Valuing the Health Impacts of Air Emissions

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DALYs, QALYs, and other Community Measures of Environment Health
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Synopsis: Air pollutants are associated with many adverse health effects, exacerbating existing conditions, increasing the incidence of acute and chronic illnesses, and leading to premature mortality. One approach for measuring these impacts is to count the number of times a particular effect occurs. However, such counts do not convey the relative severity of each outcome nor can they be easily aggregated across different endpoints. Thus economists and other social scientists have developed various metrics that allow comparison and integration of different health outcomes. These metrics include those denominated as health-adjusted life years, which focus on the effects of disease and disability on the quality of life and longevity. The most frequently used measures of this type are quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs). A second category of metrics uses dollars as the common denominator, and includes cost of illness (COI) and willingness to pay (WTP) estimates. These broad, integrative measures can aid in setting priorities, by facilitating comparison of the effects of pollutants and other hazards. In addition, they support decisions on control strategies, by providing benefit measures for comparison with the costs of alternative interventions. Which measure is most appropriate will depend on the context for the analysis.

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VALUING THE HEALTH IMPACTS OF AIR EMISSIONS

Introduction

Pollutants in outdoor ambient air are associated with many adverse health effects, exacerbating existing conditions, increasing the incidence of acute and chronic illnesses, and leading to premature mortality. These health effects harm individual and societal welfare in several respects, increasing expenditures on medical care and protective measures, decreasing productivity and quality of life, restricting activities, and causing pain and suffering. Depending on the pollutant type and source, these impacts may occur in the same community as the emissions or in more distant areas.

Common air pollutants include particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead (Pb). The most severe and widespread health threats are generally associated with particulate matter and ground level ozone, which lead to a number of cardiovascular and respiratory conditions as well as premature mortality. In addition, toxic air pollutants such as benzene, lead, mercury, methylene chloride and others are associated with various additional health problems, including cancers, birth defects, reproductive difficulties, and cognitive declines.

One approach for measuring these impacts is to estimate the association between a particular exposure level and the risk of each health outcome, and to develop methods for counting the number of times each effect is likely to occur. Examples include estimating the number of cases of premature mortality, new or exacerbated illnesses, hospitalizations, or restricted activity days. Thus for a community affected by a change in particulate matter emissions, the annual impacts could be described as including 1,000 asthma attacks, nine new cases of chronic obstructive pulmonary disease, 10 premature deaths, etc. Such counts are familiar and easy to understand, and are important to report in any analysis. However, while providing useful information, they cannot be directly aggregated in a way that can be easily compared to the impacts of other hazards or to the costs of regulatory or other interventions. In addition, these counts are incomplete measures; they do not indicate the relative severity of the impacts nor the overall effect on well-being. Thus it is often desirable to supplement these types of physical measures with those that allow for a more comprehensive and integrative approach.

Economists and other social scientists have developed several metrics that more completely account for the effects of morbidity and mortality on individual and societal well-being, and allow comparison and integration of different health outcomes. These metrics generally fall into two categories: health adjusted-life year measures and monetary measures.

Health-adjusted life year measures focus on the effects of disease and disability on the quality of life and longevity. The most frequently used of these measures are quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs), which are often applied in health policy and medical decision-making as well as in estimating the global burden of disease. Depending on the context, they may be used to indicate the relative impacts of different hazards or to determine the cost-effectiveness of different interventions. In the latter case, the costs of the interventions are divided by the number of QALYs or DALYs to determine the cost per unit of benefit.

The second set of metrics uses money as the common denominator. These metrics include estimates of the cost of illness (COI) or willingness to pay (WTP). COI estimates focus on real resource expenditures, including medical costs and lost productivity, but do not account for quality of life impacts, the value of avoided pain and suffering, nor any effects of decreased longevity other than lost earnings. WTP is a broader measure, grounded in economic theory, which considers how much income or wealth individuals would be willing to exchange for decreases in the risks of particular health impairments or premature mortality. As a result, WTP estimates can address those impacts omitted from COI measures. Monetary metrics may be used to assess the direct and indirect costs associated with illness, or to compare the costs of different medical or public health interventions to their expected benefits.

These types of broad, integrative measures provide important information for policymakers. They aid in setting priorities, by facilitating comparison of the relative burden of pollutants and other hazards associated with different health outcomes. In addition, they support decisions on control strategies, by providing a benefit measure that can be compared to the costs of alternative interventions, such as emission standards of varying stringency or different levels of emission taxes. Which measure is appropriate will depend on the focus of the analysis; at times, the choice of measure will be limited by the available data.

Health-Adjusted Life Year Measures

Health-adjusted life year measures integrate different morbidity and mortality effects by converting them into equivalent life years. QALYs refer to a broad category of health-adjusted life year measures originally developed to estimate benefits in cost-effectiveness analyses of health policy and medical treatment decisions, and encompass a number of different estimation approaches. DALYs are a related method and are most often estimated using an approach developed for the World Health Organization (WHO) in the 1990s to measure the global burden of disease.

Creating a QALY estimate generally involves: (1) determining the effects of a health state on health-related quality of life (HRQL); (2) assigning a value or a weight to these HRQL impacts relative to those associated with other health states, using a value of one for perfect or optimal health and a value of zero to reflect death; and then (3) multiplying the weight for that state by its duration, taking life expectancy into account. The results are the QALYs associated with each state, which then can be summed to determine the total QALYs associated with a particular condition.

DALYs are estimated using a similar set of steps, but are based on a scale that is the inverse of that used for QALYs, with a value of one representing death and a value of zero representing perfect health. More importantly, as implemented by WHO (e.g., in WHO 1996), DALYs were designed to be egalitarian. DALYs use the same assumptions about disability weights and life expectancy for the entire population, varying only by age and gender, as discussed in more detail below.

Developing Estimates

The initial step in estimating QALYs, describing the effects of each health state on HRQL, is usually completed by experts or by patients familiar with the condition. Patient data are generally preferable, although often more expensive and time-consuming to collect. This description addresses the different ways in which the condition affects the quality of life, potentially including physical limitations, social or cognitive effects, and emotional impacts. A condition could be described, for example, as significantly limiting mobility, preventing involvement in one's usual activities, leading to moderate pain or discomfort, and creating mild anxiety or depression. DALYs (as implemented by the WHO) use a somewhat different approach, focusing on a range of 22 indicator conditions such as diarrhea, blindness, paraplegia, and dementia. Other conditions were then categorized based on their similarity to these 22 conditions.

The second step, valuing the HRQL impacts, involves placing them on a scale anchored at "zero" and "one." In the case of QALYs, zero represents death and one represents perfect or optimal health. Other health states are typically assigned intermediate values, with lower values for more severe conditions. (Values below zero are possible for health states ranked as worse than death.) The placement of health states on this scale is determined by asking individuals to rank or compare the condition to other health states, indicating their relative preferences for each condition. Researchers generally apply one of three methods to determine the relative weights (or preferences) for each state. These methods include: standard gamble (trade-offs between different health risks); time trade-off (trade-offs between time spent in different health states); or category weighting (locating each condition on a visual analog or similar scale). Another approach is the person trade-off method (trade-offs between health improvements affecting different groups of people).

For DALYs, WHO uses an inverse scale (with "one" representing death and "zero" representing perfect health) to weight each condition. The weights were developed using the person trade-off method, following a structured and iterative expert deliberation process. While QALY weights for a particular health state or condition may vary depending on the population surveyed and the methods used, WHO's DALY weights are the same for all populations considered globally. Furthermore, WHO adjusts the weights for age, so that more weight is given to years lived in mid-life (at working ages) and less weight is given to years lived at younger and older ages.

WHO assumes that life years lost to premature mortality would have been lived in perfect health, whereas the best practice recommendations for QALYs suggest that these years should be valued using estimates of likely actual health status. The former approach is designed to be egalitarian. Under the latter approach, the value of a lost life year will depend on age as well as other factors, because studies show that reported HRQL generally declines with age.

The third step, multiplying the HRQL impacts by duration, is relatively straightforward. The weighted HRQL results (i.e., the values on the zero-to-one scale) are simply multiplied by the estimated length of time each health state is likely to be experienced, taking into account the remaining life expectancy of the affected individuals. When applying QALY estimates, duration and longevity are generally estimated based on data for the population of concern. As developed by the WHO, DALYs use the same assumptions about life expectancy for the entire population worldwide, discriminating only by age and gender. However, some researchers have used the DALY approach without this standard life expectancy assumption, as well as without the age weighting noted earlier.

The resulting estimates can be used to assess the health impacts of a particular policy as well as to estimate the overall burden of disease associated with air pollution or other hazards. An example is provided in Box 1 below.

<< Insert Box 1, Example of QALY calculations, here>>

Sources of Estimates

The process described above can be implemented using new primary research; e.g., by surveying the affected population to ascertain their HRQL estimates for the endpoints of concern. However, analysts often rely on other approaches that require less time and funding to implement. One frequently used option is to apply one of several generic HRQL indices, which include the EuroQol (EQ)-5D, the Health Utilities Index (HUI), the Quality of Well-Being (QWB) scale, and the Short Form (SF)-6D. Each of these indices employ classification systems with several dimensions; e.g., in the case of the EQ-5D, mobility, self-care, usual activities, pain, and anxiety and depression. A particular health state is rated within each dimension; for example, as causing no, some, or extreme problems. Each attribute of the health state (such as having "some" problems with mobility) is then weighted based on a survey developed especially for that index. For example, the EQ-5D weights for the U.S. population are based on the time trade-off method. These indices have the advantage of standardizing the approach for describing each health state and including pre-established weights for each attribute.

Applying a generic index involves first determining the attributes that correspond to the condition. As discussed above, this initial step can be undertaken by experts or by individuals with the condition, but data from patients are generally preferable. These attributes are then weighted using the values associated with the specific index, and multiplied by the duration of the specific health state.

Alternatively, analysts can use "off-the-shelf" weights; i.e., estimates from studies of the same or similar health conditions. Weights for many conditions can be found in the Cost-Effectiveness Analysis Registry maintained by the Center for the Evaluation of Value and Risk in Health at Tufts-New England Medical Center (http://www.tufts-nemc.org/cearegistry/default.asp). Analysts can search this database to determine whether the health effects of concern have been addressed in previously completed studies, and then review the available research to determine its quality and applicability to the populations and risks of concern. A broader search of the research literature also may be desirable, because this database excludes studies that provide HRQL or QALY estimates without comparison to costs.

A third source of values is data collected in population surveys. Some large national surveys (such as the U.S. Medical Expenditure Panel Survey or MEPS) now include one or more of the generic indices. The resulting data can be used to derive estimates of the impacts of different conditions, using statistical analysis to control for the impacts of other factors (such as age) on HRQL. For example, Sullivan and Ghushchyan (2006) use MEPS data to estimate weights for a range of chronic conditions based on the EQ-5D. Relying on population surveys avoids the time and expense of collecting new data (through primary research or application of one of the generic HRQL indices), and has the advantage of providing consistently-derived estimates across a wide range of health outcomes based on a large sample.

For DALYs, the standard weights developed by WHO are available on its website (http://www.who.int) for each health condition included in its analysis. This site also provides information on WHO's continuing work on enhancing and applying these weights. Other sources of DALY values, based on different estimation methods, can be identified by a review of the research literature.

Examples of Air Pollution Studies

QALYs and DALYs are frequently used to assess the cost-effectiveness of different interventions and to determine the total burden of disease. Recent analyses conducted by the U.S. Environmental Protection Agency (USEPA) provide examples of the use of QALYs to assess the cost-effectiveness of air pollution regulations. For instance, to assess the impacts of its National Ambient Air Quality Standards for fine particulate pollution, the USEPA provides an illustrative analysis that applies "off-the-shelf" weights for chronic bronchitis and nonfatal acute myocardial infarction and also considers premature mortality (EPA 2006).

The USEPA's analysis uses different comparisons depending on whether the outcome is premature mortality or a nonfatal health effect. For premature mortality, it compares life years lost to life years lived in perfect health (i.e., to an HRQL value of 1.0), while for nonfatal effects, life years lived in impaired health (due to chronic bronchitis or nonfatal acute myocardial infarction) are compared to the expected average health of the affected individuals in the absence of the condition (i.e., to a value of 0.95). Thus the assumptions about health status in the absence of exposure to the pollutants vary depending on whether the effect of concern is premature mortality or morbidity. The USEPA designed this approach to ensure that each year of life lost is valued equally regardless of whether the affected individual is in poor health, and refers to it as "Morbidity-Inclusive Life Years" (MILYs).

The USEPA finds that its revised standards for fine particulate matter will lead to a gain of about 43,000 MILYs associated with these health impacts (using a 3 percent discount rate); about 60 percent of this gain is attributed to avoided premature mortality. The USEPA examines the uncertainty in its estimate using probabilistic analysis and also considers its sensitivity to the choice of discount rate. The MILY estimates do not include other health effects associated with the pollution due to limitations in the available HRQL research and, by definition, also do not include nonhealth-related impacts such as effects on visibility. Thus the USEPA's MILY estimates understate the total benefits of the regulations.

Another example is a case study prepared for the Institute of Medicine's (IOM's) Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety

Regulation (Robinson et al. 2005). This case study experiments with different approaches for estimating the QALY gains associated with the USEPA's regulations addressing emissions from nonroad diesel engines, including: (1) estimates based on the EQ-5D using expert judgment; (2) "off-the-shelf" weights from the Cost-Effectiveness Analysis Registry; and, (3) EQ-5D estimates from a preliminary version of the Sullivan and Ghushchyan MEPS analysis referenced earlier.

The IOM results were dominated by the estimates for premature mortality (which were valued the same under all three approaches), but the estimates for the nonfatal effects considered (chronic bronchitis and nonfatal acute myocardial infarction) varied depending on the approach. Total gains ranged from about 109,000 to 119,000 QALYs across the three approaches, with about 93,000 QALYs (78 to 85 percent of the total) attributable to premature mortality in each case (3 percent discount rate). This case study highlights a number of challenges, suggesting that a more rigorous approach is needed when expert judgment is used, and indicating the difficulties inherent in identifying a consistently-derived set of "off-the-shelf" weights for the conditions of concern. Carefully developed weights from well-established and representative data sources (such as MEPS) may be preferable.

Other examples of health-adjusted life year metrics consider the total burden of disease. For example, a recent WHO study considered the relative burden of diseases associated with different causes internationally (Cohen et al. 2004). For air pollution, the researchers only quantified the effects of premature mortality associated with particulate matter exposure. They found that, in the year 2000, such exposure led to 800,000 premature deaths globally, representing 6.4 million years of life lost. They estimated that particulate matter was associated with 3 percent of all deaths from cardiopulmonary disease among adults, 5 percent of all deaths from cancers of the trachea, bronchus, and lungs, and 1 percent of all deaths from acute respiratory infections in children. Compared to other causes, air pollution accounted for about 1.2 percent of all premature deaths, and 0.5 percent of total DALY losses. The latter is likely to be underestimated, however, because the analysis did not account for the nonfatal health impacts associated with air pollution.

Another study, prepared for the World Bank, used DALYs to estimate the burden of disease associated with air pollution from fossil fuel use in six cities around the world (Lvovsky et al. 2000). Because DALY estimates were not available for many of the morbidity effects considered, the authors estimated DALY losses based on the ratio of the monetary estimates used to value morbidity and mortality. In total, the analysts found that the associated health burden was equivalent to losses of about 237,000 DALYs, with 41 percent of the total attributable to premature mortality.

Each approach for estimating the QALY or DALY gains or losses attributable to air pollution has strengths and weaknesses. Two expert panels considered these concerns and recommended best practices for different contexts: the Panel on Cost-Effectiveness in Health and Medicine (Gold et al. 1996), and the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation (IOM 2006). The more general question of whether to use a measure based on life-years or money depends on the type of trade-off considered. QALYs and DALYs only reflect preferences across health states, not preferences between improved health and other aspects of well-being, and cannot be easily combined with measures of other welfare effects such as ecological risk reductions. Thus they are most useful in analyses focused on the combined impacts of different health states, such as choosing among medical treatments that have differing implications for morbidity and mortality or assessing the relative health of different populations.

Monetary Measures

A second set of metrics uses money to reflect the combined impact of air pollution or other hazards on morbidity and mortality. The COI approach is the narrowest of these measures, focusing solely on expenditures and on human capital costs (i.e., lost productivity). WTP is a more comprehensive measure, considering how much income or wealth individuals would be willing to exchange for decreased health risks. In some cases, cost estimates can be added to a WTP measure, if they address financial externalities not taken into account in the reported WTP estimates. The value per statistical life (VSL) is a WTP measure developed to address mortality risk reductions, and is discussed separately below due to its importance in the air pollution context.

<u>Cost of Illness</u>

The simplest approach for determining the combined impacts of different health outcomes on a community may be to estimate related monetary expenditures. Depending on their goals, COI studies may include costs funded by patients, their families, and/or third parties (such as insurance companies or government programs) as well as employers. They typically address direct medical costs, such as those associated with physician services, medication, and hospital stays. Many studies also consider the indirect costs associated with lost productivity. These latter costs may result from absence from work or from decreased productivity while at work, and may also include employer costs such as those related to idling assets or training replacement workers. Some studies consider unpaid work (e.g., volunteer and household services) as well as paid work. Productive time is generally valued using measures of compensation, often referred to as the human capital approach. Other costs, such as those related to litigation or to processing claims, may be included in COI studies in some cases.

A number of publically-available databases track illness-related costs, and can be used to develop estimates for conditions of interest. In addition, completed studies are available for many health outcomes. However, this research is often prevalence-based, calculating the costs of all cases of an illness that exist at a particular point in time on a cross-sectional basis. Alternatively, COI estimates may be incidence-based, tracking a cohort of individuals over time and yielding longitudinal estimates of long term or lifetime costs per case. Which type of study is appropriate depends on the goals of the analysis. If the goal is to estimate the total costs of air pollution-related illness incurred in a particular year, then data from prevalence-based studies would be appropriate. If the goal is to instead calculate the change in costs over time associated with a change in pollution levels, incidence-based estimates are generally needed.

Incidence-based estimates are relatively rare, however, due in part to the resources needed to track individuals over time. Annual, prevalence-based estimates can be converted to rough estimates of lifetime costs; e.g., by assuming that the annual costs are constant (at an amount equal to the prevalence-based estimate) in each year of the illness. However, such simple calculations ignore the variation in costs from year-to-year over the course of the illness, and may lead to erroneous results particularly if the prevalence-based estimates are dominated by those cases that are in their most (or least) costly phase.

COI studies have many advantages: (1) the methods they use are well-developed, widely applied, and easily explained; (2) data on many costs are routinely collected and easily accessed; and (3) existing studies provide estimates for a large number of health conditions. However, such studies do not address the value of avoiding pain and suffering or other quality of life impacts, and ignore effects on leisure activities. Hence they understate the impacts of air pollution on social welfare. In addition, there are no generally accepted best practice standards for these studies, which may report widely varying estimates for individual health conditions depending on the costs included and the data sources used.

The approaches used to estimate lost productivity (which can be equal to or greater than medical costs in many cases) present larger challenges, given the difficulties of measuring the impacts of illness on an individual's productivity as well as the impacts of individual productivity on overall production. For example, the results will depend on the assumptions regarding the level of unemployment and the characteristics of replacement workers. If an ill worker is simply replaced by an individual with similar skills who would otherwise be unemployed, there may be little net effect on overall production aside from the costs of transitioning to a new employee. Assessing the impact of illness on production thus requires clear specification of the scenarios being compared.

<u>Willingness to Pay</u>

A more complete monetary measure of the value of health effects associated with air pollution involves estimating individual WTP for increases or decreases in related risks. Comparison of WTP and COI estimates for nonfatal health effects suggests that the latter may significantly understate these values, with WTP estimates often exceeding the costs of illness by a factor ranging from three or six. This results in part because the COI estimates exclude the value of adverse impacts on the quality of life and related pain and suffering. However, COI estimates are available for a wider range of health effects.

WTP estimates are often applied in benefit-cost analyses, where the social costs of alternative air pollution control strategies are compared to the value of the associated health risk reductions as well as other nonhealth benefits. These analyses identify the policy that is preferable from the perspective of economic efficiency. Decision-makers can then weigh these results, along with other quantifiable and non-quantifiable factors (such as the distribution of the effects and their equity or fairness), to determine the most appropriate policy.

For these types of analyses, benefit values are most appropriately measured by the change in income that has the same effect on individual well-being (referred to as "utility" by economists) as the policy. In this context, WTP is the maximum amount of money an individual would voluntarily exchange to obtain an improvement, given his or her budget constraints. (Willingness to accept compensation, or the least amount of money an individual would accept to forego the improvement, is less frequently used due largely to difficulties in its measurement.) For public goods that are not traded in the marketplace, such as reductions in air pollution or the resulting health risks, economists use a variety of approaches to estimate WTP.

These approaches can be divided into two categories: stated preference methods and revealed preference methods. Stated preference methods typically employ survey techniques to ask respondents what they would pay for a risk reduction of a particular type. Examples of stated preference methods include contingent valuation surveys, which directly elicit statements of WTP for the hypothetical scenario(s) that the survey describes. Another method includes conjoint analyses or choice experiments, which present respondents with several scenarios involving different amenities and prices. Estimates of WTP are then developed based on the way in which respondents rank, rate, or construct equivalent sets of alternatives. Some studies ask respondents about risk-risk trade-offs, such as the costs of living in a particular location vs. the risks of traffic accidents.

Revealed preference methods estimate the value of non-marketed goods based on observed behaviors or prices and preferences for related marketed goods. One such method involves estimating compensating wage differentials. These wage-risk (or hedonic wage) studies examine the additional compensation associated with jobs that involve higher risks. Researchers use statistical methods to separate out the effects of risk on compensation from the effects of other job and personal characteristics. Another revealed preference approach involves consideration of averting behaviors or purchases of consumer safety products; e.g., defensive measures undertaken by individuals or households to protect against perceived risks. For example, individuals may purchase an air conditioner or stay indoors to protect against the effects of air pollution. A key challenge in these studies is isolating the value of the behavior that is associated with the effect of concern (i.e., health risks) from the value of its other benefits (i.e., cooling). Each of these methods has advantages and limitations (see Freeman 2003), and it is often desirable to use values from more than one study to explore the sensitivity of the results to the methods and data sources used.

In the context of policy analysis, analysts generally transfer estimates from available studies rather than conducting new primary research, due to time and resource constraints. In many cases, the available studies address risks or populations that are somewhat different than those related to air pollutants, in which case analysts generally rely on the benefit transfer framework in applying the study results. This framework involves carefully considering the quality of the available research (the data and methods used) and the suitability of the estimates (the extent to which they consider populations and risks that are similar to those associated with air pollution). In some cases, the results from the primary research studies can be adjusted quantitatively to better fit the air pollution context. Otherwise, the potential implications of the differences must be discussed qualitatively, along with other sources of uncertainty that are difficult to quantify.

Relevant WTP studies have been identified in many previous analyses, examples of which are provided later in this article. However, relatively few studies estimate WTP to avert the types of nonfatal acute and chronic illnesses associated with air pollutants, and analysts instead often rely on COI estimates. The number of WTP studies is steadily increasing; to identify newer studies, analysts may wish to search bibliographic databases such as EconLit (http://www.econlit.org/) or the Environmental Valuation Reference Inventory (EVRI) (http://www.evri.ca/).

Value per Statistical Life

In contrast to nonfatal risks, WTP for mortality risk reductions has been relatively well-studied. In this context, estimates of the value per statistical life (VSL) are usually used for valuation. The VSL aggregates individual WTP for small changes in risk across a large population; it is not the value of saving a particular person's life. For example, a $5 million VSL would result if each member of a population was willing to pay an average of $50 for a one in 100,000 decrease in his or her annual risk of dying ($5 million = $50 divided by the risk of 1/100,000). The VSL has been extensively studied, with most estimates (for the U.S.) ranging roughly from $1 million to $10 million. These estimates are often adjusted to reflect some of the differences between the scenarios studied and the scenarios addressed in policy analysis.

The USEPA for many years relied on VSL estimates derived largely from work completed in the early 1990s to support its retrospective and prospective analyses of the benefits and costs of the Clean Air Act (USEPA 1997, USEPA 1999). Its approach was based on analysis of 26 VSL estimates from the U.S. and other countries. Of this total, 21 estimates were from studies that examine the wage or salary premium received by workers who accept riskier jobs, controlling for the effects of other factors (such as education or nonfatal job risks) on wages. The remaining five estimates were from contingent valuation studies that used survey methods to elicit individual WTP for changes in fatality risks. In 2007 dollars, the mean VSL estimates from each individual study range from $1.0 million to $21.4 million, with an overall mean of $7.6 million across the 26 estimates.

More recently, the USEPA has begun to rely on the results of several VSL meta-analyses for its assessments of air pollution regulations (e.g., Viscusi and Aldy 2003). These meta-analyses use statistical methods to combine data across individual VSL studies. When applying these results (e.g., in USEPA 2006), the USEPA uses a normally-distributed range with a 95 percent confidence interval between $1 million and $10 million, and a mean of $5.5 million (1999 dollars). If inflated to 2007 dollars, this range becomes $1.2 million to $12.5 million with a mean of $6.9 million.

Most, but not all, of the estimates in these analyses are from studies of U.S. workers and focus on accidental job-related deaths. In general, the average risk faced by workers (roughly 1 in 10,000 to 1 in 100,000) is relatively similar to the magnitude of the risk associated with overall air pollution averaged across the U.S. population. However, the workers in these studies are younger than the majority of those affected by air pollution-related mortality risks, and the deaths are generally from accidents rather than from pollution-related illnesses. In addition, exposure to air pollutants may be perceived as less voluntary and controllable than job-related risks.

Many of these differences, such as those related to how the risks are perceived, cannot be addressed quantitatively due to the need for more research. Based on the available evidence and advice from several expert panels, the USEPA currently adjusts its VSL estimates quantitatively for changes in real income (net of inflation) over time, for any time lags between changes in exposure and changes in incidence (i.e., latency or cessation lag), and (in some cases) for the costs of medical treatment prior to death. It does not adjust for differences between the ages of those studied and those affected by air pollution, due to both inconsistencies in the research findings and policy issues related to using different values for different age groups. More generally, the USEPA does not make adjustments for differences in WTP across population subgroups (rich vs. poor as well as young vs. old) due to concerns about the perceived equity of such adjustments. Instead, it uses the same average VSL across all individuals affected by its regulations. Due to the importance of these VSL estimates in its regulatory analyses, the USEPA continues to conduct research and sponsor expert review on these issues.

Examples of Air Pollution Studies

Examples of the use of monetary estimates to value the health risks associated with air pollution include two major USEPA studies of the retrospective (1970-1990) and prospective (1990-2010) impacts of the Clean Air Act (USEPA 1997, USEPA 1999), as well as its analysis of the more recent National Ambient Air Quality Standards for particle pollution (USEPA 2006). These studies use VSL estimates to value mortality risks. While the USEPA would prefer to use WTP estimates for nonfatal risks as well, it relies on COI estimates in some cases due to the limited valuation research available. The estimates are adjusted for changes in real income over time as relevant, as well as for other differences between the underlying studies and the scenarios addressed by the regulations. Table 1 summarizes the central estimates used in its 2006 study, which also assesses uncertainty using probabilistic analysis and a distribution of values for each health outcome, includes values for nonhealth benefits, and discusses a number of impacts that could not be quantified.

<<Insert Table 1, Values used in the USEPA's..., here>>

In these USEPA analyses, averted premature mortality risks dominate the monetized benefit estimates. The Clean Air Act retrospective analysis indicated that mortality risks accounted for 95 percent of the present value of monetized benefits over 20 years (1970 – 1990); the prospective analysis found that premature mortality accounted for 88 percent of the monetized benefits over the period assessed (1990 – 2010), excluding the impacts of stratospheric ozone. For the National Ambient Air Quality Standards for particle pollution, premature mortality also dominated the benefits estimates, but the extent varied depending on the approach used to estimate the relationship between pollutant concentrations and premature mortality.

In sum, estimates of WTP are the preferred approach for determining the monetary value of health risk reductions in benefit-cost analyses. Such estimates allow analysts and decision-makers to compare the costs of different policies to benefits measured in the same units, and provide the most complete measure of welfare losses consistent with economic theory. However, due to gaps in the available research, COI estimates are sometimes used as a proxy measure of benefit values. COI estimates are also useful in cases where analysts are interested solely in determining the costs (in terms of expenditures and lost productivity) associated with pollution-related health risks. However, COI estimates are an incomplete measure of the effects of health risks on societal welfare because they exclude consideration of pain and suffering and other quality of life impacts, and address cases incurred rather than the risks associated with continued pollutant exposure.

See Also:

57, 61, 62, 220, 222-226, 301-306, 310, 577

Further Reading

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Environmental Valuation Reference Inventory (EVRI), Environment Canada, 70 Cremazie Street, Gatineau, Quebec, K1A 0H3, Canada, Web: http://www.evri.ca/.

Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, 20460, USA. Web: http://www.epa.gov/oar/.

World Health Organization, United Nations, Geneva, Switzerland. Web: http://www.who.int/

Abbreviations

COI:	cost of illness
DALY:	disability adjusted life year
EQ-5D:	EuroQOL-5D
HRQL:	health-related quality of life
HUI:	Health Utilities Index
MEPS:	Medical Expenditure Panel Survey
MILY:	morbidity-inclusive life year
QALY:	quality-adjusted life year
QWB:	Quality of Well-Being scale
SF-6D:	Short Form-6D
USEPA:	U.S. Environmental Protection Agency
VSL:	value per statistical life
WHO:	World Health Organization
WTP:	willingness to pay

Table 1

Values used in the USEPA's 2006 analysis of the National Ambient Air Quality Standards for particle pollution (1999 dollars, no adjustment for real income growth, 3 percent discount rate)

Health Endpoint	**Central Estimate in 1999 Dollars (method used)**
Premature mortality	$5.5 million per statistical life (WTP)
Chronic bronchitis	$340,000 per case (WTP)
Nonfatal myocardial infarction	$66,902 to $140,649 per attack depending on age (COI)
Hospital admissions (respiratory and cardiovascular)	$6,634 to $18,387 per admission depending on condition (COI)
Emergency room visits for asthma	$286 per visit (COI)
Respiratory ailments not requiring hospitalization	$16 to $360 per episode depending on condition (WTP)
Work loss days	$110 per day (COI)
Mild restricted activity days	$51 per day (WTP)

Box 1

Example of QALY calculations

If the average individual in a community is likely to live for 15 more years with a health status of 0.9 (on a QALY scale) in the absence of exposure to air pollutants, but will live for only 10 more years with a health status of 0.7 given the exposure, than the QALY loss attributable to the pollution will have two components.

- First, the air pollution-related morbidity during the survival period would lead to an average loss of 2.0 QALYs (0.9 - 0.7 = a HRQL decrement of 0.2, multiplied by 10 years).

- In addition, had the individual survived for the additional five years, his or her HRQL would have been 0.9 over this time period. Hence premature mortality leads to an additional loss of 4.5 QALYs (0.9 – 0.0 = a HRQL decrement of 0.9, multiplied by 5 years).

The total loss is thus 6.5 QALYs (2.0 QALYs plus 4.5 QALYs) for the average individual affected.

If the community includes 500 such affected individuals, then the total loss attributable to the pollution would be 3,250 QALYs (6.5 QALYs x 500 individuals).