Particulate air pollution is one of the most serious environmental health risks in the United States. In 1997, the United States Environmental Protection Agency (USEPA) finalized a stricter national standard for particulate matter that would require further reductions in pollution from automobiles, power plants, and industrial facilities. Recently, this standard was overturned on constitutional grounds by a federal appeals court. If the decision is upheld on appeal, USEPA will be asked to reconsider the rationale for the standard.

USEPA is not permitted to consider the costs of pollution control when setting air quality standards, but it is permitted to consider costs when implementation strategies are developed to meet air quality standards. In its regulatory impact analysis, USEPA estimated that implementation of the standard could cost $8.6 billion per year. Given the magnitude of this cost, will the stricter standard deliver commensurate benefits? USEPA concluded that health benefits could outweigh costs by a factor of two ("low-end") to eleven ("high-end").

Is this conclusion justified in the face of the many uncertainties underlying these estimates? USEPA’s discussion explored the significant uncertainties involved in predicting human exposures and adverse health effects, but less attention was given to the uncertainties regarding how the effects should be valued.

"Valuation" refers to the process of assigning dollar values to averted health impairments. Should it matter whether an "air pollution death" represents a life shortened by several weeks or several decades? Our ongoing review of the subject has concluded that such valuation uncertainties deserve more significant attention in regulatory analysis. In this issue of RISK IN PERSPECTIVE, we discuss the health effects of particulate air pollution and the uncertainty over how to value them.
THE NEED FOR VALUATION

Although regulating air pollution can provide significant health benefits to society, it can also consume labor and material resources that could have been used to achieve other social goals such as improved housing or education. In deciding how much or how fast to reduce pollution, it is appropriate to perform an economic analysis of the relative costs and benefits of different reduction strategies.

To estimate costs, analysts measure the direct compliance costs of a regulation, such as the costs of installing and maintaining better catalytic converters in new cars, as well as the indirect costs, such as the time motorists spend waiting in line for a "smog-check".

To estimate the benefits of pollution control, analysts must first estimate the reductions in adverse effects, such as premature deaths and asthma attacks, and then translate the effects into a common unit, usually dollars. Without the second step, comparison of costs and benefits on a common scale would not be possible.

USEPA’S APPROACH

USEPA’s "high-end" estimate found that 78% of the monetized health benefits of particulate control came from reducing premature deaths attributable to short-term pollution episodes. The Value of Statistical Life (VSL) approach was used to value reductions in premature deaths. VSL measures how much wealth people are willing to forgo for small reductions in mortality risk. It does not represent the amount one person would pay to avoid certain death, but the total amount that a large group of people would pay to reduce one expected fatality among them. The VSL used by USEPA was derived primarily from a body of studies that determined the range of wage premiums paid to workers in hazardous, blue-collar occupations. USEPA used a value from the middle of the range, $4.8 million, and reported the range as $2 to $8 million per life. In other words, a worker might be paid a wage premium of $480 per year to accept an added fatality risk on the job of 1 in 10,000 per year.

Use of this VSL in the air pollution context assumes that the deaths attributed to air pollution are comparable to occupational deaths. However, there are important differences between these contexts. Accidents in the workplace tend to strike healthy, middle-aged adults. Yet most acute air pollution deaths occur among elderly persons with serious preexisting cardiac and respiratory disease. If length and quality of life are relevant to valuation, then use of a VSL derived from healthy workers may result in significant overestimation of benefits.

In recognition of this concern, USEPA presented an alternate method for valuation of premature deaths based strictly on life expectancy. By assuming that each air pollution death was premature by 4.5 years and using a value of $120,000 per life year saved, USEPA estimated the value of preventing an air pollution death at $540,000, about one-ninth of the $4.8 million VSL used for their "high-end" analysis. Although there were other differences between USEPA’s "high-end" and "low-end" analyses, the different valuation method alone reduced the benefit-cost ratio from 11 to 3.5.
THE QUALITY-ADJUSTED-LIFE-YEAR APPROACH

In medicine and public health, life-saving interventions are valued based on changes in life expectancy and quality of life. The quantitative metric most frequently used has been the Quality-Adjusted-Life-Year (QALY).

The QALY allows the analyst to deal explicitly with two important properties of health effects. First, the QALY approach deals in changes in expected survival, i.e., years of life lost. It allows the analyst to treat a death (or sickness) that involves a loss of 10 years of life differently than one involving a loss of 10 months. Second, the QALY approach weights the years lived by a measure of their health-based quality. This allows the analyst to incorporate the intensity of people’s preferences for being healthy versus sick.

Ongoing research at HCRA entails applying a QALY-based approach to the health effects of particulate air pollution. The first step in this process involves estimating the longevity and quality-of-life changes attributable to each health effect. Once the QALYs are estimated, they are then converted to dollars using a specific value, say $100,000 per QALY. Although there is no generally accepted value for a QALY, medical cost-effectiveness reports $50,000 to $100,000 as a possible range of social preference. Note that the appropriate value may be somewhat larger in the environmental context due to differences in psychological characteristics such as voluntariness, fairness, and dread, all of which have been shown to affect people’s preferences about lifesaving.

People vary in their preferences regarding tradeoffs between life expectancy, health, and wealth. For instance, while some people may value life extension in strict proportion to the length of the extension, other people may not. An additional source of variability arises from different strengths of preference among people for the same state of health. While variability by itself is not a problem, studies to date have provided limited information about the central tendency and spread of preferences.

Since the evidence for health effects comes primarily from epidemiology, it is necessary to understand the limited information epidemiology can provide. This information, along with medical information on expected survival and quality of life in the relevant health states, can be used to determine the QALY impact associated with each health outcome.

AIR POLLUTION EPIDEMIOLOGY

Scientists have studied the connection between air pollution and human health for over four decades. Although large advances have been made, we still lack an understanding of the biological mechanisms by which particulate air pollution affects human health at the relatively low concentrations seen in US cities today. Yet, there is a growing body of epidemiological evidence that suggests that such effects do exist.

The epidemiological evidence used today to estimate health benefits can be categorized broadly by two types of study design: the prospective cohort and the daily time-series. Each of these study designs is used to estimate the correlation
between particulate levels in the air and measures of premature mortality or nonfatal illness, but the designs differ in important ways.

The first type of study, the prospective cohort, follows an identified group of individuals for a period of several years or decades and relates the mortality experienced in the cohort to the pollution exposures of the cohort. These studies have the advantage of measuring any long term human health outcomes caused by pollution, but they can be confounded by unmeasured risk factors such as diet. This confounding can induce an inflated or deflated relationship between pollution and health.

The second type of study, the daily time-series, compares daily changes in pollution levels to daily changes in health outcomes within a specified geographical area. Unlike the prospective cohort design, the daily time-series studies are only subject to possible confounding by factors that are correlated with pollution on a day-to-day basis (e.g., temperature or humidity). Time-series studies only measure short term responses to short term changes in pollution levels.

The biological mechanisms by which low levels of ambient air pollution affect human health are poorly understood. One current hypothesis states that cardiac rhythm can be affected by exposure to combustion particles, causing ischemia, or lack of oxygen, in heart muscle. Another hypothesis states that particles can cause inflammation of the lungs, leading to effects in the closely linked pulmonary and cardiovascular systems. Current laboratory studies of rodents and dogs, as well as daily-life monitoring of elderly humans, seek to test these hypotheses.

QUANTIFYING CHANGES IN HEALTH

USEPA’s main analysis derived its estimate of premature deaths based on evidence from the time-series studies. Who is dying in these studies, and what is the resulting valuation under a QALY framework?

The time-series literature has found specific causes of death to be correlated with short-term increases in pollution. These include heart attacks, emphysema, and chronic bronchitis. Thus, the deaths attributed to air pollution in the daily time-series studies occur primarily among persons with serious pre-existing health problems. These persons also tend to be elderly. In the absence of the fatal air pollution episode, we would expect them to live anywhere between a few days and a few years. The quality of life during this added life expectancy would generally be less than that experienced by a healthy individual of the same age.

Our valuation of the mortality effects seen in the time-series studies incorporates this knowledge. As a result, our analysis values the reductions in time-series deaths at less than ten percent of the $4.8 million value used in USEPA’s "high-end" analysis. Since USEPA’s "high-end" analysis derived most of its total benefits from reductions in premature mortalities, our analysis would indicate that the substantial net benefits (i.e., total benefits minus total costs) shown in USEPA’s "high-end" analysis are implausible.
BETTER VALUATION OF MORBIDITY

Examples of morbidity changes correlated with pollution include hospital admissions from cardiovascular and respiratory system failures. For example, for each premature death from cardiovascular causes that is induced by particulate air pollution, it appears that there may be several non-fatal heart attacks. Although these nonfatal cases do not result in immediate death of the patient, they may cause permanent damage to the patient’s cardiovascular system (e.g., heart failure) and induce a loss of life expectancy. As shown in Table 1, this shift from Coronary Heart Disease (w/o heart failure) to Diagnosed Coronary Heart Failure represents a loss in life expectancy of 4 years for a 70 year old male.

Thus, when placed into a life expectancy-based valuation framework, reductions in non-fatal heart attacks attributed to air pollution by the time-series studies may be of equal or greater importance than the reduction in premature mortalities. None of the benefit analyses to date have considered this possibility.

As with the premature mortalities, the exact valuation depends on knowing the health status and age of the persons experiencing these attacks. Current epidemiological research is focusing on reviews of medical records to better answer this question.

Likewise, if air pollution is causing population-wide decreases in lung function, as some evidence suggests, these changes could have substantial impacts on life-expectancy. Even though air pollution would not be the direct cause of death, it would accelerate the process by which people become sick and die from other causes.

Further research in this area can be used to examine the plausibility of the larger mortality effects seen in the chronic cohort studies versus the daily mortality studies.

CONCLUSION

A proper valuation of human health effects needs to reflect citizen preferences for life extension and improved quality-of-life. Valuations derived from QALY approaches may give substantially different results than VSL methods. The uncertainties in the valuation process are large enough to have a significant impact on the overall policy decision. As such, there is a need to first carefully characterize the uncertainty in estimating the value of avoided health effects and, second, to conduct additional theoretical and empirical research to determine these values with greater accuracy and precision.

Basing air pollution policy analysis in a life-expectancy and quality-of-life framework will better inform the multi-billion dollar decisions at stake.
Table 1

Age-specific average life expectancy (in years) of a U.S. male based on health status (1990).

<table>
<thead>
<tr>
<th>Health Status</th>
<th>Age 50</th>
<th>Age 70</th>
</tr>
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<tbody>
<tr>
<td>Average&lt;sup&gt;1&lt;/sup&gt;</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td>Prior Heart Attack (w/o diagnosed heart failure)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Diagnosed Coronary Heart Failure&lt;sup&gt;3&lt;/sup&gt;</td>
<td>5</td>
<td>2</td>
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