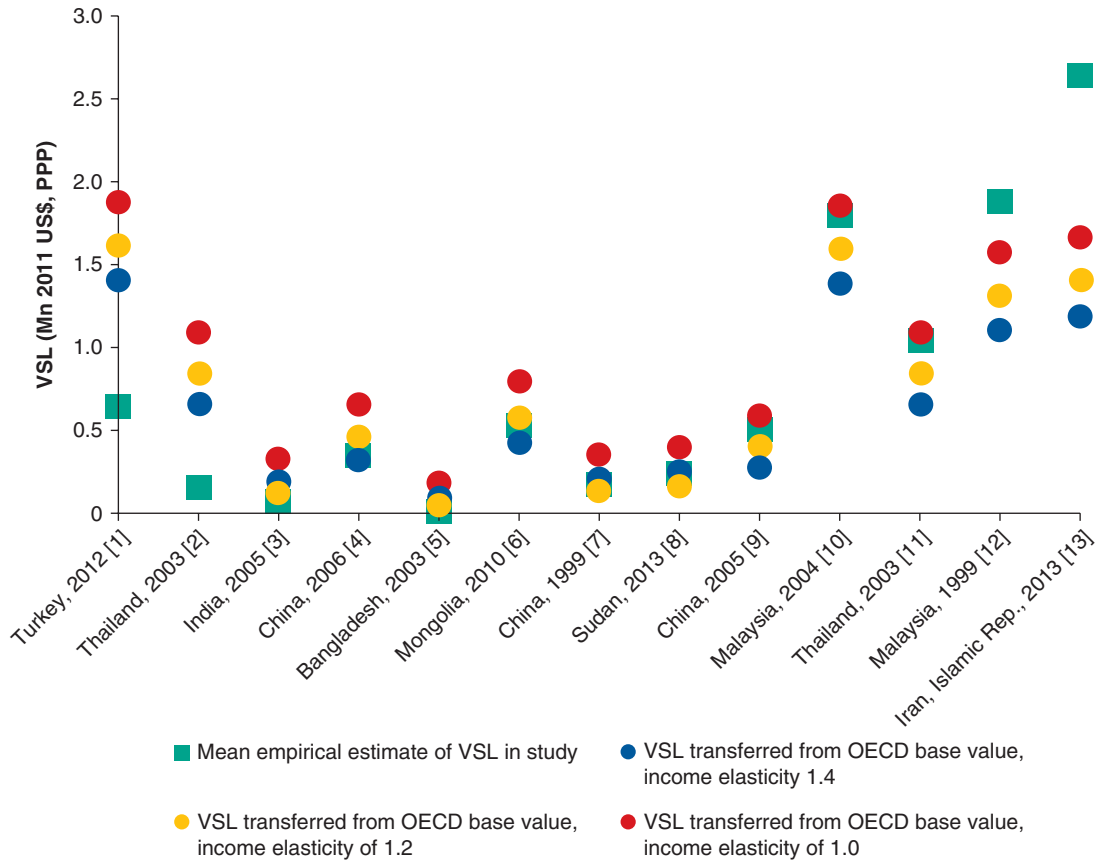
Sources: [1] Tekeşin and Ara 2014; [2] Vassanadumrondgee and Matsuoka 2005; [3] Bhattacharya, Alberini, and Cropper 2007; [4] Krupnick, Hoffmann, and Qin 2010; [5] Mahmud 2009; [6] Hoffmann et al. 2012; [7] Hammitt and Zhou 2006; [8] Mofadal, Kanitpong, and Jiwattanakulpaisarn 2015; [9] Krupnick et al. 2006; [10] ADB-ASEAN 2005; [11] Gibson et al. 2007; [12] Ghani and Faudzi 2003; [13] Ainy et al. 2014.

Note: VSL = value of statistical life; OECD = Organisation for Economic Co-operation and Development.

Choice of Exchange Rate

Transferring the VSL by comparing GDP per capita in the study country with the policy country, the choice of exchange rate is particularly important. In general, VSL estimates in local currency units are converted into US$ at PPP rates rather than market exchange rates in making comparisons between countries because PPP rates are a better reflection of opportunity costs in the economy (Krupnick, Hoffmann, and Qin 2010, 23). However, as Cropper and Khanna (2014) note in their review of the World Bank's methodology for calculating air pollution damages, if health costs are reported as a percentage of GNI—as they are in the World Bank's adjusted net savings database—and GNI is measured at market exchange rates, then the estimated VSL should be transferred using market rates, too. Also, for economic analysis of pollution reduction projects and policies, benefits and costs should be estimated on the same basis using either the PPP or market exchange rate. Although the benefits of pollution reduction policies in terms of avoided health impacts are typically monetized on a PPP basis, it is more common to report costs at market exchange rates, leading to potential inconsistencies when calculating net benefits over costs. (See box 3.9.)

BOX 3.9 Question: How Should the Base Value of Statistical Life Be Transferred between Countries?

Proposal: Country-specific values of statistical life (VSLs) may be derived from a base VSL following two methods: (1) a simple unit-value transfer adjusting for cross-sectional differences in income, price inflation, and growth over time; and (2) a function-based transfer, with parameters estimated from a meta-regression analysis using the Organisation for Economic Co-operation and Development database, as in figure 3.2. For the unit value transfer, and as previously discussed, a range of income elasticities should be used for the sensitivity analysis. For each country, the ratio of the estimated VSL to gross domestic product (GDP) or expected lifetime income should also be used as a benchmark to judge the reasonableness of the VSL.

Unit-value transfer has the advantage of being the most straightforward transfer method, though it requires stricter assumptions about the comparability of individual tastes and characteristics in the study context versus the policy setting and about the nature of the risk being valued. It is the method that will be applied for the global assessment, assuming the range of income elasticity values previously noted (0.6–1.0 for high-income countries, with a central value of 0.8, and 1.0–1.4 for low-income and middle-income countries, with a central value of 1.2). Function-based transfers, on the other hand, may be highly sensitive to how the function is specified and to what variables are included. Re-estimating a base VSL or transfer function may be too time intensive and burdensome for individual project analysis. If functions from other analyses or contexts are used, they should be carefully examined and compared to rule-of-thumb measures such as the ratio of the estimated VSL to GDP to judge their reliability.

For the purposes of valuing the global burden of disease associated with air pollution, transferring the base VSL at PPP rates is appropriate for cross-country comparisons. For cost-benefit analysis of specific projects or policies to reduce pollution, however, using market rates may be more appropriate for the calculation of net benefits. This is because costs are usually taken at market rates, so the monetary basis for comparing costs and benefits should be consistent.

Implementing the Forgone Output Approach

The following section discusses some of the practical issues in implementing a forgone labor output approach for the financial accounting of pollution health costs, including defining the workforce, valuing child mortality, and accounting for future income growth. Under this approach, the expected loss of income for the average person in each age group is typically valued as

$$PV(I) = \sum_{i=0}^{T} I(1+g)^i/(1+r)^i$$

where I is average per capita labor income in the present year; T is the expected number of working years for the average person in a particular age group (conditional on survival probabilities and labor force participation rates); g is the annual rate of income growth; and r is the social discount rate. Ideally, I would be differentiated by age groups, as people of different ages

may have varying levels of education, experience, and other characteristics that affect their average earning potential. However, a lack of detailed wage data in many countries does not allow for this level of disaggregation as part of a global assessment.

Defining the Workforce

For the sake of convenience, in estimating forgone labor output, one typically assumes working age to be 15–64 for cross-country analyses.[28] Defining the scope of the workforce in this way excludes the contribution of persons aged 65 and over to the economy. According to data from the International Labor Organization (ILO), about 25 percent of the population ages 65 and over in middle-income countries were economically active in 2013. For low-income countries, the figure was even higher, around 56 percent.[29] As noted, the 65-and-over population suffers a disproportionate share of health impacts from pollution. Out of concerns for equity, analysts may use an adjusted form of the FO approach that values YLLs among the 65-and-over population using the economywide average for GDP per capita, as is often done in countries such as China. However, this practice does not really capture the value of lost income or reduced labor productivity in the economy and would be contrary to the purposes of financial accounting for the ANS indicator, for which the FO approach is proposed. Also, although retired people contribute to the economy as consumers of goods and services, these sorts of losses beyond the individual's time endowment are outside the scope of the FO approach.

Working Life Expectancy

Working life expectancy, T, may be calculated by adjusting life expectancy during working age by the probability that an individual will be active in the labor force:

$$T_j = \sum_{t=j+1}^{M} s_{j,t} \cdot \ell_{t-1}$$

where $s_{j,t}$ is the probability that a person of age j will survive to the beginning of age t; ℓ is the labor force participation rate;[30] and M is the end of working age. Survival probabilities, s, may be calculated from mean death rates as

$$s_{j,t} = (1-d_j)(1-d_{j+1})...(1-d_{t-1})$$

$$s_{j,t} = s_j \cdot s_{j+1} \cdot ... \cdot s_{t-1}$$

where d_j is the portion of individuals alive at the beginning of year j who die during that year, and the probability of survival is $1 - d$.

The calculation of T is done recursively, starting with the oldest age group. For example, if maximum working age is assumed to be 79, (such that all individuals stop working once they turn 80)

$$T_{79} = s_{79,80} \cdot \ell_{79}$$

$$T_{78} = \sum_{t=79}^{80} s_{78,t} \cdot \ell_{t-1} = s_{78,79} \cdot \ell_{78} + s_{78,80} \cdot \ell_{79} = s_{78,79}(\ell_{78} + T_{79})$$

$$\vdots$$

$$T_{15} = s_{15,16}(\ell_{15} + T_{16})$$

Because working age is typically assumed to begin at 15, children represent a special case. Using ages 13 and 14 as an example, T would be

$$T_{14} = \sum_{t=16}^{80} s_{14,t} \cdot \ell_{t-1} = s_{14,15} \cdot s_{15,16}(\ell_{15} + T_{16}) = (s_{14,15} \cdot T_{15})$$

$$T_{13} = \sum_{t=16}^{80} s_{13,t} \cdot \ell_{t-1} = s_{13,14} \cdot T_{14}$$

Of course, not all individuals begin working as soon as they are 15, and not all individuals will work until they are 80. Weighting T by labor force participation is one way of accounting for variation in the demographic makeup of the labor force, including delayed entry until later age and retirement.

Workforce participation rates vary widely by region, and there is longstanding evidence that participation by women is frequently underestimated (see Boserup 1970; Benería 1982, 1992; Benería, Berik, and Floro 2015). Low participation rates among women are the main reason that overall participation rates for both sexes in some regions are much lower than in others. These estimates of labor force participation by the ILO are based on reported rates in nationally representative labor force surveys and population censuses. Over the past decades, the statistical definition of employment used in these surveys has expanded to account for greater diversity in the way in which people work, and data collection has greatly improved. However, labor force statistics are still prone to measurement error, particularly in capturing work by people in the informal sector. In countries with high levels of informality in the labor market, this measurement bias particularly affects women, whose work may be intermittent, temporary, short term, or home based and who may have multiple work arrangements, such as caring for children as well as engaging in market activities. Also, although international standards for employment and labor force statistics have evolved to be more inclusive, definitions and reporting by agencies in different countries vary.

Hirway and Jose (2011) provide evidence of the potential magnitude of bias in the labor force participation statistics for India. According to data from India's national labor force survey of 1999–2000, only 25 percent of rural women and 13 percent of urban women were active in the workforce in the states of Haryana, Madhya Pradesh, Gujarat, Orissa, Tamil Nadu, and Meghalaya. By comparison, 51 percent of men in rural and urban areas were estimated to be active. However, using data from a large-scale time-use survey from 1998 to 1999 in these states, Hirway and Jose take advantage of more detailed information about how people spend their time and to accurately distinguish between work and nonwork. With these data, they find that 58 percent of rural women and 31 percent of urban women were actually active in the

FIGURE 3.6 Labor Force Participation, by Men and Women in South Asia, 2013
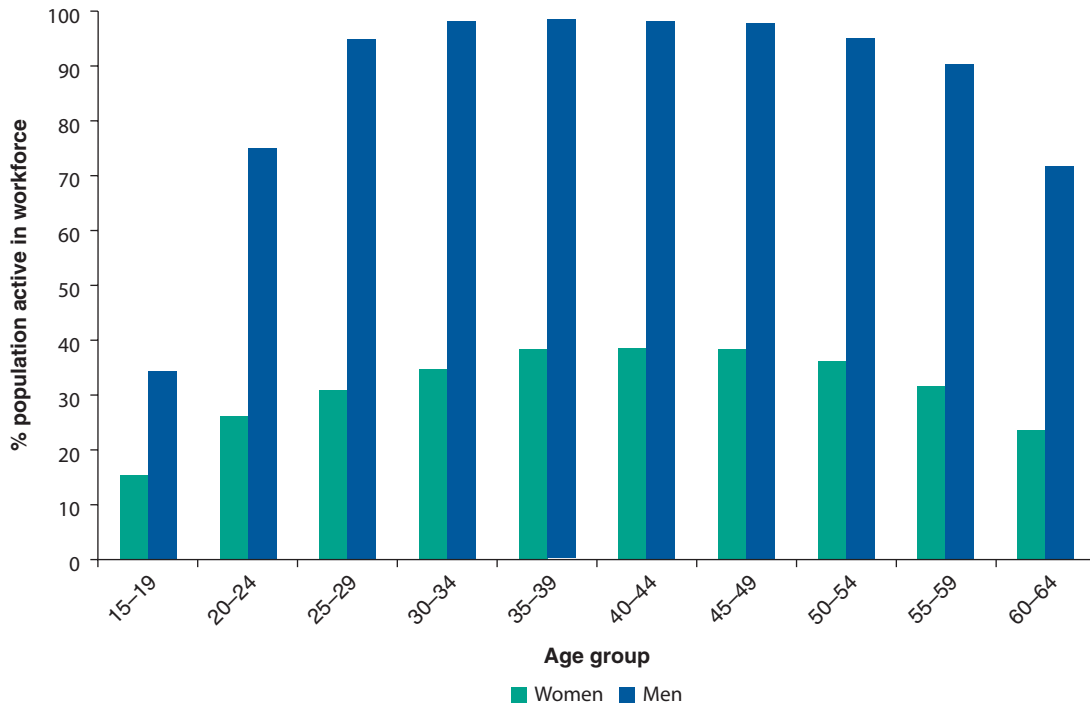
Source: World Bank, using data from International Labour Organization, ILOSTAT Database, http://www.ilo.org/ilostat.

workforce, compared with 63 percent of rural men and 59 percent of urban men. Thus, although there is still a gap between workforce participation by men and women, this gap may be much smaller than reflected in labor force survey and population census data. To illustrate the size of this gap in the ILO estimates of participation using labor force survey and population census data, average rates of participation for men and women in South Asia in 2013 are shown in figure 3.6.

By lowering working life expectancy, gender bias in the labor force participation data would bias the overall estimates of forgone labor output due to air pollution exposure. This oversight would suggest that women are much less productive and would, in effect, assume zero loss of income for a large share of the working-age population that no doubt contributes to the economy. On the flip side, failing to account for labor force participation rates as part of working life expectancy would lead to overestimates of forgone labor output by assuming that all individuals will work from the moment they turn 15 until they are 79, as long as they are still alive.

Faced with this dilemma, a reasonable compromise is to assume that estimated rates of labor force participation for men apply to both men and women. This option addresses concerns about gender bias in the labor force participation data while also accounting for varying work life patterns between countries. Indeed, there is precedence for this approach in the real world, and courts have sometimes assumed the average working life of men in calculating the lost earnings capacity of women. For example, in establishing a special fund for the victims of the 9/11 attacks, the U.S. Justice Department used the average working life of men to determine

Methodology for Valuing the Health Impacts of Air Pollution

FIGURE 3.7 **Labor Force Participation Rates, by Income Group, 2013**
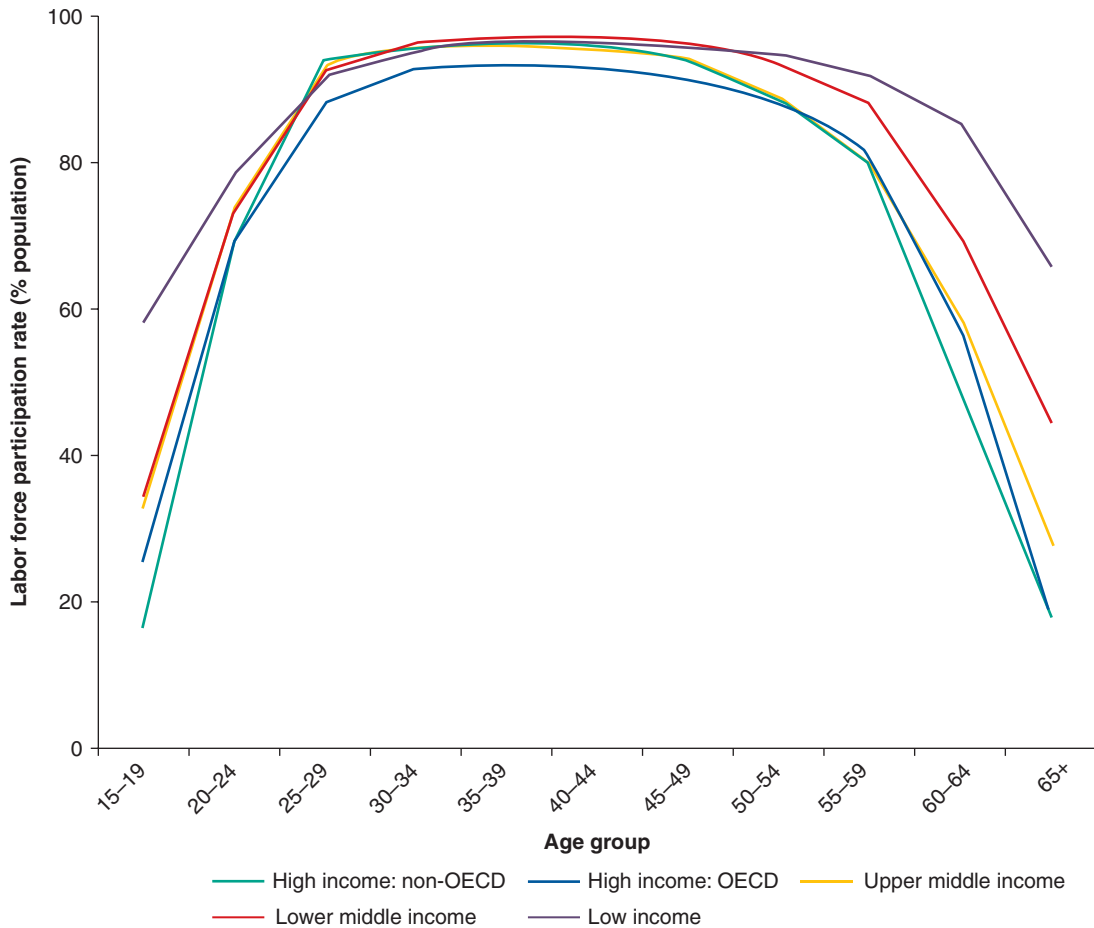
Source: World Bank, using data from International Labour Organization, ILOSTAT database, http://www.ilo.org/ilostat/.
Note: Data are for labor force participation among males.

compensation amounts for both men and women "to avoid gender bias … and to ensure consistency" (Feinberg 2004). Adopting this approach for a global assessment of forgone labor output would imply labor force participation rates for the general population such as those illustrated in figure 3.7. (See box 3.10.)

Child Mortality

In previous COED studies by the World Bank, the forgone output approach has been used to value of the cost of child mortality by taking the present value of wages beginning 10 or 15 years in the future, when those children would be expected to enter the workforce.[31] As Larsen (2015) has argued, this approach assumes zero replacement of lost children, an approach which may be inconsistent with actual household decision making and family planning, particularly in countries with high baseline rates of child mortality. Families in these settings may take into account higher levels of health risk when planning the desired number of children in their households, especially if death occurs at a very young age. If this is the case, the actual loss in terms of labor productivity would be less than predicted. Furthermore, because the majority of YLLs among children are suffered in countries with higher rates of solid fuel use

BOX 3.10 Question: How Should the Workforce and Working Life Be Defined?

Proposal: Defining working age as 15–64 is arbitrary. Excluding the population ages 65 and over can be avoided by accounting for country-specific labor force participation rates among the elderly conditional on survival probability when specifying T. This approach is seen in the economic literature on human capital accounting. (See the United Nations University International Human Dimensions Programme on Environmental Change and United Nations Environment Programme estimates of human capital for the *Inclusive Wealth Report 2014*, for example.) However, although the International Labor Organization provides data on labor force participation among the population ages 65 and over in 185 countries, there are no comparable data on average retirement age for the subset of the older population that is economically active. Although this makes it difficult to avoid imposing an arbitrary cap on maximum working age altogether, given the high rates of labor participation among older persons in low-income and medium-income countries, a compromise would be to raise the maximum age to 79 and to discount working life expectancy for labor participation.

On grounds of equity, an analysis could alternatively value years of life lost at gross domestic product per capita for people of all ages. Though simpler to implement, strictly speaking this alternative approach would represent a departure from an income-based measure of forgone output for financial accounting purposes.

Adjusting life expectancy by rates of labor force participation introduces possible bias in the estimates of forgone labor output for regions where workforce participation by women is underreported. The possibility of bias in the labor statistics is especially a problem in contexts in which women tend to work outside the formal labor market. For the global assessment in the World Bank–IHME report, a compromise approach is taken by assuming the same rates of labor force participation for both men and women.

BOX 3.11 Question: How Should Deaths among Children Be Valued under the Forgone Output Approach?

Proposal: As done in previous cost of environmental degradation studies, for this study the present value of forgone income among children will be calculated by discounting average wages into the future, assuming that working age begins at 15. Again, although this definition of the start of working age is somewhat arbitrary, it is conventional practice. The term T may be conditioned on survival probability and average working-life expectancy for persons in each age group, to avoid overstating damages in countries with high baseline rates of child mortality (and lower life expectancies). This has the same effect as discounting expected lifetime income for children more heavily into the future. At present, there is insufficient evidence to make any adjustments for household family planning decisions and child replacement rates, which might partially offset expected losses in labor output.

for cooking and a greater burden from household air pollution—and the average damage cost for the loss of a child under the forgone output approach is significantly higher than that for adults in their late 50s and 60s—this has the effect of amplifying damage estimates in low-income countries. (See box 3.11.)

Accounting for Income Growth

Currently, in the World Bank's global estimates of air pollution damages for the ANS indicator, a constant annual income growth rate of 2.5 percent is assumed for all countries and years. Country-specific studies in fast-growing developing countries have used higher rates, for example, 6–8 percent in the World Bank–SEPA study of pollution costs in China (2007). For the United States, the U.S. EPA typically assumes an annual income growth rate of 1 percent. (box 3.12.)

Discount Rate

Related to the assumed rate of future income growth is the discount rate. In *The Changing Wealth of Nations,* the World Bank estimates human capital for China using a lifetime income approach and sets the discount rate of 8.26 percent (World Bank 2011). This rate is assumed on the basis of the Ramsey formula:

$$r = \rho + \eta \frac{\dot{C}}{C}$$

where the discount rate, *r,* is equal to the pure rate of time preference, ρ, plus the elasticity of utility with respect to consumption. For the World Bank's human capital accounts in China, the pure rate of time preference is assumed to be 1.5 and utility is assumed to be iso-elastic with respect to consumption ($\eta = 1$). With average annual growth in real annual per capita consumption of 6.76 percent between 1970 and 2008, the social discount rate equals 8.26 percent (8.26 = 1.50 + 6.76). This is close to the discount rate of 8.5 percent assumed in the United Nations University International Human Dimensions Programme on Environmental Change and United Nations Environment Programme's human capital accounts for the *Inclusive Wealth Report* (see UNU-IHDP and UNEP 2012). However, for slower-growing economies, setting *r* at 8.5 percent would be too high. For most assets included in the World Bank's comprehensive wealth accounts and ANS calculation, a social discount rate of 4 percent is chosen. (See box 3.13.)

BOX 3.12   Question: What Assumptions Should Be Made about Future Income Growth?

Proposal: Under a forgone output approach, assuming a constant income growth rate of 2.5 percent may understate damages in fast-growing economies such as China and India. It may also overstate damages in high-income countries with lower rates of growth. Yet, any assumption about long-term income growth, especially in valuing health impacts among young people with long working-life expectancies, involves significant uncertainty. For the global assessment, and to the extent possible, a constant rate of 3 percent will be assumed for low-income and middle-income countries in keeping with recent guidance by the World Bank for estimating long-term rates of growth in project economic analysis. A growth rate of 2 percent will be assumed for high-income countries.

Notes

1. Neoclassical economic theory suggests that people's WTP and WTA for nonmarket goods should be equal, but this is often not the case. The contrast suggests that people's WTP and WTA are influenced by behavioral factors and by differences in the properties of welfare measures that depend on how public goods are provided (see Carson 2012 and Kling et al. 2012).
2. This example borrows from the example in OECD (2012, 14).
3. This claim is based on reviews of wage-risk studies and stated-preference studies in North America. In their review of the more recent literature, Robinson and Hammitt (2015) find that "high-quality" stated-preference studies tend to yield VSL estimates close to those from wage-risk studies.
4. Similarly, in the literature on human capital accounting, the accumulation of human capital is often valued in terms of the expected gain in lifetime earnings potential due to higher levels of schooling among workers, following the approach first developed in the United States by Dale Jorgenson and Barbara Fraumeni (1992).
5. Recent examples include Croitoru et al. 2010 (Jordan); Klytchnikova et al. 2013 (Nicaragua); World Bank 2013a (India); World Bank 2013c (Kosovo); Meisner et al. 2015 (Macedonia); Sander et al. 2015 (Ecuador).
6. In contrast with the stated-preference studies, wage-risk studies have more consistently demonstrated an inverted U-shaped relationship between the VSL and age such that the VSL rises with age for younger workers, peaks for workers around the age of 50, and then declines (Aldy and Viscusi 2007, 2008; Kniesner, Viscusi, and Ziliak 2006; Viscusi 2014). However, as noted, these wage-risk studies deal mainly with the working-age population in decent health considering occupational injuries rather than illness-related health risks, so they do not reflect the preferences of individuals across the broad swath of age groups affected by pollution, particularly the elderly.
7. Recent examples include Golub et al. 2014 (Colombia); World Bank 2015a (Georgia); Croitoru et al. 2010 (Jordan); World Bank 2013a (India); World Bank 2013c (Kosovo); Meisner et al. 2015 (Macedonia).
8. For the meta-regression analysis, income is approximated by country-level GDP per capita (in constant purchasing power parities [PPPs]).
9. In other words, people of higher incomes assign a larger value to marginal reductions in mortality risk than do people of lower incomes, and this difference in value exceeds their proportional differences in income. Note, however, that the income elasticity of WTP is different from the income elasticity of demand, and usually smaller, so the usual definition of a luxury good does not apply in the same way.
10. These quality standards are (1) the study reports a value for the risk change (for example, 5 in 10,000); (2) the survey sample includes a sample of more than 200 observations and subsamples of 100 observations or more; and (3) the sample is representative of the broader population.
11. The tests considered are internal and external scope tests.
12. The VSLY is also commonly referred to as the value of a life year, or VOLY.
13. Examples include Johannesson and Johansson (1996), Chilton et al. (2004), and Desaigues et al. (2007, 2011).
14. US$56,000, with an uncertainty interval of US$35,000 to US$141,000 (PPP-adjusted, year 2011 prices). The EU-25 are Austria, Belgium, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the

Netherlands, Poland, Portugal, Slovenia, the Slovak Republic, Spain, Sweden, and the United Kingdom.

15. US$82,000 to US$184,000 (PPP-adjusted, year 2011 prices)
16. US$85,000 to US$209,000 (PPP-adjusted, year 2011 prices)
17. US$1.545 million to US$3.316 million (PPP-adjusted, year 2011 prices)
18. Some of these uncertainties are elaborated by the U.S. EPA in its sensitivity analysis of the health benefits of the Clean Air Act using the VSLY (U.S. EPA 1997, appendix I).
19. The U.K. VSLY figures are PPP-adjusted and expressed in 2012 prices, as in the Defra guidance note.
20. The average associated GDP per capita for the OECD countries studied is about US$30,000 (year 2005, PPP).
21. See also Lindhjem and coauthors (2011), OECD (2012), and Lindhjem and Navrud (2015).
22. The quality-screened VSL estimates included in the sample meet the following conditions: (1) the study reports a value for the risk change (e.g., 5 in 10,000); (2) the estimates are drawn from a study sample of more than 200 observations or a sub-sample of 100 observations or more; (3) the study sample is representative of the broader population; (4) the estimates pass an internal and/or external scope test for validity.
23. Restricting the sample of studies to those that satisfy internal or external scope tests yields slightly lower VSL/Y ratios of 103:1 to 120:1 for high-income countries and 30:1 to 37:1 for middle-income countries.
24. The log-transformed VSL/Y ratios in the database of WTP studies follow a lognormal distribution. In comparing the distributions of logged VSL/Y ratios for middle-income and high-income countries, the null hypotheses that the average VSL/Y ratio is equal or higher for middle-income countries can be rejected at the 99 percent level.
25. The life-cycle model of consumption and savings that underpins the VSL is described by Yaari (1965); Shepard and Zeckhauer (1982, 1984); Cropper and Sussman (1990); Cropper and Sahin (2009); and others.
26. Wealth, savings, insurance, and other financial instruments or assets may bend this constraint.
27. Note that these conclusions are for the base VSL in the World Bank–IHME report and would not necessarily hold for other base VSL estimates and GDP per capita values. The results should not be generalized to other cases without doing the analysis.
28. This is the age limit assumed by the World Bank in estimating labor productivity losses from pollution as a component of adjusted net savings for the World Development Indicators database (World Bank 2015). See Liu and Fraumeni (2014) for an example from the human capital accounting literature.
29. That said, the age 65-and-over population represents only 4 and 3 percent of the workforce in middle-income and low-income countries, respectively. Data are not available on the share of the age 65-and-over population in total wages.
30. This assumes that life expectancy increases monotonically with age, which is not the case for countries with high rates of infant mortality where life expectancy at birth is lower than it is for children who survive to age 1.
31. See World Bank 2013a, for example.

4. Valuing Morbidity Costs

No standard method exists for monetizing the costs of nonfatal health outcomes (OECD 2014). Hunt and Ferguson (2010) propose that the economic cost of morbidity equals the sum of the following:

- *Resource costs:* direct financial costs for avoiding or protecting against exposure or for the care and treatment of pollution-associated illness;
- *Opportunity costs:* indirect costs from the loss of time for work and leisure; and
- *Disutility costs:* the cost of pain, suffering, discomfort, or inconvenience.

The difficulty in aggregating morbidity costs owes to the complex nature of nonfatal outcomes, as noted by the WHO and OECD in their study of air pollution costs in Europe (WHO-OECD 2015). Morbidity involves a plurality of health endpoints (lost work days, hospital admissions, expenditures for long-term medical treatment, and so on) suffered by a plurality of agents (the patient as well as the patient's friends, family, coworkers, and so on). This raises the possibility of double counting or inconsistency in cost estimation methods for different outcomes. Data may be missing on health expenditures and medical treatment costs for a wide array of countries. Differences in health care systems between countries—and how health care costs are allocated to patients, care providers, and the public treasury—is also a problem. Finally, there are fewer studies of WTP to avoid different kinds of illnesses and other medical conditions associated with pollution exposure than there are of WTP to avoid mortality risk, so measuring disutility costs is more difficult. Expressed WTP to avoid pain and suffering from illness may also be entangled with other costs (such as expensive or lengthy medical treatment) that individuals associate with conditions such as chronic bronchitis.

Hunt and coauthors (2016) have further proposed a core set of health endpoints that could potentially be used to value the disutility, resource, and opportunity costs associated with air pollution:

- Respiratory and cardiovascular hospital admissions related to PM or ozone exposure
- Restricted activity days and days of lost work due to PM and ozone exposure
- Chronic bronchitis in adults due to PM exposure
- Acute bronchitis in children ages 6 to 18 due to PM exposure
- Acute lower respiratory illness in children ages 5 and under due to PM exposure

The common set of endpoints is the result of an extensive review of regulatory analysis in Europe, the United States, and non-OECD countries such as China, as well as the GBD. Despite this, Hunt and coauthors note that "the empirical evidence for these pollutant-health outcomes remains limited" (Hunt et al. 2016, 5). Furthermore, some outcomes such as lost workdays are "strongly socio-culturally determined" and "point to major uncertainties about transferability" (Hunt et al. 2016, 39).

The question of the transferability is especially thorny. Because they are strongly influenced by social context and are often measured in different ways, unit cost values for different morbidity

endpoints vary widely, even among countries of similar income levels. For example, in their review of the literature, Hunt and coauthors (2016) find that estimates of WTP to avoid chronic bronchitis range from around US$40,000 to US$90,000 in European countries to US$880,000 to US$2.03 million in the United States. Hospital treatment costs for respiratory and cardio-vascular conditions associated with air pollution range from US$1,500 to US$2,600 per case in European countries and to US$20,000 to US$40,000 per case in the United States. Though disutility costs represent the largest and arguably the most easily transferable component of morbidity costs, it is unclear whether they can be transferred from one country to another in the same way as the VSL.

Confronting these problems of measurement, the OECD has taken the pragmatic stance that morbidity costs are at least greater than nothing and so can be estimated provisionally as a small percentage of mortality costs (see OECD 2012 and 2014 and Hunt et al. 2016). As a benchmark value, the OECD has proposed a 10 percent markup of mortality costs to account for morbidity on the basis of the relative share of avoided morbidity costs in the total health benefits of air pollution control as estimated in regulatory analyses by the U.S. EPA and EC DG Environment. Whether this benchmark value holds for countries outside the OECD is questionable. As shown in table 3.6, previous studies by the World Bank in middle-income countries have estimated a wide range of morbidity costs. Studies in Nicaragua and China, for instance, have found that morbidity costs may be as great as 44 percent of total health costs (World Ban–SEPA 2007; Golub et al. 2014). However, because the studies included in table 4.1 take differing approaches to estimating morbidity costs, these figures are not really comparable. (See box 4.1.)

TABLE 4.1   Share of Morbidity Costs in Total Health Costs from Ambient Air Pollution, World Bank Studies

Country	Year studied	Morbidity share of total costs (%)	Morbidity cost components	Source
Argentina	2012	7–16	*Opportunity costs:* Days of illness x 50% average daily income	World Bank (2015a)
China	2003	18–44	*Disutility costs:* WTP to avoid chronic bronchitis (using VSL and QALY weights) *Resource costs:* Hospital admission costs (direct and indirect)	World Bank– SEPA (2007)
Colombia	2012	20	*Disutility costs:* WTP calculated as 2.27 x (resource + opportunity costs), as done by Bogota government *Resource costs:* Upper bound of publicly listed prices that public insurers pay health care providers *Opportunity costs:* For urban PM, time lost valued at 75% urban wage, applied to both working and nonworking people; for HAP, time lost valued at 75% rural wage; for chronic bronchitis, time loss valued over 20-year period	Golub et al. (2014)

table continues next page

TABLE 4.1   Share of Morbidity Costs in Total Health Costs from Ambient Air Pollution, World Bank Studies *(continued)*

Country	Year studied	Morbidity share of total costs (%)	Morbidity cost components	Source
India	2009	7	*Disutility costs:* YLDs valued using VSLY (as part of DALYs) *Resource costs:* Medical treatment costs from previous studies and consultations with medical providers, costs of chronic bronchitis and COPD taken over 20-year period *Opportunity costs:* 75% average wage x days of illness	World Bank (2013a)
Jordan	2006	28	*Disutility costs:* VSL used to value YLDs *Resource costs:* Medical treatment costs	Croituru, Cervigni, and Jabarin (2010)
Kosovo	2010	10	*Disutility costs:* WTP is 2 x (resource + opportunity costs) *Resource costs:* Total public medical costs (not just cost to patient) for hospitalization, doctor visits, and ER visits Opportunity costs: Time of illness valued at 50% average wage for patients and caregivers	World Bank (2013c)
Nicaragua	2007	44	*Disutility costs:* YLDs valued using VSLY *Resource costs:* Hospital admissions, ER visits, doctor visits *Opportunity costs:* Time of illness valued at 75% urban wage for both wage earners and nonwage earners; for chronic bronchitis, costs are discounted over 20-year period	Klytchnikova et al. (2013)

BOX 4.1   Question: How Should Morbidity Costs Be Valued?

Proposal: Standard approaches to measuring the costs of morbidity across countries are still in an early stage of development, and consistency is still lacking. The most common approach is to value resource and opportunity costs using country-specific data on medical treatment costs and wages. Disutility costs of nonfatal health outcomes are also sometimes valued in terms of years lived with disability (YLDs) or disability-adjusted life years (DALYs) using a value per statistical life year (VSLY), though issues with the use of YLDs and DALYs for economic valuation and the derivation of the VSLY remain.

For the World Bank–IHME study, the goal is to provide estimates of the overall economic costs of the health burden from air pollution in countries around the world. As has been shown, nonfatal health outcomes represent a relatively small fraction of the total health burden. Because there is still no standard approach for valuing morbidity costs and gathering country-specific data on resource costs would be prohibitive, it may be reasonable for the World Bank–IHME study to exclude morbidity costs. Mortality costs may be presented with the caveat that total health costs including morbidity may be at least another 10 percent, on the basis of expert judgment and previous studies by the World Bank and OECD.

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