Valuation of Human Health and Welfare Effects of Criteria Pollutants

Appendix H

This appendix describes the derivations of the economic valuations for health and welfare endpoints considered in the benefits analysis. It includes three primary sections. First, we introduce the method for monetizing improvements in health and welfare. Second, we summarize dollar estimates used to value benefits and outline the derivation of each estimate. Valuation estimates were obtained from the literature and reported in dollars per case avoided for health effects, and dollars per unit of avoided damage for welfare effects. Economic valuations are characterized in terms of a central (point) estimate as well as a probability distribution which reflects the uncertainty around the central estimate. Third, we present the results of the economic benefits analysis. All dollar values are in 1990 dollars. This third section concludes with an exploration of the uncertainties in valuing the benefits attributable to the CAAA.

Methods Used to Value Health And Welfare Effects

The general approach to benefits analysis involves a three-step process— (i) identification of potential physical effects (i.e., individual health and welfare endpoints); (ii) quantification of significant endpoints; and (iii) monetization of benefits. The first two steps, identification and quantification of physical effects, are described in Appendix D, Human Health and Welfare Effects of Criteria Pollutants. The third step is detailed in this appendix. Monetization of benefits attributed to the CAAA involves applying dollar estimates obtained from economic literature to individual health and welfare endpoints relevant for the 812 prospective analysis. As context to understanding the methodology for transferring estimated values of physical effects, this section provides a brief discussion of the theoretical economic foundation of, and general approach to, valuing the benefits of improved air quality.

Economists equate the dollar value of a benefit to the level of well-being an individual enjoys from the provision or consumption of a particular good or composite good (i.e., bundle or mix of goods). A fundamental assumption in economic theory is that individuals can trade between different consumption levels of these goods, services, or money, and maintain the same level of welfare. Typically, this willingness to trade-off between goods is measured as willingness to pay (WTP) or willingness to accept compensation (WTA). These measures are essentially dollar equivalents to changes in the level of consumption of a good or service so that the individual maintains the same level of well-being. In other words, the individual is indifferent between his or her current bundle of goods and the alternative bundle of goods.

While WTP and WTA represent an individual's own assessment of the dollar value of better health, they are not necessarily equivalent measures.[1] WTP, in the case of health, is the largest amount of money a person would pay to obtain an improvement (or avoid a decline) in health. When faced with two

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[1] The measures differ for several reasons. For example the measures have different points of reference from which to evaluate changes in welfare. WTP's reference point is the level of utility without the improvement. WTA's reference point is the level of utility with the improvement. Moreover, the measures have different upper bound constraints. WTP measures what a person would pay to obtain better health and is bound by the person's wealth and income. WTA, on the other hand, measures what a person must be paid to forego better health. WTA does not have an upper bound, but it must be at least as large as WTP. Economists, however, do not expect significant differences between WTP and WTA when the dollar amounts are small relative to the individual's wealth and income.

options, to either (1) pay a certain dollar amount to enjoy the health improvement or (2) abstain from paying the dollar amount and not experience the health improvement, the individual feels either choice provides the same degree of well-being. Alternatively, willingness to accept compensation (WTA) is the smallest amount of money a person would voluntarily accept as compensation to forego an improvement, or endure a decline, in health. The individual feels that to accept the payment and not experience the health improvement or refuse the compensation and experience improved health will provide the same degree of well-being. In practice, WTP is generally used to value benefits because it is often easier to measure and quantify.[2] In this report, we refer to all valuation estimates as WTP values, even though the underlying economic valuation literature is based on studies which elicited expressions of WTP and/or WTA.[3]

In the context of cost-benefit analysis, WTP is useful for estimating the monetary value of non-market, public goods. A major characteristic of public goods is that they are nonrival (i.e., one person's consumption of the good does not reduce the amount available to others). In the case of health-related improvements due to environmental quality, the benefits are also nonexclusive. Benefits are not (and to some extent, cannot be) regulated. As a result, the benefits are actually reductions in the probabilities or risk of enduring certain health problems. In theory, the total social value associated with the decrease in risk is

$$\sum_{i=1}^{N} (number\ of\ units\ of\ risk\ reduction)_i * (WTP\ per\ unit\ risk\ reduction) \quad (1)$$

where (number of units of risk reduction)$_i$ is the number of units of risk reduction conferred on the ith exposed individual as a result of the pollution reduction, (WTP per unit risk reduction)$_i$ is the ith individual's willingness to pay for a unit risk reduction, and N is the number of exposed individuals. The units are in terms of cases reduced per unit of time (usually one year).

Using mortality risk as an example, suppose that a given reduction in PM concentrations results in lowering the risk of death by 1/10,000 per year. Then for every 10,000 individuals, one less death would be expected if ambient PM concentrations are reduced. If an individual's WTP for this 1/10,000 decrease in mortality risk is $500 (assuming, for now, that all individuals' WTPs are the same), then the value of a statistical life is 10,000 x $500, or $5 million.

While the estimation of WTP for a market good (i.e., the estimation of a demand schedule) is not a simple matter, the estimation of WTP for a nonmarket good, such as a decrease in the risk of having a particular health problem, is substantially more difficult. Estimation of WTP for decreases in very specific health risks (e.g., WTP to decrease the risk of a day of coughing or WTP to decrease the risk of admission to the hospital for a respiratory illness) is further complicated by several factors, such as wealth, income, age, pre-existing health impairments, or other personal characteristics. There are many policy contexts where distinguishing among WTP estimates based on categorical differences (e.g., distinguishing between WTP of a low-income group and a high-income group) is controversial. Given the consideration of these influencing factors and the limitations on information available for developing WTP estimates, EPA sought to develop the most appropriate and accurate estimates possible. Derivations of the dollar value estimates for this study are discussed below.

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[2] It is worth noting that the appropriateness of either WTP or WTA also depends on property rights. In the case of a policy aimed at reducing existing pollution levels, a WTP measure implicitly assumes that the property rights rest with the polluting firm. Alternatively, WTA measures implicitly assume that the property rights rest with the public. (Carson and Mitchell, 1993.)

[3] In some cases (e.g., hospital admissions), neither WTA nor WTP estimates are available. In those cases, cost of illness (COI) estimates are applied in lieu of WTP values. COI estimates understate the true welfare change since important value components (e.g., pain and suffering associated with the health effect) are not reflected in the out-of-pocket costs for the hospital stay.

Valuation of Specific Health Endpoints

Since the Section 812 CAA retrospective analysis (U.S. EPA 1997), there have been significant advances made in economic valuation methodologies for both mortality and morbidity effects. Much of the literature presents emerging new approaches for characterizing the effects of potentially important determinants of WTP, such as age, income, risk perception, and current health status. Despite this progress, many of the more recent studies test techniques that are in the development stage and use data from work reviewed and incorporated in the Section 812 retrospective analysis. This section reviews the sources and methodology used to derive WTP estimates for premature mortality and a variety of morbidity effects valued in the present study. In addition, there are brief discussions of more recent advances relevant to particular endpoints.

Valuation of Premature Mortality Avoided

The economic benefits associated with premature mortality were the largest category of monetized benefits in the Section 812 CAA retrospective analysis (U.S. EPA 1997).[4] In addition, EPA identified valuation of mortality benefits as the largest contributor to the range of uncertainty in monetized benefits. Because of the uncertainty in estimates of the value of premature mortality avoidance, it is important to adequately characterize and understand the various types of economic approaches available for mortality valuation. Such an assessment also requires an understanding of how alternative valuation approaches reflect that some individuals may be more susceptible to air pollution-induced mortality.

The health science literature on air pollution indicates that several human characteristics affect the degree to which mortality risk affects an individual. For example, some age groups are more susceptible to air pollution than others (e.g., the elderly and children). Health status prior to exposure also affects susceptibility – at risk individuals include those who have suffered strokes or are suffering from cardiovascular disease and angina (Rowlatt, et al. 1998).

To reflect the full range of knowledge of air pollution-induced mortality, an ideal estimate of mortality risk reduction benefits would be an *ex ante* willingness to pay (WTP) to improve one's own chances of survival plus WTP to improve other individuals' survival rates.[5] The measure would take into account the specific nature of the risk reduction commodity that is provided to individuals, as well as the context in which risk is reduced. To measure this value, it is important to assess how reductions in air pollution reduce the risk of dying from the time that reductions take effect onward, and how individuals value these changes. Each individual's survival curve, or the probability of surviving beyond a given age, should shift as a result of an environmental quality improvement. That is, changing the current probability of survival for an individual also shifts future probabilities of that individual's survival. This probability shift will differ across individuals because survival curves are dependent on such characteristics as age, health state, and the current age to which the individual is likely to survive. For example, Figure H-1 illustrates how a risk reduction may change a survival curve for a given population. In this figure, the solid line shows a survival curve for white males, from California 1980 life tables (adapted from Selvin, 1996), up to age 80. The dashed line shows that the probability of survival beyond a given age increases with a reduction in mortality risk.

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[4] As noted in the methods section, it is actually reductions in mortality risk that are valued in a monetized benefit analysis. Individual WTPs for small reductions in mortality risk are summed over enough individuals to infer the value of a *statistical* life saved. This is different from the value of a particular, identified life saved. The "value of a premature death avoided," then, should be understood as shorthand for "the value of a *statistical* premature death avoided."

[5] For a more detailed discussion of altruistic values related to the value of life, see Jones-Lee (1992).

While the change in a survival curve represents a cumulative effect of a change in risk over time, the annual change in risk of death represents a static effect of a risk reduction. As discussed in Appendix D in greater detail, the instantaneous risk of death at a specific age is often used to illustrate the effects of changes in risk. The annual risk of death is related to the probability of survival in that it represents the rate at which the survival probability changes at any given age, divided by the probability of surviving beyond that age. Figure H-2 shows how a constant risk reduction reduces annual risk of death across various age cohorts. The baseline risk of death increases with each cohort (solid line). As a result, the reduction in risk (in this hypothetical example a constant 25 percent reduction) lowers each cohorts' risk level at a different rate. The elderly experience a greater reduction in risk than younger cohorts as can be seen by the increasing difference between the solid and dashed line. It is important to note that this example shows the effect of a uniform risk reduction, and air pollution controls may have risk reduction effects that vary across age cohorts.

An alternative way to view the age-dependent effect of risk reduction is to consider changes in the cumulative effect of risk as measured by changes in remaining life expectancy. Remaining life expectancy is measured as the average number of additional years expected to be lived by those individuals alive at a given age, and derives from the area under the survival curve at any given age. The age-dependent effects of a hypothetical change in risk are portrayed in Figure H-3. Consider the effect of risk reduction on two cohorts, aged 10 years apart. When each cohort was at age 40 both had the same life expectancy shown in Figure H-3 as point A′. Given a risk reduction in the future that occurs when one cohort is at age 60 and the other at age 70, the life expectancy of the 60 year old increases by the amount A′B′, and the life

Figure H-1
Hypothetical Survival Curve Shift

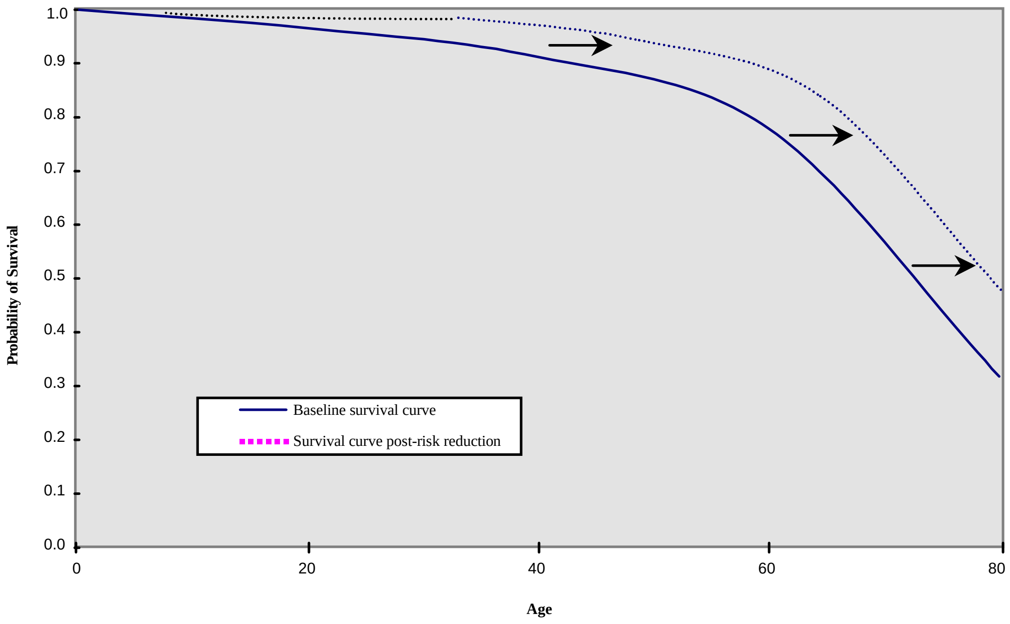


Figure H-2
Change in 1990 Annual Risk of Death by 25 Percent

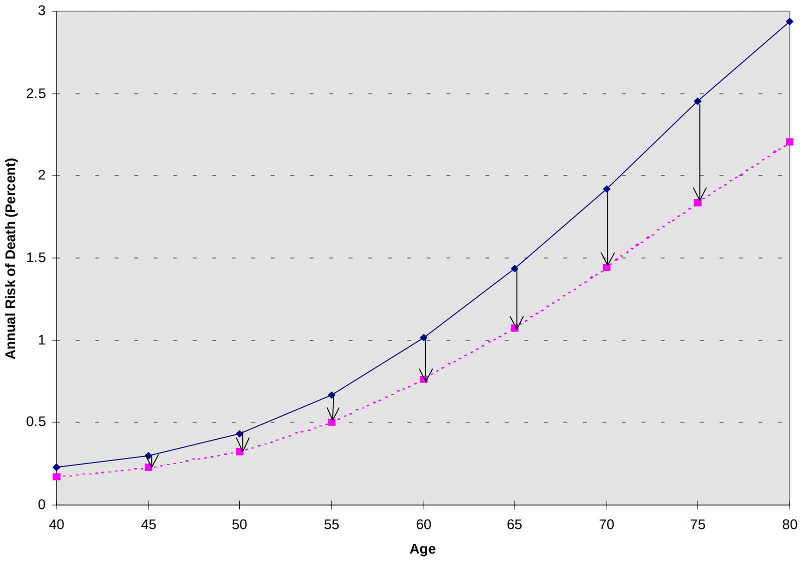
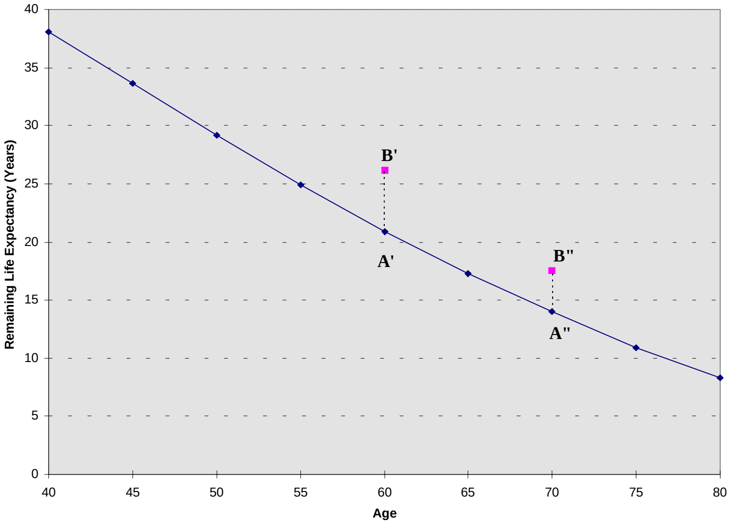


Figure H-3
Increase in 1990 Remaining Life Expectancy



expectancy of the 70 year old increases by the amount A′′B′′. The change in life expectancy is greater for the younger cohort than the older cohort because these measures represent a cumulative accrual of increased life expectancy (i.e., the younger cohort will benefit from the lower risk environment for more years).

Because the risk reduction results in various changes in risk levels, individual values for risk reduction are likely to vary as well. Some individuals having a greater change in risk, and hence life expectancy, may have different values for the change than those individuals experiencing a smaller change in risk. Note that future generations may hold values for health as well. Cropper and Sussman (1990) develop theoretical models formalizing these concepts when investigating how an individual's values for reduction of a future risk to oneself and to future generations should be discounted to the present.

While these theoretical models reflect the types of values necessary to estimate the impact of the CAAA, they are difficult to implement. First, they require an estimate of individuals' survival curves. In order to develop these survival probabilities, it is necessary to characterize the dose/response relationship for the regulated pollutants and know how this information varies with age and health states over time. Second, it is necessary to estimate values for risk reductions, considering the key dimensions in which risk and valuation of risk reduction may vary (e.g., with age and health state).

Mortality Valuation Methodologies

This section summarizes alternative approaches to mortality risk valuation, and outlines the approach used to measure the economic value of these types of benefits for air pollution reductions associated with the CAAA. The first part provides background on the methods that individuals have developed to estimate the value of risk reduction benefits, including commonly-applied approaches to valuation as well as approaches that are beginning to be established in the risk valuation literature. The second part discusses the appropriateness of using these methodologies for assessing the economic value of mortality benefits associated with air pollution reduction. The Agency has concluded that recent advances in the literature show promise in incorporating several of the factors that are likely to influence value, but problems with the methodological approaches and lack of data needed to reliably to appropriately estimate values with the newer models leads us to adopt a value of statistical life approach for the primary estimate of air pollution-related mortality benefits.

Commonly Applied Approaches

The preferred approach researchers have taken to estimate values for avoiding premature mortality is based on individual WTP for risk reduction. Although some cost-benefit analyses have based values on avoided lost earnings (i.e., the human capital approach), the WTP approach is preferred because it more closely conforms to economic theory.[6] The common WTP measures of the value of life-saving programs include the value of statistical life (VSL) and the value of a statistical life year (VSLY). Newer approaches to estimate values incorporate changes in life expectancy, risk of dying, life-days per person, and age-specific preferences. This section describes these approaches and discusses issues that arise in their application to estimate the value of mortality risk reduction benefits.

The most commonly applied approaches for mortality valuation are the value of statistical life and value of statistical life year. Both of these approaches

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[6] In a recent article by Ireland and Gilbert (1998), the authors evaluate value of life estimates used in tort recovery cases. The article discusses the concept that for an individual there can be finite utility (or determined value) to life and at the same time no monetary equivalent. The authors do, however, build on this argument to demonstrate that existing value of life estimates are in fact lower bounds to the true value. By "lower bound," the authors refer to a value representative of a specific individual, not of a statistical life. In citing a reasonable value of life range, they use a range similar to that of the 812 retrospective analysis, although the authors do not cite the source of this range. Ireland and Gilbert write, "A decedent has lost something of immense value, for which estimates in the $4-$6 million range is clearly a low market value estimate".

directly address the value of premature death and health impairment. The VSL method measures the value of a given reduction in risk and an individual's WTP to reduce that risk, relying on wage and occupational risk tradeoff data or the results of contingent valuation surveys. Individual WTP amounts for small reductions in mortality risk are "standardized" to reflect reduction of population risk of one statistical life saved. The result of applying this method is not the value of an identifiable life, but instead the value of reducing fatal risks in a population (Viscusi 1992).

Viscusi (1992) summarizes the value of life literature, including almost forty studies providing VSL estimates relevant for policy application. For the section 812 retrospective analysis, EPA identified 26 studies from that review that reflect the application of the most sound and defensible methodological elements (see Table H-1). Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP on estimates of the additional compensation demanded in the labor market for riskier jobs. Using a Weibull distribution to describe the distribution of the mean mortality risk valuation estimates from these studies, the mean estimate of the distribution is $4.8 million with a standard deviation of $3.2 million (1990$).

Since EPA's retrospective analysis, Desvousges *et al.* (1998) has conducted a meta-analysis of twenty-nine mortality studies presented in Viscusi (1993) and Fisher, Chestnut, and Violette (1989).[7] Desvousges *et al.'s* meta-analysis yields $3.3. million (1990 dollars) as a value of statistical life, with a 90 percent confidence interval between $0.4 and $6.3 million.[8] Their estimate, $3.3 million, falls well within the range generated by EPA's uncertainty analysis of VSL estimates. The selection of studies accounts for much of the difference between their analysis and EPA's. The Desvousges *et al.* analysis includes thirteen studies that EPA did not use and EPA includes ten studies omitted by Desvousges *et al.*

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[7] In addition to the Viscusi (1993) study, the 812 retrospective examined two other studies, Miller et al. (1990) and the Fisher, Chestnut, and Violette (1989). We opted to not use the Miller et al. study given our concerns regarding the appropriateness of the selection of studies for valuing reductions in environment-related mortality risk and concerns about the adjustments made to the underlying data. The Fisher, Chestnut, and Violette (1989) study was not used because the data was not as current or comprehensive as the data in the Viscusi study.

[8] Desvousges *et al.* do not adjust the value of statistical life to account for age differences. They do note that a single estimate for the value of statistical life may not be a good representation of the differences between willingness-to-pay of the elderly and young, healthy workers. They state that Moore and Viscusi (1988) demonstrate that willingness-to-pay is higher for people with more life years to lose while Desvousges et al. (1996) and Johnson et al. (1998) indicate that willingness-to-pay is lower for people with limited abilities to engage in activities and care for themselves.

Table H-1
Summary of Mortality Valuation Estimates

Study	Type of Estimate	Valuation (millions 1990$)
Kneisner and Leeth (1991) (US)	Labor Market	0.6
Smith and Gilbert (1984)	Labor Market	0.7
Dillingham (1985)	Labor Market	0.9
Butler (1983)	Labor Market	1.1
Miller and Guria (1991)	Cont. Value	1.2
Moore and Viscusi (1988a)	Labor Market	2.5
Viscusi, Magat, and Huber (1991b)	Cont. Value	2.7
Gegax et al. (1985)	Cont. Value	3.3
Marin and Psacharopoulos (1982)	Labor Market	2.8
Kneisner and Leeth (1991) (Australia)	Labor Market	3.3
Gerking, de Haan, and Schulze (1988)	Cont. Value	3.4
Cousineau, Lacroix, and Girard (1988)	Labor Market	3.6
Jones-Lee (1989)	Cont. Value	3.8
Dillingham (1985)	Labor Market	3.9
Viscusi (1978, 1979)	Labor Market	4.1
R.S. Smith (1976)	Labor Market	4.6
V.K. Smith (1976)	Labor Market	4.7
Olson (1981)	Labor Market	5.2
Viscusi (1981)	Labor Market	6.5
R.S. Smith (1974)	Labor Market	7.2
Moore and Viscusi (1988a)	Labor Market	7.3
Kneisner and Leeth (1991) (Japan)	Labor Market	7.6
Herzog and Schlottman (1987)	Labor Market	9.1
Leigh and Folson (1984)	Labor Market	9.7
Leigh (1987)	Labor Market	10.4
Garen (1988)	Labor Market	13.5

SOURCE: Viscusi, 1992 and EPA analysis.

When applying VSL estimates to estimate mortality benefits, it is important to determine the differences between the nature of air pollution risk and risks faced by persons whose risk-dollar tradeoff decisions have been addressed in the literature. First, several studies indicate that the value people place on mortality risk reduction may depend on the nature of the risk (e.g., Fisher et al. 1989; Beggs 1984). Current VSL estimates do not account for a number of the important factors that affect risk perception. For example, premature mortality risks from air pollution are experienced on an involuntary basis and are generally uncompensated, while job-related risks are assumed by individuals who presumably have some choice as to occupation and are compensated for taking a riskier job. Second, the demographics of the population at risk from air pollution, particularly in terms of age, income, and health state, may differ from the demographics of individuals surveyed in the literature. For a more detailed discussion of how these factors can affect the economic valuation of premature mortality, and specifically estimates derived from the VSL approach, see the discussion, "Benefits Transfer and VSL," presented in the section titled, "Uncertainties in the Valuation Estimates."

The VSLY method values life-years that would be lost if an individual were to die prematurely. Most commonly, VSLY estimates are an annualized equivalent of VSL estimates (Moore and Viscusi 1988, French and Mauskopf 1992). A VSLY estimate may imply a stream of constant values per year. The annualized VSLY estimate depends on three factors: the underlying VSL estimate; a discount rate; and the number of remaining life years implied by the underlying VSL estimate.

We develop an estimate of the value of a statistical life-year lost (VSLY) based on an approach suggested by Moore and Viscusi (1988). They assume that the willingness to pay to save a statistical life is the value of a single year of life times the expected number of years of life remaining for an individual. They also suggest that the typical respondent in a mortality risk study may have a life expectancy of an additional 35 years. Using the 35-year life expectancy and VSL estimate of $4.8 million, their approach yields an estimate of $137,000 per life-year lost or saved. In the prospective analysis, we also assume that an individual discounts future additional years. This implies that the value of each life-year lost must be greater than the non-discounted value. Assuming a five percent discount rate and adopting the above outlined approach, the implied value of each life year lost used in the prospective analysis is $293,000 (in 1990 dollars).

Critics note several disadvantages to using this type of VSLY method, most notably that the value of avoiding premature death depends on more than just lifespan. With the VSLY approach, the benefit attributed to avoiding a premature death depends directly on how premature it is – resulting in smaller values for older people, who have shorter life expectancies, and larger values for younger people.

While this approach attempts to derive age-adjusted values of expected life remaining using VSL estimates, it does not address potential differences in the value of a statistical life due to differences in the average age of the affected population or the average age at which an effect is experienced. Studies have shown that simple progressive declines in value as estimated with the VSLY method may be an oversimplification; in many cases, values for health peak several times throughout a lifetime (e.g., after having children, after retirement). In addition, in many cases, data restrictions limit researchers' ability to estimate VSLY because it is difficult to obtain estimates of age-specific risks and the number of life-years lost.

Life Quality Adjustments

Another way to make adjustments to account for heterogeneity in value of life estimates is an approach that incorporates health status by applying a VSLY estimate (generated from the VSL literature) to an estimate of quality-adjusted life years (QALY). The resulting value estimates measure improvements in health based on individuals' attitudes toward symptoms or different levels of pain or physical impairment (Tolley et al. 1994). This approach utilizes survey techniques to rate different health conditions and adjust the number of life years lost to represent lost quality-adjusted life years. As a result, this approach aims to develop a value for a single QALY that is the same regardless of individual characteristics. In other words, the approach tries to standardize the measure of mortality risk reduction that emerges from a health effects analysis, making valuation more straightforward.

The Life Quality Adjustment approach may implicitly incorporate morbidity impacts to assess values for various causes of death, and is often used in health economics to assess the cost effectiveness of medical spending programs, to value morbidity avoidance, and to value mortality avoidance. Using a QALY rating system, health quality ranges from 0 to

1, where 1 may represent full health, 0 death, and some number in between (e.g., 0.8) an impaired condition. If an individual lives with a health quality index of 0.8, then the implied value of avoiding a year with this condition and having full health in its place would be 0.2 × VSLY. By the same token, the value of gaining an additional life year in this condition is 80 percent of the value of gaining a year in full health (i.e., 0.8 × VSLY) and represents an annual value for mortality risk avoidance for a person with the condition.

Tolley, et al. (1994) estimate values for a variety of health conditions using numerous techniques, including, in some cases, valuation of quality-adjusted life years. For example, when estimating values for acute and chronic symptoms using QALYs, the authors calculate low, medium and high value estimates based on a range of VSL estimates. Specifically, the authors use the following three VSLY estimates (1991$) for QALY valuation:

- <u>Low Estimate = $70,000 VSLY</u>: Derived from Miller, Calhoun and Arthur (1990) – VSL of $1.95 million, two percent discount rate.
- <u>Medium Estimate = $120,000 VSLY</u>: Derived from Miller, Calhoun and Arthur (1990) – VSL of $1.95 million, six percent discount rate.
- <u>High Estimate = $175,000 VSLY</u>: Derived from Moore and Viscusi (1988) – VSL of $6.0 million, 0 percent discount rate.

The authors multiply the VSLY estimate by the estimate of QALYs to calculate a value for each symptom. It is not clear from the analysis discussion which symptom values represent the application of this approach.

Cutler and Richardson (1998) apply a VSL estimate to an estimate of QALYs to measure the value of health improvements between 1970 and 1990 for ten health conditions. To do this, the authors use an VSLY estimate of $100,000, derived as the intermediate value of results reported in studies by Viscusi (1993) and Tolley et al. (1994). In addition, the authors estimate QALYs using information on disease prevalence in the US from 1970 to 1990, weighted by a factor that represents how quality of life for a given condition has changed over time (e.g., more buildings have ramps and elevators for individuals who have mobility problems, thus raising quality of life over time).

Murray and Lopez (1996) modify the above theoretical approach by deriving an estimate of disability-adjusted life years (DALYs). DALY estimates consider the years of life lost and years lived with disability, adjusted for the severity of the disability. The approach to estimate DALYs is similar to that used to estimate QALYs in that both incorporate judgments about the value of time spent in different health states. However, DALY and QALY estimation methods differ in that the methods to estimate DALYs are elicited from preferences for particular value choices using a specific standardized set of value choices.

The Life Quality Adjustment approach scales WTP values (VSL estimates) using a measure of life years that reflect heterogeneity in quality of health (QALYs). In many cases, the applied VSLY estimates do not reflect consistent use of VSL estimates or discount rates. In addition, in each of these valuation analyses health economists have constructed a scale or index that ranks health outcomes in terms of how adverse individuals believe them to be. Often, the extreme points on the scale are "perfect health" and "immediate death," but some applications allow for health outcomes that might be viewed as worse than death. These ranking methods do not yield estimates of WTP, and therefore are not linked to utility theory. It is not clear that the ranking of health outcomes obtained by these indices would match the ranking obtained by knowing individuals' WTP for various health effects. As discussed by Johansson (1995), these scales or indices rely on much more restrictive assumptions about the nature of individual preferences than are normally made in WTP studies.

Longevity

Several recent efforts estimate values for an identifiable life by estimating the WTP for own life extension. Johannesson and Johansson (1996, 1997) estimate the WTP to increase one's life expectancy by one additional year (i.e., extending men's life expectancy from age 75 to 76, and women's from age 80 to 81, conditional on reaching age 75 or 80). Johannesson, Johansson, and Lofgren (1997) estimate the value of an immediate small reduction in mortality risk (a "blip" or one year of fatal risk prevention).

While this methodology represents a utility-theory based value, the value estimate for a single year of longevity does not exactly correspond to what is needed for an assessment of air pollution benefits. Johannesson and Johansson (1996, 1997) estimate a value for a single year of life extension near the end of one's lifetime – values at this age are likely to be low because of a low expectation of quality of life at this advanced age. It is likely that mortality values will vary within an individual's lifetime and with probability of survival. In addition, mortality associated with pollutant exposure will likely yield a longevity loss greater than one year (e.g., mortality associated with particulate matter yields an average longevity loss of approximately 14 life years among those who are afflicted). Moreover, because of the hypothetical nature of the contingent valuation method, it is unclear whether respondents accept the scenarios presented and whether enough context was provided to understand the risk and the budget implications of the scenario and the response.

Cost Effectiveness

Garber and Phelps (1997) present a methodology for valuing a discounted life year that is determined by income and risk aversion in a life-cycle model. To calculate the optimal cost effectiveness cut-off for medical intervention, the authors assume values of a utility function, health production function, income, discount rate, and baseline mortality to derive a value equivalent to WTP for a discounted life year. In this model, utility is a function of income (less medical expenditures), and future income is a function of survival and medical expenditures. As a result, the authors use mortality rates to calculate expected income. Changes in these mortality rates result in changes in survival probabilities, and hence income. The model estimates an individual's willingness to trade income from one period to another; the discounted change in income is equivalent to WTP for a change in risk.

Although this methodology is based on a life-cycle model using survival probabilities, it is simplistic in its assumptions and is based on assumed preferences, rather than on revealed preferences or those stated by an individual. In effect, the model estimates values based largely on one empirical input: individual income. For example, the VSL for a 40 year-old cannot exceed $250,000 because that amount exceeds the discounted expected income. The largest value of discounted life-year obtained by the authors is approximately $37,000.

Valuation Strategy Chosen for this Analysis

To estimate the economic value of mortality benefits associated with air pollution reductions, economic theorists prefer estimates that reflect *ex ante* values of reducing the risk of mortality across the population (i.e., for individuals having different health states and other characteristics such as income level and risk perception). This requires an estimate of an individual WTP for a reduction in an involuntary risk that will change individuals' survival probabilities for a lifetime. Developing a valuation estimate based on this theoretically ideal approach, however, is currently subject to significant data and methodological problems. Moreover, many of the valuation methods that are frequently presented as an alternative to the VSL approach rely on VSL estimates and calculate values that depend on lifespan data, which may be difficult to measure given the current health data limitations. Consequently, EPA's current interpretation of the state-of-the-art in premature mortality valuation leads to adoption of the VSL approach for development of the primary benefit estimate.

As discussed above, several different approaches for estimating a mortality-related value have been developed. Each, however, has either methodological inconsistencies with the preferred utility-based approach, or does not provide a value estimate for a commodity comparable to that provided by reduced air pollution. We summarize the potential problems of these alternatives below and in Table H-2:

- **Life Quality Adjustment:** This approach relies on VSL estimates applied to survey estimates of life-years (i.e., QALYs or DALYs) for the economic valuation. Currently, no generally accepted estimate or range of estimates of VSLY have been established, instead these values derive from various VSL studies and reflect numerous discount rates. In addition, the life years estimates require data sets that can account for the health states or utilities specific to a wide variety of health effects associated with air pollution. In many cases, these estimates are not available or are based on health professionals' perceptions of various health outcomes, and not necessarily based in economic utility theory.

- **Longevity:** The longevity valuation approach of Johannesson and Johansson (1996 and 1997) provides an estimate of the value for an identifiable one-year life extension. While the contingent valuation approach used may be consistent with utility theory, the commodity valued does not represent the commodity gained through improvement of ambient air quality.

- **Cost Effectiveness:** While the approach taken by Garber and Phelps relies on survival probabilities throughout an individual's lifetime, the methodology is based on a utility function that makes specific assumptions about individual preferences to measure WTP rather than eliciting value from either a revealed or stated preference approach. Moreover, this approach measures a WTP that is constrained by income. Where individual risks are small (perhaps one in ten thousand) relative to certain loss of life, individual WTP may also be small relative to income.

Exhibit H-2

Summary of Alternative Methods for Assessing the Value of Reduced Mortality Risk

Method	Description	Strengths	Weaknesses	References
Value of Statistical Life (VSL) - hedonic wage studies	Uses wage and risk data to estimate WTP to avoid risk in the workplace	- Revealed preference - Well-established approach: more than 60 primary studies	- Workplace risk context; working-age subjects and voluntary risk - VSL may imply ex post risk	Summaries by Viscusi (1992) and others; many primary studies
VSL - contingent valuation studies	Uses survey responses to estimate WTP to avoid risks	- Flexible approach; some studies use environmental risk context - Good data on WTP by respondent	- Risk information not well-understood by subjects; questions may be unfamiliar - VSL may imply ex post risk	Summaries by Viscusi (1992) and others
VSL - consumer market studies	Uses consumer expense and risk data (e.g., smoke detectors) to estimate WTP to avoid risks	- Revealed preference - Flexible approach	- Major difficulties estimating both risk and expense variables - VSL may imply ex post risk	Summaries by Viscusi (1992) and others
Value of Statistical Life Year (VSLY)	Annual equivalent of VSL estimates	- Provides financially accurate adjustment for age at death	- Adjustment may not reflect how individuals consider life-years; assumes they have equal value for all remaining life-years	Viscusi and Moore (1988); French and Mauskopf (1992)
Quality Adjusted Life Year (QALY)	Applies quality adjustment to life-extension data, uses cost-effectiveness data to value	- Widely used in public health literature that assess different private medical interventions	- Lack of data on health state indices and life quality adjustments that are applicable to an air pollution context	Tolley (1994); Cutler and Richardson (1998)
WTP for change in survival curve	Reflects WTP for change in risk, potentially incorporates age-specific nature of risk reduction	- Theoretically preferred approach that most accurately reflects nature of risk reductions from air pollution control	- Almost no current literature - Lack of available data due to the severe methodological difficulties in presenting complex risk data to subjects and eliciting reliable values	Cropper and Sussman (1990)
WTP for change in longevity	Uses stated preference approach to generate WTP for longevity or longer life expectancy	- Life expectancy is familiar term to most individuals	- Life expectancy is a simplifed term that does not incorporate age-specific risk information -Methodological and data problems in attempting to adapt to air pollution context	Johannesson and Johansson (1997); Health Canada (1998)
Cost-Effectiveness	Develops a standard of comparison to measure the efficiency of various treatments in achieving a given health outcome	- Widely used in public health contexts	- Public health context may be for private goods (i.e., treatment) - Dollar values do not necessarily reflect patient preferences	Garber and Phelps (1997)

Note: WTP = willingness to pay

Valuation of Hospital Admissions Avoided

The valuation of this benefits category reflects the value of reduced incidences of hospital admissions due to respiratory or cardiovascular conditions. We measure avoided hospital admissions as opposed to the number of avoided cases of respiratory or cardiovascular conditions, because of the availability of C-R relationships for the hospital admissions endpoint. Hospital admissions reflect a class of health effects linked to air pollution which are acute in nature but more severe than the symptom-day measures discussed below.

As described in Chapter 5, our approach to estimating the number of incidences for this category involves reliance on several concentration-response (C-R) functions. Each concentration-response function provides an alternative definition of either respiratory effects or cardiovascular effects, and defines alternative relationships between a single health affect and different pollutants. For the valuation of these incidences, the current literature provides well-developed and detailed cost estimates of hospitalization by health effect or illness. Using illness-specific estimates of avoided medical costs and avoided costs of lost work-time, developed by Elixhauser (1993), we construct cost of illness (COI) estimates that are specific to the suite of health effects defined by each C-R function. For example, we use twelve distinct C-R functions to quantify the expected change in respiratory admissions.[9] Consequently in this analysis, we develop twelve separate COI estimates, each reflecting the unique composition of health effects considered in the individual studies.

Because each epidemiology study defines a health effect by a group of ICD codes, we construct COI estimates for each study by aggregating estimates that are specific to an ICD code. These estimates use the following information reported by Elixhauser (1993): average hospital costs, average length of stay, and baseline incidences.[10] We use this ICD code information to develop valuation estimates that have two components, hospital charges and lost earnings due to the hospital stay. Our estimate of lost earnings due to time spent in the hospital is based on valuing the average length of hospital stay at a daily rate of $83. This daily rate is the median weekly wage divided by five work days and is based on U.S. Department of Commerce figures (1992). After developing values for each relevant ICD code (i.e., hospital costs plus lost earnings), we weight these values based on their prevalence in the baseline. The final COI estimate, specific to each study, is the sum of the weighted value of ICD code-specific estimates.

We use a Monte Carlo approach to combines the valuation and physical effects modeling to generate a benefits estimate for hospital admissions. This approach also allows us to account for the variability in costs due to alternative definitions of respiratory and cardiovascular conditions that result in a hospital admission. The Monte Carlo process for integrating the C-R function and its COI value involves first randomly selecting an estimated change in incidences from the suite of applicable C-R functions. For example, we use five epidemiology studies for the endpoint hospital admissions due to cardiovascular effects, and develop COI estimates specific to each study. The Monte Carlo modeling then selects the COI estimate specifically developed for that C-R function. These values are multiplied to generate a single benefits estimate for reduced hospital admissions. This process is repeated so that the value from each iteration is collected to generate a distribution that characterizes the range and probability of possible benefits estimates. The primary benefit estimates of avoided cardiovascular-related hospital admissions reflect the central value of this distribution.

The use of COI estimates suggests we are likely to significantly underestimate the WTP to avoid hospital

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[9] For more detailed discussion of the various health effects considered by each C-R function and methodology for estimating the number of avoided hospital admissions, see Appendix D.

[10] Potential illnesses associated with respiratory and cardiovascular admissions were identified by ICD-9 code.

admission. The valuation of any given health effect, such as hospitalization, should reflect the value of avoiding associated pain and suffering and lost leisure time, in addition to medical costs and lost work time. While the probability distributions in this analysis characterize a range of potential costs associated with hospitalization, they do not account for the omission of factors from the COI estimates, such as pain and suffering. Consequently, the valuations for these endpoints most likely understate the true social values for avoiding hospital admissions due to respiratory or cardiovascular conditions.

Valuation of Chronic Bronchitis Avoided

In this analysis, chronic bronchitis is one of the two monetized morbidity endpoints whose effects may be expected to last from the initial onset of the illness throughout the rest of the individual's life. WTP to avoid chronic bronchitis therefore incorporates the present discounted value of a potentially long stream of costs (e.g., medical expenditures and lost earnings) and reduced health-state utility.[11]

Two studies, Viscusi *et al.* (1991) and Krupnick and Cropper (1992) provide estimates of WTP to avoid a case of chronic bronchitis. While alternative estimates exist, many are derived from these two primary studies.[12] The study by Viscusi *et al.* uses a sample that is larger and more representative of the general population, while the Krupnick and Cropper study solicits values only from individuals who have a relative with the disease. As a result, the valuation of chronic bronchitis is based on the distribution of WTP responses from Viscusi *et al.* (1991).

Both the Viscusi *et al.* and the Krupnick and Cropper studies estimate the WTP to avoid a severe case of chronic bronchitis (CB). The incidence of pollution-related chronic bronchitis, however, is based on three studies which consider only new incidences of the illness and the resulting severity is unknown.[13] In response to the uncertainty regarding how the severity of a new case may progress, the prospective analysis adjusts Viscusi *et al.*'s WTP estimates downward. This adjustment reflects the decrease in severity of a case of pollution-related CB relative to the case in the Viscusi study and the elasticity of WTP with respect to severity. The elasticity of WTP to avoid CB is a marginal value and not unit elastic (i.e., not equal to one). Consequently, WTP adjustments are made in one percent increments. At each step, the WTP specific to a given CB severity level *(sev)*, is adjusted to derive the WTP to avoid a case with a one percent lower level of severity by calculating (0.99**sev*).[14] In this analysis, we derive an estimate of WTP for a case of chronic bronchitis that represents a 50 percent reduction in the severity described in the Viscusi study. The iterative procedure continues until the severity is half of the of the Viscusi value.

With the downward adjustment to Viscusi *et al.*'s WTP estimate, calculating the WTP to avoid a case of

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[11] The severity of cases of chronic bronchitis valued in some studies approaches that of chronic obstructive pulmonary disease. To maintain consistency with the existing literature, we do not treat those cases separately in this analysis.

[12] For examples of alternative estimates see Desvousges *et al.* (1998) and Tolley *et al.* (1994). Both studies present estimates of avoiding one year of chronic bronchitis that are based on adjusting values from either Viscusi *et al.* (1991) or Krupnick and Cropper (1992).

[13] The three studies are Abbey *et al.* (1993), Abbey *et al.* (1995) and Schwartz (1993). For more discussion of estimating the number of avoided cases of chronic bronchitis see Appendix D, Human Health Effect of Criteria Pollutants. Incidences are predicted separately for each year during the period 1990-2010. It is important that only new cases of chronic bronchitis are considered in this analysis because WTP estimates reflect lifetime expenditures and lower utility associated with the illness. If the total prevalence of chronic bronchitis, rather than the incidence of only new chronic bronchitis were predicted each year, valuation estimates reflecting lifetime losses could be repeatedly applied to the same individual for many years, resulting in a severe overestimation of the value of avoiding pollution-related chronic bronchitis.

[14] Note that the elasticity changes at each iteration because the elasticity of WTP with respect to severity is a function of severity.

pollution-related chronic bronchitis has three components, each introducing some uncertainty. The components are (1) WTP to avoid a case of severe CB, (2) the severity level of an average pollution-related case of CB relative to that of the severe case, and (3) the elasticity of WTP with respect to severity. Based on assumptions about the distributions of each component's value, a distribution of WTP to avoid a pollution-related case of CB is derived by Monte Carlo methods. Each of the three underlying distributions is described briefly below.

The distribution of WTP to avoid a severe case of CB is based on the distribution of WTP responses in the Viscusi study. Viscusi *et al.* derived an implicit WTP to avoid a statistical case of chronic bronchitis from respondents' WTP for a specified reduction in risk. The mean response implied a WTP of about $1 million (1990 dollars); the median response implied a WTP of about $530,000 (1990 dollars).[15] Viscusi *et al.* report the mean and median of their distribution of WTP responses and the decile points. The distribution of reliable WTP responses from the Viscusi study can therefore be approximated by a discrete distribution, assigning equal probability to each of the first nine decile points (or one-ninth probability to each decile). This method omits five percent of the responses from each end of the distribution (i.e., the extreme tails which are considered unreliable). Our present study uses this trimmed distribution of Viscusi *et al.*'s WTP responses, for which the mean is $720,000 (1990 dollars), as the distribution of WTPs to avoid a severe case of CB.

The distribution of the severity level of an average case of pollution-related CB is based on the severity levels used in Krupnick and Cropper's study, which estimates the relationship between severity level and the natural log of WTP. The distribution is triangular with a mean of 6.5 and endpoints at 1.0 and 12, although the most severe case of CB in that study is assigned a severity level of 13.[16]

The elasticity of WTP to avoid a case of CB with respect to the severity of the case equals a constant times the severity level. This constant, estimated in Krupnick and Cropper's study of the relationship between severity and the natural log of WTP, is normally distributed with mean of 0.18 and standard deviation of 0.0669.

Using distributions of the three WTP components described above, the Monte Carlo analysis generates a distribution with a mean of $260,000 for WTP to avoid a pollution-related case of CB. Consistent with economic theory, the COI estimates generated by Cropper and Krupnick (1990) are lower than the mean WTP estimate (i.e., COI does not reflects the desire to avoid pain and suffering).[17] These COI estimates are approximately $86,000 for a 30 year old, $84,000 for a 40 year old, $76,000 for a 50 year old, and $43,000 for a 60 year old (in 1990 dollars). The prospective's WTP estimate is 3 to 6 times greater than the full COI estimate for 30 year olds and 60 year olds, respectively.

Valuation of Chronic Asthma Avoided

Chronic asthma is the other morbidity endpoint that is valued as a health condition lasting throughout an individual's lifetime. The number of new cases of chronic asthma is based on a study by McDonnell *et al.* (1999), and specifically examines the effects of ozone as a potential cause of the illness among adult males (i.e., ages 27 and older). Similar to the valuation of chronic bronchitis, WTP to avoid chronic asthma

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[15] There is an indication in the Viscusi paper that the dollar values in the paper are in 1987 dollars. Under this assumption, the dollar values were converted to 1990 dollars.

[16] The Krupnick and Cropper study bases its most severe case of CB (i.e., severity level equal to 13) on that used in the Viscusi study.

[17] Using a 5 percent discount rate and assuming that 1) lost earnings continue until age 65, 2) medical expenditures are incurred until death, and 3) life expectancy is unchanged by chronic bronchitis, Cropper and Desvousges calculate several estimates of the present value of the stream of medical expenditures and lost earnings associated with an average case of chronic bronchitis.

is presented as the net present value of what would potentially be a stream of costs and lower well-being incurred over a lifetime.

Estimates of WTP to avoid asthma are provided in two studies, one by Blumenschein and Johannesson (1998) and one by O'Conor and Blomquist (1997). Both studies use the contingent valuation method to solicit annual WTP estimates from individuals who have been diagnosed as asthmatics. Each study, however, applies a different valuation approach. Blumenschein and Johannesson solicit WTP values by asking dichotomous choice and open-ended bidding game questions. They report an average monthly WTP of $162 which amounts to an annual value of approximately $1,900 (1990 dollars). Alternatively, O'Conor and Blomquist apply a risk-risk tradeoff approach similar to that used in the chronic bronchitis studies. They calculate $1,200 (1990 dollars) as the average annual WTP to avoid asthma.

To maintain consistency between the health effects modeling and the valuation, the WTP estimates were adjusted to account for two factors. As mentioned earlier, valuation of chronic morbidity endpoints should approximate the costs and lowered health-state utility that are incurred over an individual's lifetime. We assume that the health condition does not affect the average life expectancy of an individual (i.e., does not cause premature mortality). Recognizing that the average life expectancy will vary with different age groups and that each age group does not represent an equal portion of the population, the present discounted stream of WTP is calculated for seven different age cohorts (between the ages 27 and 85). In turn, the net present value for each age group is weighted by that age category's representative share of the total population. This calculation was performed for the mean WTP estimates presented in the two studies. The central estimate of WTP to avoid a case of chronic asthma among adult males, approximately $25,000, is the average of the present discounted value from the two studies. The analysis characterizes the uncertainty around this estimate by applying upper and lower values based on the present discounted value derived from each study, $19,000 derived from O'Conor and Blomquist study and $29,000 from the Blumenschein and Johannesson study.

Valuation of Other Morbidity Endpoints Avoided

The valuation of a specific short-term morbidity endpoint is generally solicited by representing the illness as a cluster of acute symptoms. For each symptom, the WTP is calculated. These values, in turn, are aggregated to arrive at the WTP to avoid a specific short term condition. For example, the endpoint lower respiratory symptoms (LRS) is represented by two or more of the following symptoms: runny or stuffy nose; coughing; and eye irritation. The WTP to avoid one day of LRS is the sum of values associated with these symptoms. The primary advantage of this approach is that is provides some flexibility in constructing estimates to represent a variety of health effects.

At the time of the Section 812 retrospective analysis there were only a small number of available studies on which to base estimates (two or three studies, for some endpoints; only one study for others). Since the retrospective analysis, much of the literature suggests there are developing approaches that may eventually lead to the refinement of estimates and the overcoming of some limitations to the current approach to constructing values. For example there is extensive progress in developing valuation techniques that reflect an individual's current health state and more accurately account for a symptoms's attributes (i.e., duration and severity).

There are several aspects of the short-term morbidity valuation estimates worth noting. First, estimates of WTP may be understated for at least two reasons. If exposure to pollution has any cumulative or lagged effects, then a given reduction in pollution concentrations in one year may confer benefits not only in that year but in future years as well. Benefits achieved in later years are not included. In addition, the possible effects of altruism are not considered in any of the economic value derivations. Individuals' WTP for reductions in health risks for others are implicitly assumed to be zero. The second point worth noting is that the total benefit attributed to the reduction of particular pollutant's concentration is determined largely by the benefit associated with its corresponding reduction in mortality risk. This is largely due to the dollar value associated with mortality which is significantly greater than any other valuation estimate. More detailed explanations for valuation of specific morbidity endpoints are given in Table H-3. The table summarizes the sources and derivation of the economic values used in the analysis.

Valuation of Welfare Effects

Economic valuations for welfare effects quantified in the analysis (i.e., visibility and worker productivity) are documented in Table H-3.[18] Worker productivity, unlike the avoidance of work loss days or restricted activity days, reflects productivity benefits due to improvements in work conditions (i.e., reduced ambient ozone) rather than health improvements (i.e., reduced risk of hospitalization). It is measured in terms of the reduction in daily income of the average worker engaged in strenuous outdoor labor and estimated at $1 per ten percent increase in ozone concentration. (Crocker and Horst, 1981). We discuss the derivation of the visibility valuation further below.

Visibility Valuation

Since the late 1970s, a number of contingent valuation (CV) studies of visibility changes have been published in the economics literature. These studies often classify visibility benefits as either residential or recreational. CV studies of residential visibility generally survey individuals in urban and suburban settings. The valuation is also applicable to households in rural areas. Residential values relate to the impact of visibility changes on an individual's daily life (e.g., at home, at work, and while engaged in routine recreational activities). Benefits of recreational visibility relate to the impact of visibility changes manifested at parks and wilderness areas that are expected to be experienced by its visitors. Recreational visibility benefits may, however, reflect the value an individual places on visibility improvements regardless of whether or not the person plans to visit the park.[19]

The reported estimates, expressed as household willingness to pay (WTP) for a hypothesized improvement in visibility, have a wide range of values. For examples, studies of visibility values from western cities have reported somewhat lower values than those from eastern cities. This difference raises the question of how visibility benefits should be evaluated with respect to location (e.g., eastern U.S. versus western U.S.), commodity definition (e.g., changes in recreational areas versus residential areas), and units of measurement (e.g., visual range, light extinction, and deciview). While the differing values reported in the literature may appear to imply that visibility is valued differently in the eastern and western U.S., other evidence suggests that eastern and western visibility are not fundamentally different commodities. For example, NAPAP data indicates that California's South Coast Air Basin, which encompasses Los Angeles and extends northward to the vicinity of San Francisco, has median baseline visibility more characteristic of the eastern U.S. than of other areas of the west (NAPAP 1991; IEc 1992, 1993a). These

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[18] In valuing welfare effects, the retrospective analysis included the benefits of reduced household soiling. This valuation was based on 1972 data that projected expenditure patterns from 1972 to 1985 (Manuel *et al.*, 1982). While this study was appropriate for the twenty year time period of the retrospective (1970 to 1990), it is of questionable applicability for the current study. Since the original study, there have been alternative estimates of benefits due to reduced soiling. These estimates, however, continue to be based on the original study and its underlying data (e.g., Desvousges et al., 1998). Consequently, these valuation coefficients do not reflect more recent information on air pollution composition and potentially significant changes in patterns of household expenditure and allocation. Progress in the valuation of this category's benefits is further limited by the challenges of developing dose-response functions that accurately assess the level and rate of materials damage and soiling. Recent literature does suggest there is progress in refining approaches, although it has not quite advanced to the level necessary for credible quantification or monetization of benefits associated with reduced materials damage and soiling.

[19] This type of valuation is typically labeled "existence value." For more discussion see Chestnut and Rowe, 1990.

results suggest that the valuation of marginal visibility changes is dependent on baseline conditions and proximity to the commodity being valued (e.g., improved visibility in a region with an abundance of National Parks such as the Pacific Northwest). Returning to the NAPAP example, the similarity in values may reflect the similarities between baseline visibility in eastern and western coastal zones (i.e., coastal areas typically have higher humidity, while areas of the west tend to have lower humidity and hence a greater baseline visibility).

For the purposes of this report, we interpret recreational settings applicable for this category of effects to include National Parks throughout the nation. Other recreational settings may also be applicable, for example National Forests, state parks, or even hiking trails or roadside areas with scenic vistas. In those cases, a lack of suitable economic valuation literature to identify these other areas and/or a lack of visitation data prevents us from generating estimates for those recreational vista areas. Moreover, we develop estimates of recreational visibility changes that account for the tendency of individuals to value visibility changes based on proximity to the National Park.

We estimate visibility benefits based on a derived visibility valuation function. In both cases, residential and recreational visibility, the valuation function takes the following form:

$$HHWTP = B * \ln(VR1/VR2)$$

where:

HHWTP = annual WTP per household for visibility changes
VR1 = the starting annual average visual range
VR2 = the annual average visual range after the change in air quality
B = the estimated visibility coefficient.

The form of this valuation function is designed to reflect the way individuals perceive and express value for changes in visibility. In other words, the expressed WTP for visibility changes varies with the percentage change in visual range, a measure that is closely related to, though not exactly analogous to, the Deci View index used in Chapter 4.

We develop estimates of the visibility coefficients for residential and recreational visibility from two studies.[20] We use figures reported in Chestnut and Dennis (1997) for the valuation of residential visibility. This study publishes estimates of visibility benefits for the Eastern U.S that are based on original research conducted in two Eastern cities (Atlanta and Chicago) by McClelland et al. (1990). We use a central B coefficient for residential visibility of $141, as reported in Chestnut and Dennis (1997). For the valuation of recreational visibility benefits, we use a study by Chestnut and Rowe (1990). This study reports WTP estimates of recreational visibility in three park regions, the Western, Southwestern, and Eastern U.S. For recreational visibility, the coefficients vary based on the study region and whether the household is within or outside of the National Park region of concern. "In-region" coefficients are higher than those for "out-of-region" households. The "in-region" estimates for California, the Southwest, and Southeast are $105, $137, and $65, respectively; the corresponding "out-of-region" estimates are $73, $110, and $40, respectively.

Our valuation of visibility changes is largely based on unpublished, but peer-reviewed work. For example, we use the secondary analysis of Chestnut and Dennis (1997) to value residential visibility benefits. This article is published in the *Journal of Air and Waste Management Association*, but relies on the unpublished results reported by McClelland et al. (1990). The source of our recreational visibility estimates, Chestnut and Rowe (1990), is also unpublished. Both studies were originally developed as part of the National Acid Precipitation Assessment Program (NAPAP) and, therefore, have been subject to peer-review as part of that program. Moreover, these two studies are frequently cited and

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[20] The unit of measure for the visibility coefficients is dollars. However, these coefficients are scaled by the small incremental changes in visibility to generate our WTP estimates.

recommended for use in published analyses of visibility valuation.[21]

Concerns about the method used in the McClelland et al. study, however, suggest their results may not incorporate two potentially important adjustments. First, their study does not account for the "warm glow" effect, in which respondents may provide higher willingness to pay estimates simply because they favor "good causes" such as environmental improvement. Second, while the study accounts for non-response bias, it may not employ the best available methods. The effect of both these factors is to suggest an overestimate of WTP. As a result, we exclude residential visibility estimates from the overall primary benefits estimate.

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[21] For example see Desvousges et al. (1998).

Table H-3
Unit Values Used for Economic Valuation of Health and Welfare Endpoints

Health or Welfare Endpoint	Estimated Value Per Incidence (1990$)		Derivation of Estimates
	Central Estimate	Uncertainty Distribution	
Mortality	$4.8 million per statistical life	Weibull distribution, mean = $4.8 million std. dev. = 3,240,000	Central Estimate: Value is the mean of value-of-statistical-life estimates from 26 studies (5 contingent valuation and 21 labor market studies). Uncertainty: Best-fit distribution to the 26 sample means. The Weibull distribution prevents selection of negative WTP values.
	$293,000 per statistical life-year	Weibull distribution, mean = $293,000 std. dev. = 198,000	Central Estimate: Value is the mean of the distribution of the value of a statistical life-year, derived from the distribution of the value of a statistical life (see below). Uncertainty: Assuming the discount rate is five percent, and assuming an expected 35 years remaining to the average worker in the wage-risk studies (see above), the value of a statistical life-year is just a constant, 0.061, multiplied by the value of a statistical life. The distribution of the value of a life-year is derived from the distribution of the value of a statistical life. Because the VSL is expressed as a Weibull distribution, as indicated above, the value of a statistical life-year is also expressed as a Weibull distribution, with mean equal to 0.061 multiplied by the mean of the original Weibull distribution (0.061 x $4.8 million = $293,000) and standard deviation equal to 0.061 multiplied by the standard deviation of the original distribution (0.061 x $3.24 = $198,000).

Health or Welfare Endpoint	Estimated Value Per Incidence (1990$)		Derivation of Estimates
	Central Estimate	Uncertainty Distribution	
Chronic Bronchitis (CB)	$260,000	A Monte Carlo-generated distribution, based on three underlying distributions, as described more fully under “Derivation of Estimates” and in the text.	Central Estimate: Value is the mean of a Monte Carlo distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB. The mean of the resulting distribution is $260,000. Uncertainty: The distribution of WTP to avoid a case of pollution-related CB was generated by Monte Carlo methods, drawing from each of three distributions: (1) WTP to avoid a severe case of CB is assigned a 1/9 probability of being each of the first nine deciles of the distribution of WTP responses in Viscusi et al., 1991; (2) the severity of a pollution-related case of CB (relative to the case described in the Viscusi study) is assumed to have a triangular distribution, centered at severity level 6.5 with endpoints at 1.0 and 12.0 (see text for further explanation); and (3) the constant in the elasticity of WTP with respect to severity is normally distributed with mean = 0.18 and standard deviation = 0.0669 (from Krupnick and Cropper, 1992). See text for further explanation.
Chronic Asthma	$25,000	Triangular distribution, centered at $25,000 on the interval [$19,000, $30,000]	Central Estimate: Based on results reported in two studies (Blumenschein and Johannesson, 1998 and O'Conor and Blumquist, 1997). Assumes a 5% discount rate and reflects adjustments for age distribution among adults (ages 27 and older) and projected life years remaining. Uncertainty: Reflects the range in central estimate values reported in the two studies.

Health or Welfare Endpoint	Estimated Value Per Incidence (1990$)		Derivation of Estimates
	Central Estimate	Uncertainty Distribution	
Hospital Admissions			
1. All Respiratory - ICD codes: 460-519	variable—function of the analysis	See Derivation of Estimates	Central Estimate: Central estimate is the result of the analysis. The analysis uses 12 distinct C-R functions. A COI estimate is constructed for each. The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total respiratory illnesses) reported in Elixhauser (1993). Uncertainty: Probability distribution is a result of the analysis and reflects: (1) uncertainty range of C-R function outcome; and (2) variation in study-specific COI estimates.
2. All Cardiovascular - ICD codes: 390-429	variable—function of the analysis	See Derivation of Estimates	Central Estimate: Central estimate is the result of the analysis. The analysis uses five distinct C-R functions. A COI estimate is constructed for each. The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total respiratory illnesses) reported in Elixhauser (1993). Uncertainty: Probability distribution is a result of the analysis and reflects: (1) uncertainty range of C-R function outcome; and (2) variation in study-specific COI estimates.
3. Emergency room visits for asthma	$194	Triangular distribution, centered at $194 on the interval [$144, $269]	Central Estimate: COI estimate based on data reported by Smith et al. (1997). Uncertainty: Based on reported 95% confidence intervals for annual estimates of the number and costs of ER visits.

Health or Welfare Endpoint	Estimated Value Per Incidence (1990$)		Derivation of Estimates
	Central Estimate	Uncertainty Distribution	
Respiratory Ailments Not Requiring Hospitalization			
1. Upper Resp. Symptoms (URS) (defined as one or more of the following: runny or stuffy nose, wet cough, burning, aching, or red eyes)	$19	Continuous uniform distribution over the interval [$7, $33]	Central Estimate: Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in 7 different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using IEc mid-range estimates of WTP to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS. Uncertainty: Assumed to be a continuous uniform distribution across the range of values described by the 7 URS types.
2. Lower Resp. Symptoms (LRS) (defined in the study as two or more of the following: cough, chest pain, phlegm, and wheeze.)	$12	Continuous uniform distribution over the interval [$5, $19]	Central Estimate: Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A $ value was derived for each type of LRS, using IEc mid-range estimates of WTP to avoid each symptom in the cluster and assuming additivity of WTPs. The $ value for LRS is the average of the $ values for the 11 different types of LRS. Uncertainty: Taken to be a continuous uniform distribution across the range of values described by the 11 LRS types.
3. Acute Bronchitis	$45	Continuous uniform distribution over the interval [$13, $77]	Central Estimate: Average of low and high values recommended by IEC for use in section 812 analysis (Neumann et al., 1994). Uncertainty: Continuous distribution between low and high values (Neumann et al., 1994) assigns equal likelihood of occurrence of any value within the range.

Health or Welfare Endpoint	Estimated Value Per Incidence (1990$)		Derivation of Estimates
	Central Estimate	Uncertainty Distribution	
4. Acute Respiratory Symptoms and Illnesses - Presence of any of 19 acute respiratory symptoms - Any Resp. Symptom - Respiratory Illness	$18	1. URS, probability = 40% LRS, probability = 40% URS+LRS, prob. = 20% 2. If URS, use URS $ dist. If LRS, use LRS $ dist. If URS+LRS, randomly select one value each from URS and LRS $ distributions; sum the two	Central Estimate: Assuming that respiratory illness and symptoms can be characterized as some combination of URS and LRS, namely: URS with 40% probability, LRS with 40% probability, and both URS and LRS with 20% probability. The $ value for these endpoints is the weighted average (using the weights 0.40, 0.40, and 0.20) of the $ values derived for URS, LRS, and URS + LRS. Uncertainty: Based on variability assumed for central estimate, and URS and LRS uncertainty distributions presented previously.
5. Asthma Attack	$32	Continuous uniform distribution over the interval [$12, $54]	Central Estimate: Mean of average WTP estimates for the four severity definitions of a "bad asthma day." Source: Rowe and Chestnut (1986), a study which surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. Uncertainty: Based on the range of values estimated for each of the four severity definitions.
6. Moderate or worse asthma	$32	Continuous uniform distribution over the interval [12, 54]	Central Estimate: Reflects the mean WTP to avoid a "bad asthma day" as reported by Rowe and Chestnut (1986). Uncertainty: Taken to be a continuous uniform distribution across the range of values obtained from the study.
7. Shortness of breath, chest tightness or wheeze	$5.30	Continuous uniform distribution over the interval [$0, $10.60]	Central Estimate: From Ostro et al., 1995. This is the mean of the median estimates from two studies of WTP to avoid a day of shortness of breath: Dickie et al., 1991 ($0.00), and Loehman et al., 1979 ($10.60). Uncertainty: Taken to be a continuous uniform distribution across the range of values obtained from the two studies.

Health or Welfare Endpoint	Estimated Value Per Incidence (1990$)		Derivation of Estimates
	Central Estimate	**Uncertainty Distribution**	
Restricted Activity and Work Loss Days			
1. WLDs	$83	none available	Central Estimate: Median weekly wage for 1990 divided by 5 (U.S. Department of Commerce, 1992) Uncertainty: Insufficient information to derive an uncertainty estimate.
2. MRADs	$38	Triangular distribution centered at $38 on the interval [$16, $61]	Central Estimate: Median WTP estimate to avoid 1 MRRAD -- minor respiratory restricted activity day -- from Tolley et al. (1986) (recommended by IEc as the mid-range estimate). Uncertainty: Range is based on assumption that value should exceed WTP for a single mild symptom (the highest estimate for a single symptom--for eye irritation--is $16.00) and be less than that for a WLD. The triangular distribution acknowledges that the actual value is likely to be closer to the point estimate than either extreme.
Welfare Effects			
1. Visibility Residential Visibility "in-region" "out-of-region"	Valuation function: HHWTP= B * ln(VR1/VR2) where: HHWTP = annual WTP per household B = estimated visibility coefficient VR1 = starting annual average visual range VR2 = the annual average visual range after the change in air quality		Central Estimate: Estimated WTP for valuation of visibility changes depend upon two factors: (i) visibility coefficient, B, and (ii) incremental change in visual range. Visibility coefficients applied in the primary analysis vary by category of visibility change and region. Recreational visibility valuation is based on Chestnut and Rowe (1990). For "in region" recreational visibility, the coefficients are $105, $137, $65, for California, the Southwest, and the Southeast, respectively. For "out-of-region" recreational visibility, the coefficients are $73, $110, $40, for California, the Southwest, and the Southeast, respectively.
2. Worker Productivity	Change in daily wages: $1 per worker per 10% change in O_3	none available	Central Estimate: Based on elasticity of income with respect to O3 concentration derived from study of California citrus workers (Crocker and Horst, 1981 and U.S. EPA, 1994). Elasticity applied to the average daily income for workers engaged in strenuous outdoor labor, $73 (U.S. 1990 Census).

Note: All WTP estimates converted to 1990 dollars using the Consumer Price Index (CPI); COI estimates converted using the CPI-Medical.

Results of Valuation of Health and Welfare Effects

We estimate total human health and welfare benefits by combining the economic valuations described in this Appendix with the health and welfare effects results presented in Appendix D for projection years 2000 and 2010. The valuation results reflect the annual estimates of benefits for the 48 contiguous States, or "all U.S. population," which provides a more accurate depiction of the *trend* of economic benefits over the 20-year study period [22] For our Primary Central estimate we attribute to Titles I through V of the CAAA total annual human health benefits of $68 billion in 2000 and $118 billion in 2010.

As noted in Appendix D, we also include alternative estimates for some health and welfare impacts, which form the basis of several alternative benefit estimates. For each of the health effects estimates, we quantify statistical uncertainty. The range of estimated health and welfare effects, along with the uncertain economic unit valuations, are combined to estimate a range of possible results. We use the Monte Carlo method presented in Chapter 8 to combine the health and economic information. Both tables show the mean estimate results, as well as the measured credible range (upper and lower five percentiles of the results distribution), of economic benefits for each of the quantified health and welfare categories. We summarize our primary estimates of 2000 and 2010 monetized benefits in Table H-3 and Table H-5, respectively. The tables provide our Primary Central estimate, in addition to our Primary Low estimate, 5th percentile values, and our Primary High estimate, 95th percentile estimates, for each benefit category.

We also apply the Monte Carlo method when generating aggregate monetized benefit results. The Monte Carlo method used in the analysis assumes that each health and welfare endpoint is independent of the others. We adopt this approach in response to the very low probability that the aggregate benefits will equal the sum of the fifth percentile benefits from each of the ten endpoints. Consequently, the upper and lower fifth percentiles of the estimated benefits from the individual endpoints does not equal the estimated totals for the Primary High and Primary Low estimates.

There are two additional aspects of our results that warrant discussion. The first is the valuation of premature mortality due to PM exposure. The second is our strategy to avoid double-counting when aggregating health benefits. As discussed in Chapter 5, premature mortality is estimated based on PM exposure. Our primary estimates reflect a lag between PM exposure and the timing of premature mortality. While this lag does not alter the number of estimated incidences, it does alter the monetization of benefits. Because we value the "event" rather than the present change in risk, the value of avoided future premature mortality should be discounted. Therefore, the type of lag structure employed plays a direct role in the valuation of this endpoint.

The primary analysis reflects a five-year lag structure. Under this scenario, 50 percent of the estimated cases of avoided mortality occur within the first two years. The remaining 50 percent are then distributed across the next three years. Our valuation of avoided premature mortality applies a five percent discount rate to the lagged estimates over the periods 2000 to 2005 and 2010 to 2015. We discount over the period between the initial PM exposure change (either 2000 or 2010) and timing of the projected incidences.

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[22] In Appendix D, we present physical effect estimates for affected population in the contiguous 48 States and for affected populations within 50 kilometers of a monitor. We present those results as a sensitivity test that characterizes the possible magnitude of human health effects. For the purpose of assessing the total benefit of the CAAA, the results affecting populations in 48 states provide a better characterization of the total direct benefits than do the "monitored area only" results. The results of only monitored areas does not account for the benefits of air quality improvements affecting approximately 25 percent of the population. The "all U.S. population" results, however, rely on uncertain extrapolations of pollution concentrations, and subsequent exposures, from distant monitoring sites to provide coverage for the 25 percent or so of the population living far from air quality monitors.

Many of the monetized health benefit categories include overlapping health endpoints, creating the potential for double-counting. In an effort to avoid overstating the benefits, we do not aggregate all of the quantified health effects. For example, "asthma attacks" and "moderate to worse asthma", are all considered components of the endpoint, "Any of 19 Respiratory Symptoms". Consequently, we present the results but do not include them in our reported total benefits figures. In other cases, there are endpoints included in our aggregation of benefits that appear to have overlapping health effects. For those benefit categories that describe similar health effects, it is important to keep in mind that estimated incidences are based on unique portions of the population.

Table H-4
Primary Estimates of Health and Welfare Benefits Due to Criteria Pollutants in 2000

	Monetary Benefits (in millions 1990$)		
Benefits Category	**5th %ile**	**Mean**	**95th %ile**
Mortality			
Ages 30+	$ 8,600	$ 63,000	$ 150,000
Chronic Illness			
Chronic Bronchitis	$ 220	$ 3,600	$ 11,000
Chronic Asthma	29	140	240
Hospitalization			
All Respiratory	$ 46	$ 78	$ 120
Total Cardiovascular	53	200	430
Asthma-Related ER Visits	0.1	0.6	1.8
Minor Illness			
Acute Bronchitis	$ 0	$ 1.3	$ 3.3
URS	2.8	12	26
LRS	1.4	3.9	7.2
Respiratory Illness	0.4	2.5	6.1
Mod/Worse Asthma[1]	1.2	8.5	19
Asthma Attacks[1]	13	35	66
Chest tightness, Shortness of Breath, or Wheeze	0	0.5	2.4
Shortness of Breath	0	0.3	0.7
Work Loss Days	180	210	240
MRAD/Any-of-19	420	760	1,100
Welfare			
Decreased Worker Productivity	$ 460	$ 460	$ 460
Visibility			
Recreational	1,700	2,000	2,300
Agriculture	46	450	860
Total Benefits[2]		**$ 71,000**	

Note:

[1] Moderate to worse asthma and asthma attacks are endpoints included in the definition of MRAD/Any of 19 respiratory effects. Although valuation estimates are presented for these categories, the values are not included in total benefits to avoid the potential for double-counting.

[2] Summing 5th and 95th percentile values would yield a misleading estimate of the 5th and 95th percentile estimate of total health benefits. For example, the likelihood that the 5th percentile estimates for each endpoint would simultaneously be drawn from a Monte Carlo procedure is much less than 5 percent. As a result, we present only the total mean.

Table H-5
Primary Estimates of Health and Welfare Benefits Due to Criteria Pollutants in 2010

	Monetary Benefits (in millions 1990$)		
Benefits Category	**5th %ile**	**Mean**	**95th %ile**
Mortality			
Ages 30+	$ 14,000	$ 100,000	$ 250,000
Chronic Illness			
Chronic Bronchitis	$ 360	$ 5,600	$ 18,000
Chronic Asthma	40	180	300
Hospitalization			
All Respiratory	$ 76	$ 130	$ 200
Total Cardiovascular	93	390	960
Asthma-Related ER Visits	0.1	1	2.8
Minor Illness			
Acute Bronchitis	$ 0	$ 2.1	$ 5.2
URS	4.2	19	39
LRS	2.2	6.2	12
Respiratory Illness	0.9	6.3	15
Mod/Worse Asthma[1]	1.9	13	29
Asthma Attacks[1]	20	55	100
Chest tightness, Shortness of Breath, or Wheeze	0	0.6	3.1
Shortness of Breath	0	0.5	1.2
Work Loss Days	300	340	380
MRAD/Any-of-19	680	1,200	1,800
Welfare			
Decreased Worker Productivity	$ 710	$ 710	$710
Visibility Recreational	2,500	2,900	3,300
Agriculture	7.1	550	1,100
Total Benefits[2]		**$ 110,000**	

Note:

[1] Moderate to worse asthma, asthma attacks, and shortness of breath are endpoints included in the definition of MRAD/Any of 19 respiratory effects. Although valuation estimates are presented for these categories, the values are not included in total benefits to avoid the potential for double-counting.

[2] Summing 5th and 95th percentile values would yield a misleading estimate of the 5th and 95th percentile estimate of total health benefits. For example, the likelihood that the 5th percentile estimates for each endpoint would simultaneously be drawn from a Monte Carlo procedure is much less than 5 percent. As a result, we present only the total mean.

Uncertainties in the Valuation Estimates

The uncertainty ranges for the results on the present value of the aggregate measured monetary benefits reported in Table H-4 and Table H-5 reflect two important sources of measured uncertainty:

- Uncertainty about the avoided incidence of health and welfare effects deriving from the concentration-response functions, including both selection of scientific studies and statistical uncertainty from the original studies;
- Uncertainty about the economic value of each quantified health and welfare effect.

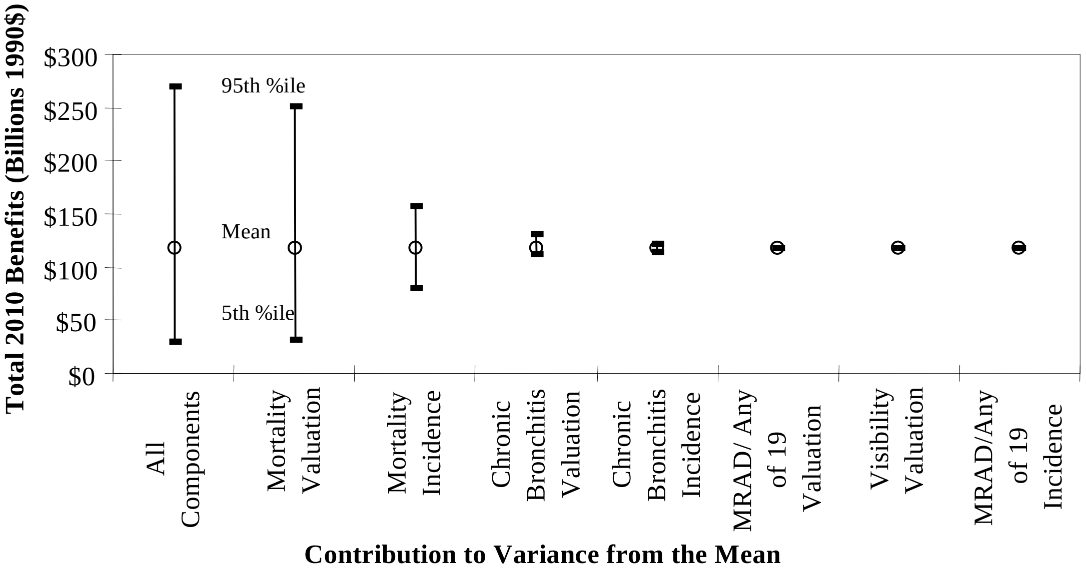
These aggregate uncertainty results incorporate many decisions about analytical procedures and specific assumptions discussed in the Appendices to this report.

In order to provide a more complete understanding of the economic benefit results, we conduct sensitivity analyses which examine several additional important aspects of the main analysis. We begin with an analysis of the sources of the measured aggregate uncertainty, identifying which of the measured uncertainty components of incidence and valuation for individual health effects categories drive the overall uncertainty results. We then follow with an examination of several issues involving the estimated economic benefits of mortality. In the third section, we provide some insight into the potential effects of income growth on the valuation of health effects.

Relative Importance of Different Components of Uncertainty

The estimated uncertainty ranges in our primary results tables, Table H-4 and Table H-5, reflect the measured uncertainty associated with both avoided incidence and economic valuation. A better understanding of the relative influence of individual

Figure H-4
Analysis of Contribution of Key Parameters to Quantified Uncertainty



variables on the overall uncertainty in the analysis can be gained by isolating the individual effects of important variables on the range of estimated total benefits. This can be accomplished by holding all the inputs to the Monte Carlo uncertainty analysis constant (at their mean values), and allowing only one variable -- for example, the economic valuation of mortality -- to vary across the range of that variable's quantified uncertainty. The sensitivity analysis then isolates how this single source of variability contributes to the variation in the primary estimates of total benefits. The results are summarized in Figure H-4. The nine individual uncertainty factors that contribute the most to the overall uncertainty are shown in Figure H-4, ordered by the relative significance of their contribution to overall uncertainty. Each of the additional sources of quantified uncertainty in the overall analysis not shown contribute a smaller amount of uncertainty to the estimates of monetized benefits than the sources that are shown.

Economic Benefits Associated with Reducing Premature Mortality

Because the economic benefits associated with premature mortality are the largest source of monetized benefits in the analysis, and because the uncertainties in both the incidence and value of premature mortality are the most important sources of uncertainty in the overall analysis, it is useful to examine the mortality benefits estimation in greater detail. We begin with a discussion of the uncertainties and possible biases related to the "benefits transfer" approach employed to develop our VSL estimate. We then discuss an alternative method for the valuation of reduced premature mortality, value of statistical life year (VSLY). We conclude this section with a sensitivity test that compare the benefit estimates using a VSL approach and a VSLY approach. Given the lag structure employed in estimating reduced premature mortality, we also provide alternative calculations for the valuation of this benefits category using two additional discount rates, three and seven percent.

Benefits Tranfer and VSL

The analytical procedure used in the main analysis to estimate the monetary benefits of avoided premature mortality assumes that the appropriate economic value for each incidence is a value from the currently accepted range of the value of a statistical life. As discussed above, the estimated value per predicted incidence of excess premature mortality is modeled as a Weibull distribution, with a mean value of $4.8 million and a standard deviation of $3.2 million. This estimate is based on 26 studies of the value of mortal risks.

There is considerable uncertainty as to whether the 26 studies on the value of a statistical life provide adequate estimates of the value of a statistical life saved by air pollution reduction. Although there is considerable variation in the analytical designs and data used in the 26 underlying studies, the majority of the studies involve the value of risks to a middle-aged working population. Most of the studies examine differences in wages of risky occupations, using a wage-hedonic approach. Certain characteristics of both the population affected and the mortality risk facing that population are believed to affect the average willingness to pay (WTP) to reduce the risk. The appropriateness of a distribution of WTP estimates from the 26 studies for valuing the mortality-related benefits of reductions in air pollution concentrations therefore depends not only on the quality of the studies (i.e., how well they measure what they are trying to measure), but also on (1) the extent to which the risks being valued are similar, and (2) the extent to which the subjects in the studies are similar to the population affected by changes in pollution concentrations. As discussed below, there are possible sources of both upward and downward bias in the estimates provided by the 26 studies when applied to the population and risk being considered in this analysis.

Although there may be several ways in which job-related mortality risks differ from air pollution-related mortality risks, the most important difference may be that job-related risks are incurred voluntarily whereas air pollution-related risks are incurred involuntarily.

There is some evidence (see, for example, Violette and Chestnut, 1983) that people will pay more to reduce involuntarily incurred risks than risks incurred voluntarily. If this is the case, WTP estimates based on wage-risk studies may be downward biased estimates of WTP to reduce involuntarily incurred air pollution-related mortality risks.

Another possible difference related to the nature of the risk may be that some workplace mortality risks tend to involve sudden, catastrophic events (e.g., workplace accidents), whereas air pollution-related risks tend to involve longer periods of disease and suffering prior to death. Several studies indicate that the value people place on mortality risk reduction may depend on the nature of the risk (e.g., Fisher et al. 1989; Beggs 1984). Some evidence suggests that WTP to avoid a risk of a protracted death involving prolonged suffering and loss of dignity and personal control is greater than the WTP to avoid a risk (of identical magnitude) of sudden death. Some workplace risks, such as risks from exposure to toxic chemicals, may be more similar to pollution-related risks. It is not clear, however, what proportion of the workplace risks in the wage-risk studies were related to workplace accidents and what proportion were risks from exposure to toxic chemicals. To the extent that the mortality risks addressed in this assessment are associated with longer periods of illness or greater pain and suffering than are the risks addressed in the valuation literature, the WTP measurements employed in the present analysis would reflect a downward bias.

If the individuals who die prematurely from air pollution are consistently older than the population in the valuation studies, the mortality valuations based on middle-aged people may provide a biased estimate of the willingness to pay of older individuals to reduce mortal risk. There is some evidence to suggest that the people who die prematurely from exposure to ambient particulate matter tend to be older than the populations in the valuation studies. In the general U.S. population far more older people die than younger people; 88 percent of the deaths are among people over 64 years old. It is difficult to establish the proportion of the pollution-related deaths that are among the older population because it is impossible to isolate individual cases where one can say with even reasonable certainty that a specific individual died because of air pollution.

There is considerable uncertainty whether older people will have a greater willingness to pay to avoid risks than younger people. There is reason to believe that those over 65 are, in general, more risk averse than the general population, while workers in wage-risk studies are likely to be less risk averse than the general population. More risk averse people would have a greater willingness to pay to avoid risk than less risk averse people. Although the list of recommended studies excludes studies that consider only much-higher-than-average occupational risks, there is nevertheless likely to be some selection bias in the remaining studies -- that is, these studies are likely to be based on samples of workers who are, on average, more risk-loving than the general population. In contrast, older people as a group exhibit more risk averse behavior.

The direction of bias resulting from the age difference is unclear, particularly because age is confounded by risk aversion (relative to the general population). It could be argued that, because an older person has fewer expected years left to lose, his WTP to reduce mortality risk would be less than that of a younger person. This hypothesis is supported by one empirical study, Jones-Lee et al. (1985), that found the value of a statistical life at age 65 to be about 90 percent of what it is at age 40. Citing the evidence provided by Jones-Lee et al. (1985), a recent sulfate-related health benefits study conducted for EPA (U.S. EPA, 1995) assumes that the value of a statistical life for those 65 and over is 75 percent of what it is for those under 65. In addition, it might be argued that because the elderly have greater average wealth than those younger, the affected population is also wealthier, on average, than wage-risk study subjects, who tend to be blue collar workers. It is possible, however, that among the elderly it is largely the poor elderly who are most vulnerable to pollution-related mortality risk (e.g., because of generally poorer health care). If this is the case, the average wealth of those affected by a pollution reduction relative to that of subjects in wage-risk studies is uncertain. In addition, the workers in the wage-risk studies will have potentially more years remaining in which to acquire streams of income from future earnings.

There is substantial evidence that the income elasticity of WTP for health risk reductions is positive (see, for example, Alberini et al., 1994; Mitchell and Carson, 1986; Loehman and Vo Hu De, 1982; Gerking et al., 1988; and Jones-Lee et al., 1985), although there is uncertainty about the exact value of this elasticity. Individuals with higher incomes (or greater wealth) should be willing to pay more to reduce risk, all else equal, than individuals with lower incomes or wealth. This does not imply that individuals with higher incomes are willing to pay proportionally higher values. While many analyses assume income elasticity of willingness to pay is unit elastic (i.e., ten percent higher income level implies a ten percent higher willingness to pay to reduce risk changes), empirical evidence suggests that income elasticity is substantially less than one.

The effects of income changes on WTP estimates can influence benefit estimates in two different ways: (i) as longitudinal changes that reflect estimates of income change in the affected population over time, and (ii) as cross-sectional changes based on differences in income between study populations and the attracted populations. Empirical evidence of the effect of income on WTP gathered to date is based on studies examining cross-sectional data. Income elasticity adjustments to better account for changes over time, therefore, will necessarily be based on potentially inappropriate data.[23]

The need to adjust wage-risk-based WTP estimates downward because of the likely upward bias introduced by the age discrepancy has received significant attention (see Chestnut, 1995; IEc, 1992). If the age difference were the only difference between the population affected by pollution changes and the subjects in the wage-risk studies, there might be some justification for trying to adjust the point estimate of $4.8 million downward. Even in this case, however, the degree of the adjustment would be unclear. There is good reason to suspect, however, that there are biases in both directions. Because in each case the extent of the bias is unknown, the overall direction of bias in the mortality values is similarly unknown. Adjusting the estimate upward or downward to compensate for any one source of bias could therefore increase the degree of bias. Therefore, the range of values from the 26 studies is used in the primary analysis without adjustment.

VSLY

An alternative valuation of avoided premature mortality is to use the VSLY. This approach uses life-years lost as the unit of measure, rather than estimating a single value of a statistical life lost (applicable to all ages). With statistical life-years lost as the unit of measure, the valuation depends on (1) how many years of expected life are lost, (2) the individual's discount rate, and (3) whether the value of an undiscounted statistical life-year is the same no matter which life-year it is (e.g., the undiscounted value of the seventy-fifth year of life is the same as the undiscounted value of the fortieth year of life).

We estimate the value of a statistical life-year assuming that the value of a statistical life is directly related to remaining life expectancy and a constant value for each life-year. Such an approach results in smaller values of a statistical life for older people, who have shorter life expectancies, and larger values for younger people. For example, if the $4.8 million mean value of avoiding death for people with a 35 year life expectancy is assumed to be the discounted present value of 35 equal-valued statistical life-years, the implied value of each statistical life-year is $293,000. This values assumes a five percent discount rate and that the undiscounted value of a life-year is the same no matter when it occurs in an individual's life.

To obtain estimates of the number of air pollution-related deaths in each age cohort, it is preferable to have age-specific relative risks. Many of

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[23] For more information on the potential impact of income elasticity on the valuation of health benefits, see the following section, "Sensitivity Test for Impact of Income Changes Over Time."

the epidemiological studies, however, do not provide any estimate of such age-specific risks. In this case, the age-specific relative risks must be assumed to be identical. Some epidemiology studies on PM do provide some estimates of relative risks specific to certain age categories. The limited information that is available suggests that relative risks of mortality associated with exposure to PM are greater for older people. Most of the available information comes from short-term exposure studies. There is considerable uncertainty in applying the evidence from short-term exposure studies to results from long-term (chronic exposure) studies. However, using the available information on the relative magnitudes of the relative risks, it is possible to form a preliminary assessment of the relative risks by different age classes.

The analysis presented below uses two alternative assumptions about age-specific risks: (1) there is a constant relative risk (obtained directly from the health literature) that is applicable to all age cohorts, and (2) the relative risks differ by age, as estimated from the available literature. Estimates of age-specific PM-10 coefficients (and, from these, age-specific relative risks) were derived from the few age-specific PM-10 or TSP coefficients reported in the epidemiological literature. These estimates in the literature were used to estimate the ratio of each age-specific coefficient to a coefficient for "all ages" in such a way that consistency among the age-specific coefficients is preserved -- that is, that the sum of the health effects incidences in the separate, non-overlapping age categories equals the health effects incidence for "all ages." These ratios were then applied to the coefficient from Pope et al. (1995). Details of this approach are provided in Post and Deck (1996). Because Pope et al. considered only individuals age 30 and older (instead of all ages), the resulting age-specific PM coefficients may be slightly different from what they would have been if the ratios had been applied to an "all ages" coefficient. The differences, however, are likely to be minimal and well within the error bounds of this exercise. The age-specific relative risks used in the example below assume that the relative risks for people under 65 are only 16 percent of the population-wide average relative risk, the risks for people from 65 to 74 are 83 percent of the population-wide risk, and people 75 and older have a relative risk 55 percent greater than the population average. Details of this approach are provided in Post and Deck (1996).

The life-years lost approach also requires an estimate of the number of life-years lost by a person dying prematurely at each given age. The approach developed for this analysis assumes that exposure to elevated levels of PM increases the probability of dying at a specific age. Increasing the probability of dying at each age lowers the life expectancy for each age cohort. The average number of life-years lost will depend on the distribution of ages in the population in a location. In addition, this analysis incorporates the five-year PM mortality lag structure described in Chapter 5 and Appendix D. It distributes the mortality for each cohort across a five-year period (25 percent in each of the first two years, 16.7 percent in each of the remaining years) and adjusts the loss of life expectancy accordingly. That is, when applying the lag assumption within a given cohort, individuals who die later are expected to lose fewer life years than those who die earlier. Further, this analysis applies a five percent discount rate when calculating the present discounted value of the avoided losses of life expectancy in each cohort over the five-year lag period.

The life-years lost approach used here assumes that people who die from air pollution are typical of people in their age group. The estimated value of the quantity of life lost assumes that the people who die from exposure to air pollution had an average life expectancy. However, it is possible that the people who die from air pollution are already in ill health, and that their life expectancy is less than a typical person of their age. If this is true, then the number of life years lost per PM-related death would be lower than calculated here, and the economic value would be smaller.

The extent to which adverse effects of particulate matter exposure are differentially imposed on people of advanced age and/or poor health is one of the most important current uncertainties in air pollution-related health studies. There is limited information, primarily from the short-term exposure studies, which suggests that at least some of the estimated premature mortality is imposed disproportionately on people who are elderly and/or of poor health. Rowlatt, et al. (1998) indicate that at risk individuals include those who have suffered strokes or are suffering from cardiovascular disease and angina. The Criteria Document for Particulate Matter (U.S. EPA, 1996), however, identifies only two studies which attempt to evaluate the disproportionality in premature mortality among people who are elderly and/or sickly. Spix et al. (1994) suggests that a small portion of the PM-associated mortality occurs in individuals who would have died in a short time anyway. Cifuentes and Lave (1996) found that 37 to 87 percent of the deaths from short-term exposure could have been premature by only a few days, although their evidence is inconclusive.

Prematurity of death on the order of only a few days is likely to occur largely among individuals with pre-existing illnesses. Such individuals might be particularly susceptible to a high PM day. To the extent that the pre-existing illness is itself caused by or exacerbated by chronic exposure to elevated levels of PM, however, it would be misleading to define the prematurity of death as only a few days. In the absence of chronic exposure to elevated levels of PM, the illness would either not exist (if it was caused by the chronic exposure to elevated PM) or might be at a less advanced stage of development (if it was not caused by but was exacerbated by elevated PM levels). The prematurity of death should be calculated as the difference between when the individual died in the "elevated PM" scenario and when he would have died in the "low PM" scenario. If the pre-existing illness was entirely unconnected with chronic exposure to PM in the "elevated PM" scenario, and if the individual who dies prematurely because of a peak PM day would have lived only a few more days, then the prematurity of that PM-related death is only those few days. If, however, in the absence of chronic exposure to elevated levels of PM, the individual's illness would have progressed more slowly, so that, in the absence of a particular peak PM day the individual would have lived several years longer, the prematurity of that PM-related death would be those several years.

Long-term studies provide evidence that a portion of the loss of life associated with long-term exposure is independent of the death from short-term exposures, and that the loss of life-years measured in the long-term studies could be on the order of years. If much of the premature mortality associated with PM represents short term prematurity of death imposed on people who are elderly and/or of ill health, the estimates of the monetary benefits of avoided mortality may overestimate society's total willingness to pay to avoid particulate matter-related premature mortality. On the other hand, if the premature mortality measured in the chronic exposure studies is detecting excess premature deaths which are largely independent of the deaths predicted from the short term studies, and the disproportionate effect on the elderly and/or sick is modest, the benefits measured in this report could be underestimates of the total value. At this time there is insufficient information from both the medical and economic sciences to satisfactorily resolve these issues from a theoretical/analytical standpoint. Until there is evidence from the physical and social sciences which is sufficiently compelling to encourage broad support of age-specific values for reducing premature mortality, EPA will continue to use for its primary analyses a range of values for mortality risk reduction which assumes society values reductions in pollution-related premature mortality equally regardless of who receives the benefit of such protection.

Sensitivity Test of Benefits Due to Reduced Premature Mortality Valuation

Examining the sensitivity of the total benefits of reduced premature mortality to alternative valuation techniques does provide some illumination to the potential impacts of alternative approaches. This section presents alternative results to our primary estimate of mortality valuation using the life-years lost approach, and also examine the effects of alternative discount rates.

The life-years lost approach also requires an estimate of the number of life-years lost by a person dying prematurely at each given age. The approach developed for this analysis assumes that exposure to elevated levels of PM increases the probability of dying at a specific age. Increasing the probability of dying at each age lowers the life expectancy for each age cohort. The average number of life-years lost will depend on the distribution of ages in the population in a location. In addition, this analysis incorporates the five-year PM mortality lag structure described in Chapter 5 and Appendix D. It distributes the mortality for each cohort across a five-year period (25 percent in each of the first two years, 16.7 percent in each of the remaining years) and adjusts the loss of life expectancy accordingly. That is, when applying the lag assumption within a given cohort, individuals who die later are expected to lose less live expectancy than those who die earlier. Further, this analysis applies a five percent discount rate when summing the value of the avoided losses of life expectancy in each cohort over the five-year lag period.

The alternative central estimates for avoided PM-related premature mortality using a five percent discount rate are $33 billion in 2000 and $53 billion in 2010. The VSLY approach results in estimates that are almost 50 percent lower than our primary estimates of benefits due to avoided pre-mature mortality. The sensitivity analysis, however, indicates that the pattern of monetized mortality benefits with each valuation procedure is essentially invariant to the discount rate. We summarize these results in Table H-6.

We emphasize that the results of the VSLY approach to valuing avoided mortality benefits represent a crude estimate of the value of changes in age-specific life expectancy. These results should be interpreted cautiously, due to the several significant assumptions required to generate a monetized estimate of life years lost from the relative risks reported in the Pope et al., 1995 study and the available economic literature. These assumptions include, but are not limited to: extrapolation of the age distribution of the U.S. population in future years; assumptions about the age-specificity of the relative risk reported by Pope et al., 1995; assumptions about the life expectancy of different age groups; assumption of a particular lag structure; assumptions about the age-specificity of the lag period (if any); derivation of VSLY estimates from VSL estimates; assumptions about the variation in VSLY with age; and selection of an appropriate rate at which to discount the lagged estimates of life years lost. Changes in any of these assumptions could significantly affect the VSLY benefit estimate. For example, if we were to assume no lag period for PM-related mortality effects instead of the five-year lag structure, VSLY benefit estimates would increase from $53 billion to $61 billion.

Table H-6
Sensitivity Analysis of Alternative Discount Rates on the Valuation of Reduced Premature Mortality

Benefit Category & Discount Rate	2000 (in millions, 1990$)			2010 (in millions, 1990$)		
	5th %ile	Central	95th %ile	5th %ile	Central	95th %ile
VSL Approach						
3% Discount Rate	$ 8,900	$ 65,000	$ 150,000	$ 14,000	$ 100,000	$ 250,000
5% Discount Rate	8,600	63,000	150,000	14,000	100,000	250,000
7% Discount Rate	8,300	61,000	150,000	14,000	97,000	240,000
VSLY Approach						
3% Discount Rate	$ 4,600	$ 30,000	$ 68,000	$ 7,400	$ 48,000	$ 110,000
5% Discount Rate	5,000	33,000	74,000	8,100	53,000	120,000
7% Discount Rate	5,400	35,000	80,000	8,800	57,000	130,000

Note: The discount rate affects the benefits estimates of VSL and VSLY approach differently. With the VSL approach, higher discount rates lead to lower estimates because of the lag structure. With the VSLY approach, the higher discount rates lead to higher estimates because of its affect on the annualized values.

Sensitivity Test for Impact of Income Changes Over Time

As an illustrative calculation, we adjust willingness-to-pay (WTP) measures to reflect the expected increase in real income over the full period of the analysis, 1990 to 2010. Our procedure results in an upward adjustment to more accurately reflect the valuation of improved health as income increases over time. In this section, we describe the procedure we use and the results of our illustrative calculation.

Background and Methodology

Economists use income elasticity to evaluate how private and public goods are valued based on the interaction between income changes and demand. A negative relationship between income and demand for a good implies that the good is an inferior good. An individual demands less of a good as income rises. A positive relationship between income and the demand for a good implies that the good is normal (i.e., income elasticity is greater than zero). As income rises an individual demands more of a good. Depending on the relative responsiveness of demand to income changes, normal goods are characterized as a necessity or a luxury. When income elasticity is between 0 and +1, the good is considered a necessity (i.e., demand is not significantly responsive to income). In contrast, when income elasticity exceeds +1, the good is considered a luxury (i.e., the relative increase in the good's demand exceeds the increase in income).

The determination of a public good as inferior or normal based on income elasticity is complicated by its nonrival nature. In the case of a private good, varying the level of consumption is measured as a marginal change and implies that an individual will adjust his or her consumption level of other good(s). Consequently, income elasticity of demand estimates a change in quantity consumed, and not necessarily a change in utility (or the individual's well-being). With public goods, the conceptual logic is different. Income elasticity of WTP for public goods measures changes in consumer surplus. For example, one person enjoying the benefits of cleaner air does not reduce the probability of another person enjoying the same benefits. There are no apparent mechanisms for regulating who specifically will enjoy the benefits. In other words, there is no direct relationship between an individual's WTP and level of consumption.[24] The consumption level of public goods is exogenous to the individual's budget constraint. At the same time, WTP for a public good is not exogenous. An individual, therefore, must consider how his or her WTP affects the allocation of income among private and public goods.[25]

Flores and Carson (1997) provide examples of how income elasticity can change depending on how the good is defined (i.e., private or public). Given the divergence between private and public goods, they conclude that income elasticity of WTP and income elasticity of demand are related. The relationship does not imply that knowledge of income elasticity of demand is sufficient to estimate income elasticity of WTP given that the income elasticity of WTP depends on factors that cannot be observed.

In addition to the theoretical issues associated with WTP for public goods, there are important empirical issues. We are interested in how WTP changes with respect to increases in U.S. median income. Measuring changes due to growth in median income reflect shifts in overall preferences and utility (or in the case of public goods, social welfare). This type of analysis requires time series data. Unfortunately, there are very few relevant studies that use this approach to estimate income elasticity.[26] Consequently, we must rely on income elasticities estimated from cross-sectional data. The estimates

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[24] The nonrival nature of public goods implies that the marginal social cost of consuming an additional unit of benefit is zero.

[25] CV studies solicit WTP estimates that are subject to the respondent's current budget constraint. The budget share factor requires that the income elasticities (for all consumed goods) sum to one. This generally implies that income elasticity of any single good is substantially less than one.

[26] Available studies using time series data estimate income elasticity of public health care expenditures by analyzing changes in government spending relative to gross domestic product (GDP). These studies are not particularly applicable to the valuation methodology used in the present study.

reflect differences in willingness to pay for improved health among various income levels. They are measures of an individual's preferences and expected utility given the person's current state (i.e., in the present).

There are several issues associated with the application of cross-sectional results to estimate longitudinal changes (i.e., changes over time). Most important is the potential for misinterpretation of our recommended application of income elasticity adjustment. Although we outline an approach that uses income elasticities derived from cross-sectional data, the adjustment is solely a proxy for how preferences and utility may change as projected overall average income (i.e., real GDP per capita) increases from 1990 to 2010. Application of these income elasticity estimates does not imply a strategy for adjusting benefits valuation by level of household income in any given year.

Derivation of Elasticity Estimates

Based on our review of the available income elasticity literature, we conducted sensitivity analyses that characterize how the valuation of human health benefits may increase with a rise in real U.S. income. Given the range of different methodological approaches and limited available research, we calculate a range of illustrative values. Table H-7 summarizes the income elasticities we used to conduct the sensitivity analysis.

Table H-7
Elasticity Values for Conducting Sensitivity Analysis

Health Endpoint	Lower Estimate	Central Estimate	Upper Estimate
Minor Health Effect	0.04	0.14	0.30
Severe and Chronic Health Effects	0.25	0.45	0.60
Premature Mortality	0.08	0.40	1.00

Note: Sources for the derivation of these values can be found in Industrial Economics 1999.

Reported income elasticities suggest that the severity of the morbidity endpoint is a primary determinant of the strength of the relationship between changes in income and the willingness to pay. Without accounting for severity, there is a fairly wide range of values for income elasticity, 0.04 to 0.60. Estimates are more closely clustered if we account for the seriousness of the health effect. For the purposes of a sensitivity analysis, we use two different ranges based on whether morbidity endpoints are minor or severe. With respect to minor health effects, we use lower and upper values of 04 and 0.30, respectively. The central estimate is 0.14. For conducting a sensitivity test of the income elasticity effect on WTP to avoid severe health effects, we use a lower and upper estiamtes of 0.25 and 0.60, with 0.45 as the central estimate. The lower and upper estimates reflect the lowest and highest estimates derived from our literature review. The central estimate is the midpoint of the averages from each study.

With respect to VSL, estimates of income elasticity range from 0.08 to 1.10. We use lower and upper estimates that reflect the full range of values. The central estimate, 0.40, represents the midpoint between the average low value and the average high value of the studies we reviewed.

Illustrative Calculations — Morbidity Benefits Estimates

Table H-8 provides a simplified example of how application of the elasticity ranges we derive could affect benefits estimates. For illustrative purposes, we use the WTP to avoid an asthma attack to represent a minor health effect and WTP to avoid a case of chronic bronchitis to represent a severe health effect. By the year 2010, the effect of income growth on WTP for a minor health effect can increase between one and eight percent, with the central estimate indicating three percent growth. The WTP to avoid a severe health effect grows faster with 2010 estimates, ranging between seven and sixteen percent and with the central estimate increasing by thirteen percent.

Table H-8
Illustrative Adjustment to Estimates of WTP to Avoid Morbidity

				WTP Estimate (1990 Dollars)[1]		
Year	**US Population (in millions)**	**Real GDP (in millions)**	**Income**	**Lower Estimate**	**Central Estimate**	**Upper Estimate**
Minor Health Effect- Asthma				**E_y=0.04**	**E_y=0.14**	**E_y=0.30**
1990	249,440	5,744	23,026	$32	$32	$32
2000	274,634	7,123	25,936	$32.20	$32.50	$33.20
2010	297,716	8,959	30,092	$32.30	$33.20	$34.70
Severe Health Effect- Chronic Bronchitis				**E_y=0.25**	**E_y=0.45**	**E_y=0.60**
1990	249,440	5,744	23,026	$260,000	$260,000	$260,000
2000	274,634	7,123	25,936	$267,850	$274,300	$279,240
2010	297,716	8,959	30,092	$277,990	$293,280	$305,290

Note:
[1] WTP estimates are reported in undiscounted 1990 dollars and represent value per case.

Illustrative Calculations — VSL Estimate

We characterize the potential effect of income elasticity on the VSL estimate in Table H-9. An income elasticity of 0.08 demonstrates the effect of a slight adjustment to the VSL estimates as median income gradually rises. As shown in the figure, between 1990 and 2010, the VSL estimates increase by approximately two percent. The central estimate, 0.40, demonstrates that by 2010, a thirty percent increase in median income would result in VSL increasing by approximately eleven percent. The upper bound value demonstrates the effect of assuming one as the value of income elasticity. In this twenty year period of the prospective analysis, the VSL estimate would increase from $4.8 to $6.3 million if income elasticity equals one.

Table H-9
Illustrative Adjustment to Estimates of The Value of Statistical Life

				Value of Life Estimate (in thousands)[1]		
Year	**US Population (in millions)**	**Real GDP (in millions)**	**Income**	**Lower Estimate E_y=0.08**	**Central Estimate E_y=0.40**	**Upper Estimate E_y=1.0**
1990	249,440	5,744	23,026	$4,800	$4,800	$4,800
2000	274,634	7,123	25,936	$4,848	$5,036	$5,410
2010	297,716	8,959	30,092	$4,905	$5,345	$6,271

Note:
[1] Value of life estimates reported in undiscounted 1990 dollars.

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